

ISSN: 3048-989X

# Innovative Agriculture

A Monthly Magazine for  
Agriculture and Allied Sciences

December 2025

World  
Soil Day

05 DECEMBER



[www.innovativeagriculture.in](http://www.innovativeagriculture.in)



# **INNOVATIVE AGRICULTURE**

## **A MONTHLY MAGAZINE**

**ISSN No.:** 3048 – 989X

**Frequency:** Monthly

**Month:** December 2025

**Volume:** 02, Issue 02

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## Agronomic strategies for managing salinity stress in field crops



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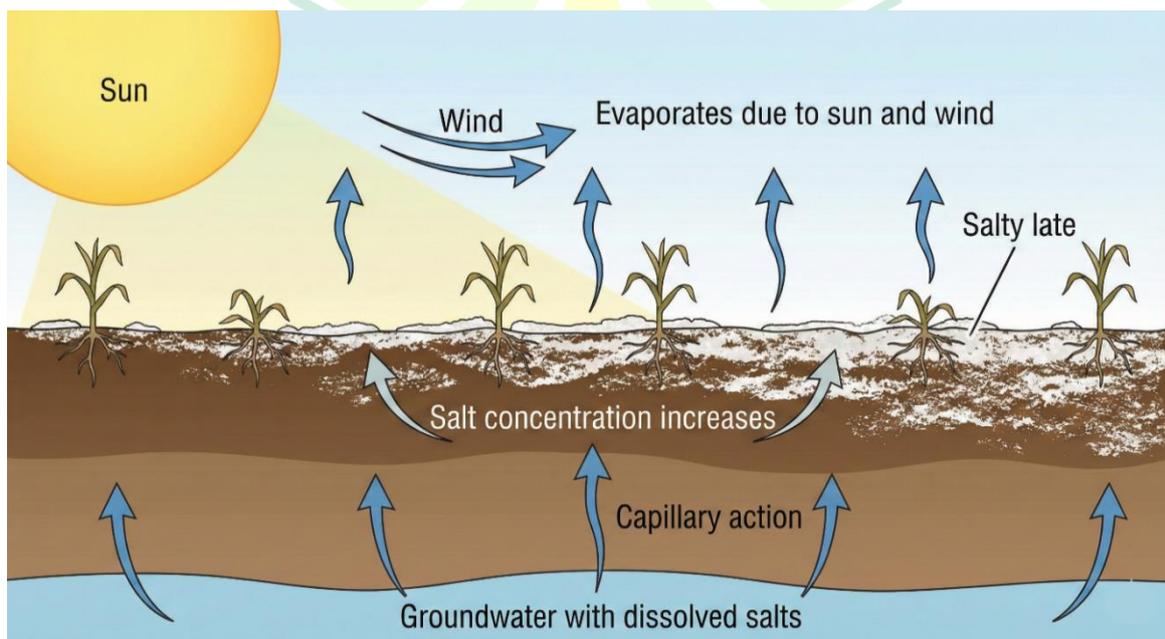
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### 1. Introduction

The salinization of soils is one of the major edaphic problems facing modern agriculture. It is characterised by excessive accumulation of water-soluble salts (mainly chlorides and sulphates of sodium, calcium and magnesium) in the soil profile to levels that adversely affect the development of plants. On the world level, it is estimated that over twenty percent of all cultivated areas, and about thirty-three percent of irrigated farms, have different levels of salinity. This phenomenon is particularly widespread in arid and semi-arid regions where the rate of evapotranspiration is greater than that of precipitation, and the upward transport and surface accumulation of salts is precipitated. While primary salinity arises from the natural weathering of parent materials, secondary salinisation is mainly anthropogenic, arising from inefficient irrigation practices, poor drainage and the use of saline water in crop production.

The negative effects of salinity on the health of the plant are bilayered. First, the concentration of salt in the soil solution has decreased, so the osmotic potential of the soil solution decreases, making the extraction of water by the roots more difficult - a condition that is similar to physiological drought. Second, the absorption of certain ions, especially Na and Cl, to toxic levels inside plant organs interferes with cell metabolism, suppresses enzyme activity, and causes nutrient imbalances by competing for the availability of essential cations, such as K and Ca. The consequent result is stunted growth, leaf necrosis, reduction in photosynthetic ability, and eventually yield losses of significant proportions. Solving this complex problem requires a multi-pronged approach. This article outlines proven and new agronomic interventions for managing soil salinity and maintaining production of field crops in salt-constrained environments.



## 2. Crop and Genotype Selection

The most basic agronomic approach to take advantage of salt affected soils is the wise choice of crops and cultivars with inherent tolerance to salinity. Plant species exhibit a broad range of responses to salt stress, from sensitive glycophytes, which experience severe yield losses at relatively low salinity concentrations, to highly tolerant halophytes which can grow at saline ecosystems. For most field crops - essentially glycophytes - there is a great deal of intra and inter specific variability in salt tolerance.

Agronomists and growers need to focus attention on species that can sustain economic viability under the salinity regimes that exist in their fields. For example, some crops, like barley (*Hordeum vulgare*), cotton (*Gossypium hirsutum*) and sugar beet (*Beta vulgaris*), show rather high tolerance, while maize (*Zea mays*), beans (Phaseolus spp.) and a considerable number of leguminous species are classed as sensitive.

The repertoire for salinity management has been further broadened by modern plant breeding and biotechnology. Breeding programmes are aimed at developing cultivars with improved characteristics of root level salt exclusion, tissue tolerance to accumulated ions and osmotic adjustment capabilities. The use of these improved genotypes is a proactive measure that complements other management practices.

**Table 1. Classification of selected field crops based on their relative salt tolerance thresholds**

Crop	Botanical Name	Salt Tolerance Rating	Threshold ECe (dS/m)*	Slope (% yield decrease per dS/m beyond threshold)**
<b>Fiber &amp; Sugar</b>				
<b>Cotton</b>	<i>Gossypium hirsutum</i>	Tolerant	7.7	5.2
<b>Sugar Beet</b>	<i>Beta vulgaris</i>	Tolerant	7.0	5.9
<b>Sugarcane</b>	<i>Saccharum officinarum</i>	Moderately Sensitive	1.7	5.9
<b>Cereals</b>				
<b>Barley</b>	<i>Hordeum vulgare</i>	Tolerant	8.0	5.0
<b>Wheat</b>	<i>Triticum aestivum</i>	Moderately Tolerant	6.0	7.1
<b>Sorghum</b>	<i>Sorghum bicolor</i>	Moderately Tolerant	6.8	16.0
<b>Maize (Corn)</b>	<i>Zea mays</i>	Moderately Sensitive	1.7	12.0
<b>Rice (Paddy)</b>	<i>Oryza sativa</i>	Sensitive	3.0	12.0
<b>Legumes</b>				
<b>Soybean</b>	<i>Glycine max</i>	Moderately Tolerant	5.0	20.0
<b>Groundnut (Peanut)</b>	<i>Arachis hypogaea</i>	Moderately Sensitive	3.2	29.0
<b>Dry Bean</b>	<i>Phaseolus vulgaris</i>	Sensitive	1.0	19.0

\*ECe: Electrical conductivity of the soil saturation extract, a standard measure of soil salinity. 10 Values are approximate thresholds beyond which yield decline begins.

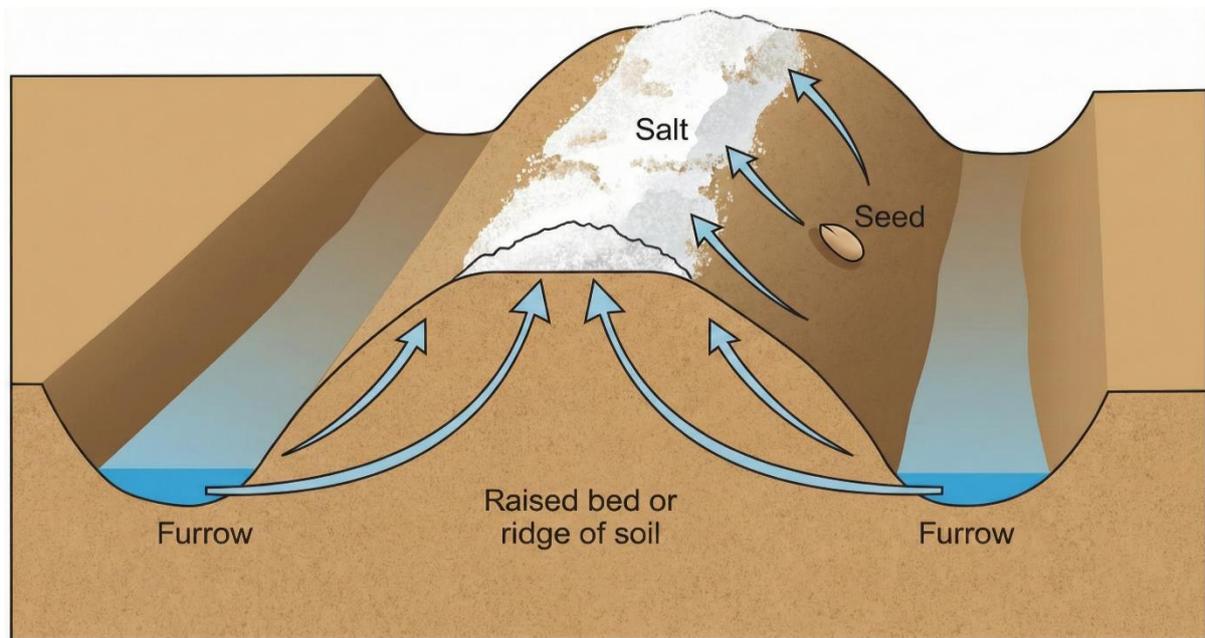
\*\*Slope indicates the percentage of expected yield loss for every 1 dS/m increase in ECe above the threshold.

## 3. Soil Management and Amendments

### 3.1 Leaching and Drainage

The primary method for reclaiming saline soils is leaching, which involves applying irrigation water in excess of the crop's evapotranspiration requirements to flush soluble salts below the active root zone. The amount of additional water needed is determined by the leaching requirement (LR), calculated based on the electrical conductivity of the irrigation water (ECw) and the target electrical conductivity of the soil drainage water (ECdw) tolerable by the crop. For successful leaching, the soil must have adequate permeability and a functional subsurface drainage system to remove the leached salts and prevent waterlogging, which can exacerbate salinity issues through capillary rise.

### 3.2 Seedbed Preparation and Planting Techniques



**Figure 1. Ridge planting strategy for salinity management**

Salts tend to accumulate on the soil surface and ridge tops due to evaporation. This poses a critical threat during germination and seedling establishment, which are often the most salt-sensitive growth stages. To mitigate this, planting techniques can be modified. Planting seeds on the sloping sides of ridges or in the irrigation furrows, rather than on the crest, can place the seed in a zone of lower salt concentration. In flat-planted fields, pre-plant irrigation can help push surface salts deeper into the soil profile before sowing.

### 3.3 Soil Amendments

- **Saline Soils:** The soils exist with neutral soluble salts and have stable structure. The main management is high quality water leaching.
- **Sodic and Saline-Sodic Soils:** these soils have high levels of exchangeable sodium, which cause poor structure, surface crusting and low infiltration. Reclamation needs replacing of exchangeable sodium with calcium. The most common and economical amendment is gypsum (calcium sulphate dihydrate,  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ). The calcium ions released from dissolved gypsum push out the sodium ions attached to the clay particles and these are leached out.
- **Organic Amendments:** The addition of organic matter (e.g., farmyard manure, compost, green manure) is always a good idea. Organic matter is beneficial for structure, water holding capacity and microbial activity. As the organic matter decays, it releases organic acids which can dissolve native soil calcium carbonates and further help displace the sodium.

## 4. Irrigation Management Strategies

### 4.1 Irrigation Method

- **Drip Irrigation:** This method is considered by many people to be the most effective in saline conditions. By allowing water to be applied slowly and often directly to the root zone, drip irrigation maintains high soil matric potential and reduces the osmotic component of salt stress. Moreover, the constant movement of water in the direction of the emitter outward, forces salts to move to the periphery of the wetted soil volume, forming a relatively salt free zone for root proliferation.
- **Sprinkler Irrigation:** Although sprinkler systems provide for uniform application of water, they are often prone to foliar injury if saline water is used for leaching salts from the soil surface. Leaf burn may

occur as a result of absorption of sodium and chloride directly through the leaves during the evaporation process.

- **Surface Irrigation (Flood/Furrow):** Traditional surface methods are generally less efficient and can lead to non-uniform salt leaching and waterlogging if not managed with precision, including land levelling and appropriate furrow design.

**Table 2. Comparative analysis of irrigation methods for crop production under saline conditions**

Irrigation Method	Advantages for Salinity Management	Disadvantages and Risks	Best Management Practices
<b>Drip Irrigation</b>	<ul style="list-style-type: none"> <li>- Maintains high soil moisture, reducing osmotic stress.</li> <li>- Pushes salts to the edge of the wetted zone.</li> <li>- High water application efficiency.</li> <li>- Allows for safe use of more saline water.</li> </ul>	<ul style="list-style-type: none"> <li>- High initial capital cost.</li> <li>- Emitter clogging risk with poor quality water.</li> <li>- Potential for salt accumulation at the soil surface between emitters.</li> </ul>	<ul style="list-style-type: none"> <li>- Use frequent, low-volume irrigations.</li> <li>- Place emitters close to the plant.</li> <li>- Periodic flushing of lines.</li> <li>- Occasional surface irrigation to leach accumulated surface salts.</li> </ul>
<b>Sprinkler Irrigation</b>	<ul style="list-style-type: none"> <li>- Uniform water application.</li> <li>- Effective for leaching surface salts prior to planting.</li> <li>- Precise control over water application depth.</li> </ul>	<ul style="list-style-type: none"> <li>- Risk of foliar salt damage (leaf burn) with saline water.</li> <li>- High evaporation losses in hot, windy climates.</li> <li>- Can promote fungal diseases.</li> </ul>	<ul style="list-style-type: none"> <li>- Irrigate at night to reduce evaporation and leaf burn risk.</li> <li>- Avoid using water with high Na<sup>+</sup> or Cl<sup>-</sup> concentrations on sensitive foliage.</li> <li>- Follow with fresh water to rinse leaves if possible.</li> </ul>
<b>Surface Irrigation (Furrow/Flood)</b>	<ul style="list-style-type: none"> <li>- Low capital cost.</li> <li>- Simple technology.</li> <li>- Can be effective for large-scale leaching events.</li> </ul>	<ul style="list-style-type: none"> <li>- Low water use efficiency.</li> <li>- High risk of waterlogging and secondary salinization.</li> <li>- Non-uniform salt leaching.</li> </ul>	<ul style="list-style-type: none"> <li>- Ensure precise land levelling.</li> <li>- Use appropriate furrow length and flow rate.</li> <li>- Implement surge flow techniques to improve uniformity.</li> <li>- Provide adequate field drainage.</li> </ul>

#### 4.2 Irrigation Frequency and Scheduling

Under saline conditions, the ability of a plant to extract water is greatly diminished even when the soil holds water. Consequently, the traditional paradigm of letting the soil moisture drop to some specified fraction of the available water content before re-irrigation is required to be changed. A high frequency irrigation regime is advocated. By providing smaller volumes of water more frequently, the water content of the soil is kept closer to field capacity, reducing matric potential and keeping the combination of matric and osmotic water potential at a less stressful level in terms of crop health.

#### 4.3 Management of Saline Irrigation Water

- **Cyclic Use:** The interspersion of saline water and high-quality water. For example, using non-saline water in the germination phase and during the initial stages of seedling development - stages when plants are most sensitive - with a recourse to the use of salty water in later periods, when plants are more tolerant.
- **Conjunctive Use:** Blending saline water with fresh water to reduce the overall salinity (EC<sub>w</sub>) and sodicity (SAR) to acceptable levels for the specific crop and soil type.

## 5. Other Agronomic Practices

### 5.1 Mulching

Surface mulching with polymeric films or crop residue is a very good practice. The mulch breaks the continuity of capillaries, significantly limiting the evaporation coming out of the soil's surface. This two-fold advantage helps to conserve soil moisture and, most importantly, breaks up the upward flow and build-up of salts in the top soil where root activity is most intense.

### 5.2 Nutrient Management

Salinity causes complex nutrient disorders. Elevated concentrations of  $\text{Na}^+$  and  $\text{Cl}^-$  in the soil solution compete with the uptake of essential nutrients such as  $\text{K}^+$ ,  $\text{Ca}^{2+}$  and  $\text{NO}_3^-$ . For instance, a high tissue  $\text{Na}^+/\text{K}^+$  ratio is a feature of salt stress. Hence, fertilization protocols have to be calibrated carefully for saline soils. Applications of potassium and calcium fertilizer can correct for National toxicity, and foliar sprays of micronutrients may be beneficial because root uptake of these elements is often inhibited under saline conditions.

## 6. Integrated Salinity Management (ISM)

It is clear that no single agronomic strategy can be considered a universally effective way of solving the problem of soil salinity. A sustainable pathway requires the creation of an Integrated Salinity Management (ISM) plan, specific to the local soil, water, climate and crop conditions. ISM brings the above-mentioned practices together in a coherent framework.

For example, a successful ISM strategy for a farm with moderate saline soil and a low availability of fresh water may include:

1. **Crop Selection:** Growing a salt-tolerant crop like barley or cotton.
2. **Irrigation:** Introducing drip irrigation technology for efficient utilization of water and controlling salt distribution in irrigation.
3. **Soil Management:** Applying gypsum to improve soil structure and conducting pre-season leaching with the available fresh water.
4. **Cultural Practices:** Utilizing furrow-side planting and applying a straw mulch to reduce surface evaporation.

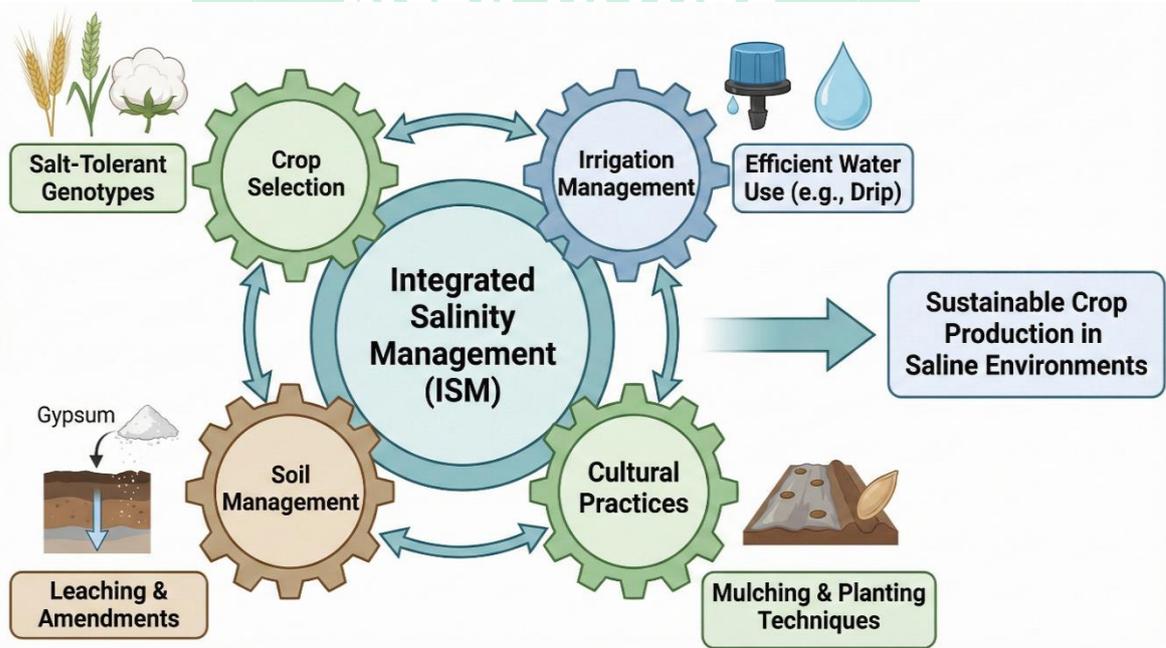


Figure 2. The Integrated Salinity Management (ISM) framework, illustrating the synergistic interaction of crop, irrigation, soil, and cultural practices to achieve sustainable production.

## 7. Conclusion

Managing soil salinity is one of the biggest challenges facing modern agriculture. It requires a shift from reactive remediation to proactive science-based agronomic approaches. The reduction of salinity stress in field crops does not depend on a single "silver bullet" but on a holistic, integrated approach with genetic resilience and proper soil and water management. By careful crop selection, optimizing irrigation techniques and timing, establishing leaching and drainage regimes and using soil amendments and mulching, agronomists can significantly improve the crop productivity and efficiency of resource use in salt-affected landscapes. Continued research needs to continue in unlocking genetic potential of crops through breeding and biotechnology, while optimizing site-specific agronomic packages for sustainable food production in the face of increasing land as well as water salinization.

## References

- Ayers, R. S., & Westcot, D. W. (1985). *Water quality for agriculture*. FAO Irrigation and Drainage Paper 29 (Rev. 1). Food and Agriculture Organization of the United Nations.
- Ghassemi, F., Jakeman, A. J., & Nix, H. A. (1995). *Salinisation of land and water resources: Human causes, extent, management and case studies*. CAB International.
- Maas, E. V., & Hoffman, G. J. (1977). Crop salt tolerance—current assessment. *Journal of the Irrigation and Drainage Division*, 103(2), 115–134.
- Munns, R., & Tester, M. (2008). Mechanisms of salinity tolerance. *Annual Review of Plant Biology*, 59, 651–681. <https://doi.org/10.1146/annurev.arplant.59.032607.092911>
- Qadir, M., & Oster, J. D. (2004). Crop and irrigation management strategies for saline-sodic soils and waters aimed at environmentally sustainable agriculture. *Science of the Total Environment*, 323(1–3), 1–19. <https://doi.org/10.1016/j.scitotenv.2003.10.012>
- Rengasamy, P. (2010). Soil processes affecting crop production in salt-affected soils. *Functional Plant Biology*, 37(7), 613–620. <https://doi.org/10.1071/FP09259>
- Shrivastava, P., & Kumar, R. (2015). Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. *Saudi Journal of Biological Sciences*, 22(2), 123–131. <https://doi.org/10.1016/j.sjbs.2014.12.001>
- Zhu, J. K. (2001). Plant salt tolerance. *Trends in Plant Science*, 6(2), 66–71. [https://doi.org/10.1016/S1360-1385\(00\)01838-0](https://doi.org/10.1016/S1360-1385(00)01838-0)

## Biochar-Nanomaterial Composites for Enhanced Soil Remediation and Fertility Restoration



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### 1. Introduction

Uncontrolled industrialization, excessive agro practices, and poor waste management and disposal are some of the factors that have put the edaphic environment under undue stress levels never witnessed before. The net result of these has been extensive pollution of soils with heavy metals and metalloids (such as lead, cadmium, arsenic) and recalcitrant organic compounds (such as polycyclic aromatic hydrocarbons and pesticides). At the same time, the unremitting exploitation of intensive agriculture without sufficient replenishment of organic matter has led to extreme loss of soil fertility, decrease in the water-retention capacity, and a significant loss of microbial diversity.

The new amendments required to deal with these two crises will require creative solutions that will be in a position to not only deal with contaminated matrices but also restore. AN Biochar Biochar which is a carbon-based byproduct of biomass pyrolysis by limiting oxygen exposure is generally recognized as useful in carbon sequestration and bio-conditioning of soils. It has a highly porous structure and a large surface area that makes it an effective adsorbent. However, pure biochar is often unsuitable with respect to possessing the functional groups needed on its surface to either target more complicated pollutants or promote more complex catalytic breakdown. Nanomaterials (NMs), which are characterized by at least one dimension less than 100nm in size, are highly reactive, possess unique electronic and high surface-to-volume ratios. Nanoscale metal oxides (such as Fe<sub>3</sub>O<sub>4</sub>, TiO<sub>2</sub>, ZnO) and carbon nanotubes (CNTs) have proven to be of immeasurable value in environmental clean-up processes. However, these materials cannot be easily applied directly to soils due to processes like aggregation, difficulty in recovering the materials after use, and possible ecotoxicity due to the high mobility of this materials. One of the strategic convergence points of these two technologies is the synthesis of biochar -nanomaterial composites. The latter acts as a dispersant and stabilizer by binding nanomaterials onto the biochar base, and thus prevents aggregation of nanomaterials and reduces their mobility in the environment. At the same time, the nanomaterials are used to functionalize the surface of the biochar and thus increase adsorptive capacity, catalytic activity, and redox potential. This paper establishes the scientific foundation of these engineered composites and clarifies how they can be used in the setting of sustainable agriculture.

### 2. Synthesis and Physicochemical Characterization

The syntheses methodology determines the performance of a biochar-nanomaterial composite by determining the size distribution of particles, nanomaterial loading, and the type of chemical interfacial interactions between the carbon frame and the nanoscale object.

#### 2.1. Synthesis Methodologies

- **In-situ Synthesis (Pre-pyrolysis):** Before thermal conversion, the precursor biomass is impregnated or treated with metallic salt-solutions (e.g. ferric chloride to create magnetic biochar). In the course of pyrolysis, the entrained metal ions are reduced and turned into metal-oxide nanoparticles which are embedded in the nascent carbon structure. This approach is used to guarantee a high level of compliance and uniformity of distribution of the nanomaterial.
- **Ex-situ Synthesis (Post-pyrolysis):** Pristine biochar is first synthesized using usual pyrolysis. The biochar surface is then coated with nanomaterials through co-precipitation, hydrothermal methods or sol-gel. Though such a procedure gives more control over the exact nanomaterial being used, the binding that results might not be as strong as what can be obtained by in-situ methods.

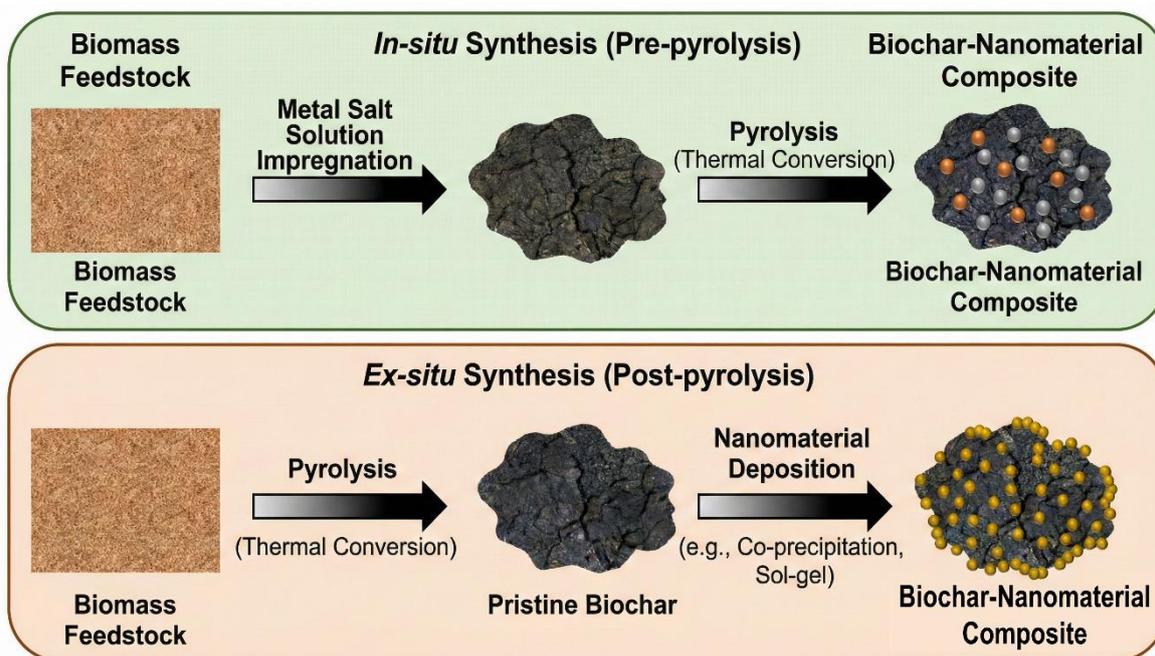


Figure 1. Schematic representation of primary synthesis methodologies for biochar-nanomaterial composites

## 2.2 Key Physicochemical Properties

- Specific Surface Area (SSA) and Porosity:** Meticulously engineered nanomaterial composites are often characterized by a high SSA (as measured by BET surface area), although nanomaterial loading sometimes completely blocks the micropores. Mesoporous nanomaterials can be included to increase the total pore volume, which will increase water retention and microbial colonization.
- Surface Functionalization:** An example is that iron oxides provide hydroxyl functional groups ( $-OH$ ) that are highly useful in binding metalloids, e.g. arsenic, by ligand-exchange reactions.
- Cation Exchange Capacity (CEC):** CEC is usually increased by inherent negative surface charges of most biochars as well as by functional groups added by NMs, which allows cationic nutrients ( $NH_4^+$ ,  $K^+$ ,  $Ca^{2+}$ ) and heavy metals ( $Pb^{2+}$ ,  $Cd^{2+}$ ) to be retained.
- Redox Potential:** Some nanomaterials, like zero-valent iron (nZVI) impart on the composite the strong reducing properties, which are essential in the detoxification of pollutants such as hexavalent chromium.

Table 1. Comparative Physicochemical Properties of Pristine Biochar vs. Biochar-Nanomaterial Composite

Property	Pristine Biochar (Typical)	Biochar-Nanomaterial Composite (Typical)	Significance in Soil Application
<b>Specific Surface Area (BET)</b>	100 – 500 m <sup>2</sup> /g	300 – 800+ m <sup>2</sup> /g (varies by NM type)	Provides sites for adsorption and microbial colonization.
<b>Surface Charge/Zeta Potential</b>	Generally Negative	Variable (Tunable depending on NM)	Determines electrostatic attraction to specific contaminants or nutrients.
<b>Surface Functionality</b>	Carboxyl, Phenolic, Hydroxyl	Enhanced functionality (e.g., Fe-OH, Ti-O sites)	Increases specific chemisorption capabilities.
<b>Reactivity</b>	Moderate Adsorbent	High Adsorptive + Catalytic/Redox Activity	Enables degradation of organic pollutants, not just sequestration.
<b>Stability in Soil</b>	High (Recalcitrant C)	High (NM stabilized by carbon matrix)	Ensures long-term effectiveness.

### 3. Mechanisms of Soil Remediation

The biochar-nanomaterial composites have a remediation capacity that is based on a multi-faceted process that takes into consideration physical, chemical and biological processes. These mechanisms can be carried out simultaneously with the help of the composite architecture.

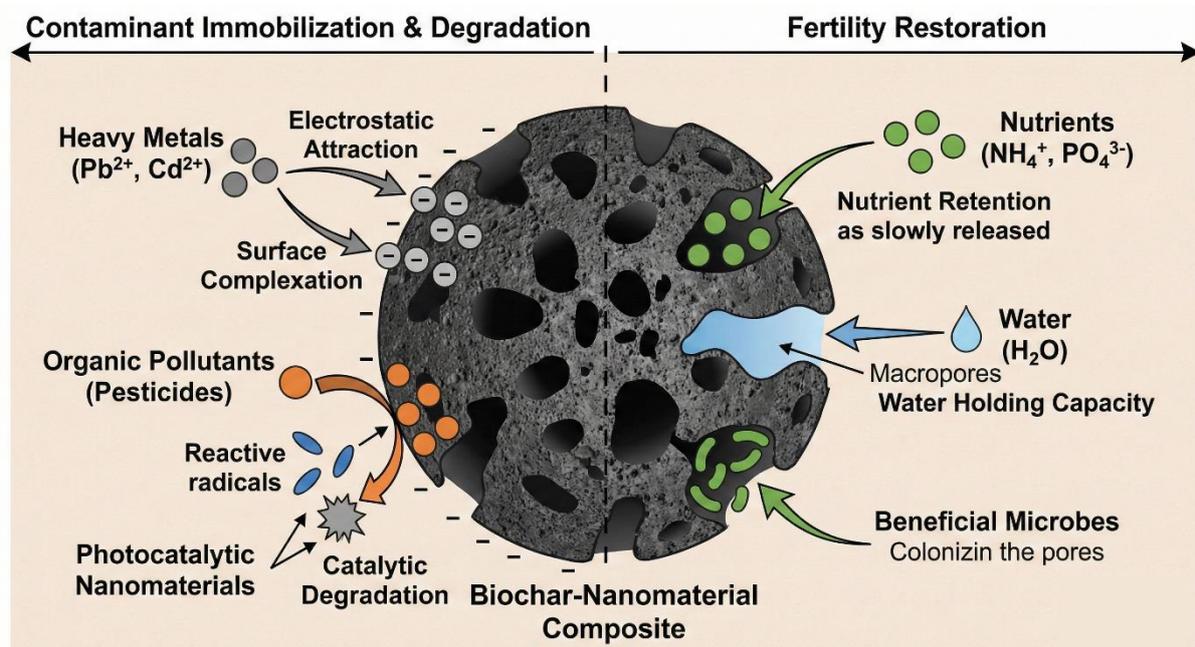


Figure 2. Conceptual illustration of the dual-mode mechanisms of biochar-nanomaterial composites in the soil environment

#### 3.1. Heavy Metal Immobilization

Since heavy metals are non-biodegradable, it is necessary that they be immobilised so that they are not absorbed by crops and washed into groundwater. Composites do this by:

- Electrostatic Attraction:** Cationic metals ( $Pb^{2+}$ ,  $Cd^{2+}$ ,  $Zn^{2+}$ ) are attracted to the negatively charged surfaces of biochar and some metal oxides.
- Ion Exchange:** Heavy metal ions in the soil solution may be exchanged with protons or alkaline earth metals ( $Ca^{2+}$ ,  $Mg^{2+}$ ) that are attached to the composite surface.
- Surface Complexation/Chemisorption:** Functional groups (e.g.,  $-COOH$ ,  $-OH$ ) form strong covalent or coordinate bonds with heavy metals. Iron oxide-biochar composites are particularly effective at forming inner-sphere complexes with arsenic and lead.
- Redox-Mediated Precipitation:** Precious metals nZVI or metal sulphides composites have the ability to reduce toxic, mobile metal species to less toxic, insoluble ones. An example is the reduction of highly mobile Cr (VI) to relatively harmless Cr (III), which later precipitates as chromium hydroxide onto the composite surface.

#### 3.2. Organic Pollutant Degradation and Sequestration

In the case of organic contaminants like pesticides, herbicides and industrial solvents, the general aim is degradation and not just the sequestration.

- Enhanced Adsorption:** The hydrophobic nature of the biochar graphene sheets strongly attracts hydrophobic organic compounds through  $\pi$ - $\pi$  electron donor-acceptor interactions (physisorption). The nanomaterials increase the accessible surface area for this process.
- Catalytic Degradation (Advanced Oxidation Processes):** This is a great advantage over pure biochar. Composites of photocatalysts (say  $TiO_2$  or  $ZnO$ ), Fenton-like catalysts (e.g. iron oxides) can be used to produce highly reactive radical species (e.g. hydroxyl radicals,  $-OH$ ) in bright light or natural soil

oxidants (e.g.  $H_2O_2$ ). These radicals destroy and decompose complex organic pollutants to produce harmless end-products,  $CO_2$  and water.

#### 4. Mechanisms of Fertility Restoration

##### 4.1. Nutrient Retention and Slow Release

Loss of vital nutrients, especially nitrogen (N) and phosphorus (P) by leaching, is a major economic cost to the farmers and a threat to the environment through the process of eutrophication. Biochar-nanomaterial composites are used as nutrient reservoirs. Their large cation-exchange capacity allows temporary capture of ammonium ( $NH_4^+$ ) and potassium ( $K^+$ ). More importantly, MgO-engineered or layered double hydroxides (LDH)-engineered composites on the biochar surface have a pronounced affinity to anionic nutrients, including nitrate ( $NO_3^-$ ) and phosphate ( $PO_4^{3-}$ ), which are usually repelled by negatively charged soil particles.

The composites increase the efficiency of nutrient utilization (NUE) by crops and reduce the chances of fertilizer runoff by adsorbing these nutrients during fertilizer application and desorbing them over time through desorption hysteresis.

##### 4.2. Improvement of Soil Physical Properties

The introduction of these porous composites will reduce the bulk density of the soil and increase the total porosity. The meso and macropores of the biochar structure have the ability to store water thus significantly enhancing the soil water holding capacity (SWHC). The feature is especially beneficial in sandy or dry areas, which increases crop resistance to droughts. Additionally, the strong carbon framework facilitates the erosion of soil, and as a result, increases the resistance to erosion.

##### 4.3. Enhancement of Soil Microbiology

The microbial abundance and diversity are closely connected to soil health. The porosity of the biochar composite also provides an optimal micro-habitat for useful soil bacteria and mycorrhizal fungi, which protect against desiccation and predation.

The composite surface is also able to adsorb inhibitory substances (toxins) of the soil solution, hence, decontaminating the environment from microorganisms. Some researchers have suggested that electrically conductive biochar materials have the potential to support direct interspecies electron transfer (DIET) between separate microbial taxa, which could enhance the rate of selected metabolic activity related to organic matter breakdown and nutrient cycling.

**Table 2. Examples of Biochar-Nanomaterial Composites and Targeted Applications**

Composite Type	Nanomaterial Component	Target Application/Contaminant	Primary Mechanism
<b>Magnetic Biochar</b>	$Fe_3O_4$ (Magnetite) or $\gamma-Fe_2O_3$ (Maghemite)	Arsenic (As), Lead (Pb), Cadmium (Cd)	Surface complexation; easy magnetic separation.
<b>nZVI-Biochar</b>	Nano-Zero Valent Iron ( $Fe^0$ )	Trichloroethylene (TCE), Cr(VI), Nitrates	Chemical reduction and precipitation.
<b>Photocatalytic Biochar</b>	$TiO_2$ (Titanium Dioxide) or ZnO (Zinc Oxide)	Pesticides (e.g., Atrazine), Antibiotics residues	Photocatalytic degradation under UV/solar light.
<b>Mg-modified Biochar</b>	MgO (Magnesium Oxide) nanoparticles	Phosphate ( $PO_4^{3-}$ ) and Ammonium ( $NH_4^+$ ) recovery	Precipitation (as struvite) and electrostatic attraction for slow-release fertilizer.

#### 5. Challenges, Risks, and Future Directions

##### 5.1. Ecotoxicology and Nanoparticle Release

The main problem is connected with the potential emission of engineered nanoparticles to the soil environment. Whereas biochar tends to stabilise nanomaterials, longer weathering, such as freeze-thaw cycles, root exudates and microbial activity, may cause them to be detached.

##### 5.2. Scalability and Economic Viability

Today, the manufacture of advanced nanomaterials is costly and energy-consuming. To ensure that agriculture is adopted, the cost of the amendment should not be too high to ensure that farmers have an attractive payback on their investments.

The future studies should therefore include the upscale synthesis protocols, consideration of green chemistry principles, and the investigation of cost-effective nanomaterial precursors like the use of industrial waste streams as the source of iron in magnetic biochar.

### 5.3. Regulatory Frameworks

The current situation is the lack of special regulatory frameworks that regulate the utilization of nano-enhanced agricultural amendments. The regulatory bodies have to be provided with clear guidelines that are based on sound risk assessment as a way of ensuring such materials are properly categorized and the application limits are set in the food production systems.

## 6. Conclusion

The composites of biochar-nanomaterials are a major technological innovation to sustainable agriculture and environmental remedial efforts. Through the exploitation of the porous and stable structure of biochar and the high reactivity of nanomaterials, these composites present an effective, dual-purpose solution to the complex issues of soil pollution and reduced soil fertility. They neutralise the toxic metal and organic pollutants, and at the same time increase the efficiency of use of nutrients, water retention and the vitality of microbes.

However, the way to the mass adoption requires a careful, evidence-based approach. The most important thing is to focus on long-term field experiments to confirm composite stability, optimise scalable production strategies to save money, and perform an in-depth life-cycle analysis (LCA). Provided that these issues can be overcome, biochar-nanomaterial composites can eventually be a part-and-parcel of technology in the quest of world soil security and sustainable food production.

## References

- Ahmad, M., Rajapaksha, A. U., Lim, J. E., Zhang, M., Bolan, N., Mohan, D., Vithanage, M., Lee, S. S., & Ok, Y. S. (2014). Biochar as a sorbent for contaminant management in soil and water: A review. *Chemosphere*, 99, 19–33. <https://doi.org/10.1016/j.chemosphere.2013.10.071>
- Lyu, H., Zhang, Q., & Shen, B. (2020). Application of biochar and its composites in catalysis. *Chemosphere*, 240, 124842. <https://doi.org/10.1016/j.chemosphere.2019.124842>
- Premarathna, K. S. D., Rajapaksha, A. U., Adassooriya, N., Sarkar, B., Sirisena, K. A., Cooray, A., Ok, Y. S., & Vithanage, M. (2019). Clay-biochar composites for sorptive removal of tetracycline antibiotics in aqueous media. *Journal of Environmental Management*, 238, 315–322. <https://doi.org/10.1016/j.jenvman.2019.02.096>
- Rajapaksha, A. U., Chen, S. S., Tsang, D. C. W., Zhang, M., Vithanage, M., Mandal, S., Gao, B., Bolan, N. S., & Ok, Y. S. (2016). Engineered/designer biochar for contaminant removal/immobilization from soil and water: Potential and implication of biochar modification. *Chemosphere*, 148, 276–291. <https://doi.org/10.1016/j.chemosphere.2016.01.043>
- Tan, X. F., Liu, Y. G., Gu, Y. L., Xu, Y., Zeng, G. M., Hu, X. J., Liu, S. B., Wang, X., Liu, S. M., & Li, J. (2016). Biochar-based nano-composites for the decontamination of wastewater: A review. *Bioresource Technology*, 212, 318–333. <https://doi.org/10.1016/j.biortech.2016.04.093>
- Wang, J., & Wang, S. (2019). Preparation, modification, and environmental application of biochar: A review. *Journal of Cleaner Production*, 227, 1002–1022. <https://doi.org/10.1016/j.jclepro.2019.04.282>
- Xiang, W., Zhang, X., Chen, J., Zou, W., He, F., Hu, X., Tsang, D. C. W., Ok, Y. S., & Gao, B. (2020). Biochar technology in wastewater treatment: A critical review. *Chemosphere*, 252, 126539. <https://doi.org/10.1016/j.chemosphere.2020.126539>
- Yao, Y., Gao, B., Inyang, M., Zimmerman, A. R., Cao, X., Pullammanappallil, P., & Yang, L. (2011). Engineered biochar reclaiming phosphate from aqueous solutions: Mechanisms and potential application as a slow-release fertilizer. *Environmental Science & Technology*, 45(3), 1504–1510. <https://doi.org/10.1021/es1031785>
- Zhang, M., & Gao, B. (2013). Removal of arsenic, methylene blue, and phosphate by biochar/AlOOH nanocomposite. *Chemical Engineering Journal*, 226, 286–292. <https://doi.org/10.1016/j.cej.2013.04.077>

## Climate-Smart Agronomy for Mitigating Abiotic Stress in Crops



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### 1. Introduction

The escalating rate of climate change has been a challenge to agricultural systems in the world like never before. The increase in the frequency and intensity of extreme meteorological events, the occurrence of oscillatory weather patterns and gradual changes in the temperature and precipitation regimes are factors that foster an intensification of abiotic stresses. Such non-biological environmental factors, drought, salinity, heat, cold and heavy metals negatively impact the growth, development and yield of plants as they disrupt a range of physiological and biochemical processes. It has been observed in the reports of the Intergovernmental Panel on Climate Change (IPCC) that agricultural systems, especially those in developing countries, are growing more susceptible to these climate-related pressures.

The concept of Climate-Smart Agriculture (CSA) has been proposed as a value system to address these two-fold challenges. Identified to be established by the Food and Agriculture Organisation (FAO) of the United Nations, CSA aims to meet three main goals, which are to sustainably increase agricultural productivity and incomes, adapt and strengthen resilience to climate change, and reduce and/or eradicate greenhouse gas emissions (mitigation) where appropriate. This paper will focus on the adaptive and resilience-forming aspects of CSA, particularly the ability of CSA to counter the adverse impacts of abiotic stress on crop yields.

### 2. Understanding Abiotic Stresses and Their Impact on Crops

Abiotic stresses cause a sequence of physiological and molecular transformations in plants, which often lead to impaired growth, loss of photosynthetic effectiveness, oxidative injury, and, eventually, loss of yield. It is imperative to have a detailed knowledge of how these stresses interact with crops and thus devise effective measures to reduce their adverse effects.

#### 2.1. Drought Stress:

The most common abiotic stress is arguably drought, which is characterized by the lack of water. It reduces turgor pressure, leading to stomatal closing, inhibition of CO<sub>2</sub> uptake, and photosynthesis. Due to drought in the long-term, cells may become dehydrated, proteins may be denatured, and eventually the plants may die.

#### 2.2. Salinity Stress

Extremes of soluble salts in the soil or in the irrigation water cause osmotic stress which prevents the uptake of water by the plants. Moreover, certain homicide of ions (e.g., Na<sup>+</sup>, Cl, etc.) might interfere with enzymes and ionic balance. This mainly occurs in dry and semi-arid regions and those where irrigation is not managed well.

#### 2.3. Heat Stress

Waves of temperatures beyond optimal levels cause instability of cell membranes, protein denaturation, enzymatic inhibition, and reduced photosynthetic ability. It is especially prone to reproductive phases like flowering and grain filling causing pollen sterility and reduced seed set.

#### 2.4. Cold Stress

Freezing (<0°C) and chilling (0-15°C) may cause irreparable damage at low temperatures. Membrane rigidification, enzyme dysfunction and metabolic imbalances are the effects of chilling stress. Stress freezing causes ice crystals in the cells, which causes mechanical damage and dehydration

**Table 1. Primary Impacts of Key Abiotic Stresses on Crop Physiology**

Abiotic Stress	Primary Physiological Impacts
<b>Drought</b>	Reduced turgor, stomatal closure, decreased photosynthesis, oxidative stress, impaired nutrient uptake, premature senescence.
<b>Salinity</b>	Osmotic stress, ion toxicity (Na <sup>+</sup> , Cl <sup>-</sup> ), reduced water uptake, nutrient imbalances, oxidative stress, reduced photosynthetic efficiency.
<b>Heat</b>	Protein denaturation, membrane damage, reduced enzyme activity, impaired photosynthesis, pollen sterility, reduced seed set, increased respiration.
<b>Cold</b>	Membrane rigidification, inhibited enzyme activity, impaired metabolism, reduced nutrient uptake, ice crystal formation (freezing), oxidative stress.

### 3. Climate-Smart Agronomy Strategies for Abiotic Stress Mitigation

CSA is a continuum of combined approaches envisaged to enhance the agricultural systems resilience to the abiotic stresses. These approaches are generic, cultural/management, and technological in nature.

#### 3.1. Genetic Enhancement and Crop Breeding:

Developing crop varieties with enhanced tolerance to abiotic stresses is a cornerstone of CSA. This involves leveraging conventional breeding techniques and advanced biotechnological tools.

- Traditional Breeding:** Selecting characteristics associated with stress tolerance (e.g., deep root systems to provide drought tolerance, salt glands to provide salinity, early vigor to provide cold).
- Molecular Breeding:** Utilizing marker-assisted selection (MAS) and genomic selection (GS) to accelerate the breeding process for stress-tolerant traits.
- Genetic Engineering:** The transfer of genes of stress-tolerant organisms or the alteration of native genes to increase the ability of a plant to tolerate stress.
- CRISPR/Cas9 Technology:** Precise gene editing of stress-response pathways.

#### 3.2. Sustainable Soil Management Practices:

- Conservation Tillage:** Reduces soil disturbance, which increases the soil structure, improves water infiltration, minimizes evaporation, and can be used in drought-prone areas, especially.
- Cover Cropping:** Planting non-cash crops in between cash crop cycles to prevent soil erosion, control weeds, enhance/increase soil organic matter and promote nutrient cycling. The cover crops also help in the retention of soil moisture.
- Organic Matter Augmentation:** Adding compost, farmyard manure, and other organic additions enhances the soil structure, water-absorption capacity, nutrient availability, and microbial activity, all enhancing stress resistance.
- Integrated Nutrient Management:** Optimal application of nutrients according to the results of soil analyses and the needs of crops and thus preventing unbalanced conditions that may increase stress sensitivity; balanced nutrition leads to plant vigour and resistance.

#### 3.3. Precision Agriculture Technologies:

Precision agriculture (PA) uses the technologies of information technology to control the input in the fields of interest with high accuracy and optimise resource use and stress resistance.

- Remote Sensing and GIS:** Satellite, drone, and geographic information systems can provide real time information on the health of crops, water conditions, and nutrient deficiencies across large scale areas to allow targeted interventions like variable-rate irrigation or fertilisation.
- Variable Rate Technology (VRT):** This technology enables the accurate application of inputs (water, fertiliser, pesticides) based on spatial or field variations, and allows the utilization of resources efficiently and to their areas of maximum benefit to reduce stress.
- Sensor-Based Irrigation:** Water sensors and physiological sensors are placed on plants to feed automated or semi-automated irrigation systems to ensure maximum water supply and prevent deficit and over-irrigation.



**Figure 1. Interconnectedness of Climate-Smart Agronomy Strategies for Abiotic Stress Mitigation**

- d) **Weather Stations and Predictive Modelling:** Predictive models with local weather information can provide early reports about the oncoming stressful situations and allow mitigation actions to be taken in advance.

### 3.4. Water Management and Irrigation Techniques:

Efficient water use is critical in the face of increasing drought frequency and water scarcity.

- a) **Drip and Micro-Sprinkler Irrigation:** These localized practices apply water to the root zone, thus reducing evaporation and runoff and attaining a much greater water-use efficiency than traditional flood irrigation.
- b) **Deficit Irrigation:** This type of irrigation applies less water than the maximum possible water needed to develop the crop, but enough water to prevent extreme stress; it may be a rational saving of the use of water on particular crops and crop growth one stage without subjecting the crop to a significant yield penalty.
- c) **Rainwater Harvesting:** Gathering and storing the rainwater that falls to irrigate fields during dry seasons can significantly increase the water supply in rain-based systems.
- d) **Water-Smart Crop Selection and Cropping Systems:** It is a prudent practice to either use varieties inherently water efficient or use crops that promote the efficient use of water during the growing period.

### 3.5. Other Agronomic Practices:

- a) **Adjusted Sowing Dates:** It is possible to give the crop a timing of sowing that ensures that more sensitive growth stages do not overlap with stress periods, i.e. flowering should not occur during a spell of intense heat.
- b) **Shelterbelts and Windbreaks:** Plants placed around fields minimize the wind velocity and, as a result, lessen the evapotranspiration, and so shield the crops against withering.

- c) **Mulching:** Mulch, which is either organic or synthetic, on the top surface of soil helps to conserve moisture, control temperatures, suppress weeds and reduce erosion.
- d) **Biostimulants and Biofertilizers:** Nutrient uptake, stress tolerance, and growth are increased by the use of useful microorganisms or natural products.

#### 4. Integration and Implementation Challenges

Although the benefits of climate-smart agriculture (CSA) are clear, it largely depends on the holistic approach that will address several challenges:

- a) **Knowledge Gaps and Capacity Building:** The farmers (especially in the developing countries) might not be knowledgeable enough, or technologically savvy, to embrace new methods; therefore, extensive training and extension services are invaluable.
- b) **Initial Investment Costs:** Some CSA technologies require a large initial capital investment that may be a barrier to smallholders.
- c) **Policy and Institutional Support:** Government policies that are enabling, that provide incentives and access to finance, are required to promote large-scale adoption.
- d) **Data Infrastructure:** To implement effective precision agriculture, it is necessary to have strong systems in collecting data, analyzing and sharing data; and in numerous places, such systems are not in place.
- e) **Local Adaptation:** CSA strategies are to be designed to fit the particular local environment, such as climate, soil type, crop kinds and socio-economic environment, because a universal strategy is ineffective.

#### 5. Monitoring, Evaluation, and Early Warning Systems

The effectiveness of CSA is based on constant monitoring and evaluation.

- a) **Real-time Monitoring:** Weather stations, soil moisture sensors, and remote sensing are used to monitor the environmental conditions and crop performance in real time.
- b) **Crop Modelling:** Crop growth models are models that simulate different stress conditions, so it is possible to assess the relative efficiency of particular CSA interventions.
- c) **Early Warning Systems:** Early warning systems, which inform farmers about upcoming abiotic stresses, based on climate predictions and local data, are beneficial to preventative action.
- d) **Participatory Approaches:** through involvement of the farmers in the monitoring and evaluation, the strategies can always be relevant and be adapted to suit the needs and local knowledge of the farmers.

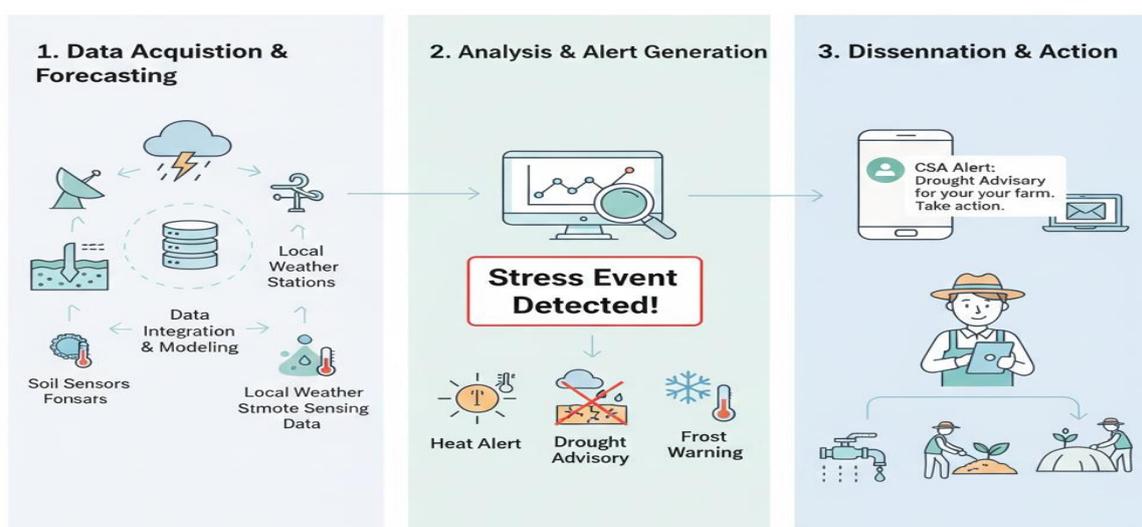


Figure 2. Climate-smart early warning system for abiotic stress

**Table 2. Key Indicators for Monitoring CSA Effectiveness in Abiotic Stress Mitigation**

Category	Indicator	Measurement Method	Relevance to Stress Mitigation
<b>Yield &amp; Production</b>	Crop Yield (e.g., kg/ha)	Field harvest, farmer records	Direct measure of productivity under stress
	Yield Stability Index	Statistical analysis of yield variations	Resilience of production across different stress levels
<b>Water Use</b>	Water Use Efficiency (WUE)	Yield/Water Applied (or ET)	Efficiency of water utilization
	Soil Moisture Content	Soil moisture sensors, gravimetric method	Availability of water to plants
<b>Soil Health</b>	Soil Organic Carbon (SOC)	Lab analysis	Indicator of long-term soil health & water retention
	Infiltration Rate	Infiltrometer	Ability of soil to absorb water
<b>Crop Physiology</b>	Canopy Temperature	Infrared thermometry, remote sensing	Indicator of plant water status & heat stress
	Chlorophyll Content	SPAD meter, remote sensing	Photosynthetic health
<b>Farmer Adoption</b>	Adoption Rate of CSA Practices	Surveys, field observations	Uptake of resilient practices
	Farmer Income	Economic analysis, farmer records	Economic viability and resilience of farming systems

## 6. Conclusion

The concept of climate-smart agronomy offers a solid, flexible blueprint for the reduction of the growing risk of abiotic stresses to the world's food security. Through a combination of genetic enhancement, sustainable soil and water management, precision technologies and context-specific agronomic practices, farmers are capable of creating more resilient cropping systems. CSA success is anchored on constant innovation, robust knowledge transfer, solid policy support and participatory mechanisms that empower the stakeholders. The popularization of CSA is not only optional in the wake of agricultural landscape transformations brought by climate change, but its implementation is a matter of life and death in the context of climate change and sustainable food production.

## References

- Anderson, R., Bayer, P. E., & Edwards, D. (2020). Climate change and the need for agricultural adaptation. *Current Opinion in Plant Biology*, 56, 197–202. <https://doi.org/10.1016/j.pbi.2020.02.007>
- Campbell, B. M., Thornton, P., Zougmore, R., van Asten, P., & Lipper, L. (2014). Sustainable intensification: What is its role in climate smart agriculture? *Current Opinion in Environmental Sustainability*, 8, 39–43. <https://doi.org/10.1016/j.cosust.2014.07.002>
- Choudhury, S., & Moulick, D. (2022). Response of field crops to abiotic stress: Current status and future prospects. In *Response of Field Crops to Abiotic Stress: Current Status and Future Prospects* (pp. 1–25). CRC Press. <https://doi.org/10.1201/9781003258063>
- Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., Caron, P., Cattaneo, A., Garrity, D., Henry, K., Hottle, R., Jackson, L., K rl, A., Loboguerrero, A. M., McCarthy, N., Meybeck, A., Neufeldt, H., Rojas, C., & Twomlow, S. (2014). Climate-smart agriculture for food security. *Nature Climate Change*, 4, 1068–1072. <https://doi.org/10.1038/nclimate2437>
- Mickelbart, M. V., Hasegawa, P. M., & Bailey-Serres, J. (2015). Genetic mechanisms of abiotic stress tolerance that translate to crop yield stability. *Nature Reviews Genetics*, 16(4), 237–251. <https://doi.org/10.1038/nrg3901>
- Mittler, R. (2006). Abiotic stress, the field environment and stress combination. *Trends in Plant Science*, 11(1), 15–19. <https://doi.org/10.1016/j.tplants.2005.10.005>
- Moran, M. S., Inoue, Y., & Barnes, E. M. (1997). Opportunities and limitations for image-based remote sensing in precision crop management. *Remote Sensing of Environment*, 61(3), 319–346. [https://doi.org/10.1016/S0034-4257\(97\)00045-8](https://doi.org/10.1016/S0034-4257(97)00045-8)
- Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., M ller, C., Arneth, A., Boote, K. J., Folberth, C., Glotter, M., Khabarov, N., Neumann, K., Olin, S., Pugh, T. A. M., Scherer, M., Smith, P., Tedeschi, V., & Zhou, B. (2014). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model

intercomparison. *Proceedings of the National Academy of Sciences*, 111(9), 3268–3273. <https://doi.org/10.1073/pnas.1222463110>

Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences*, 108(50), 20260–20264. <https://doi.org/10.1073/pnas.1116437108>

Todaka, D., Shinozaki, K., & Yamaguchi-Shinozaki, K. (2015). Recent advances in the dissection of drought-stress regulatory networks and strategies for development of drought-tolerant transgenic rice plants. *Frontiers in Plant Science*, 6, 84. <https://doi.org/10.3389/fpls.2015.00084>

Wani, S. P., Marimuthu, S., Chander, S., & Badiyala, D. (2020). Agronomic management for enhancing plant tolerance to abiotic stresses—drought, salinity, hypoxia, and lodging. *Agronomy*, 10(4), 540. <https://doi.org/10.3390/agronomy10040540>



## Impact of market price fluctuations on farmer's income and risk management



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### 1. Introduction

Agriculture is a risky business in itself. The environment in which farmers have to work is highly globalised with uncertainty prevailing at every corner, with the biological nature of production closely coupled with unpredictable ecological, economic forces. Although the yield risks are caused by pests, disease and weather conditions have long been recognized as a key factor in the viability of agriculture in the liberalised global economy, market risks especially the price volatility have also become critical factors.

In this regard, price volatility is not just the time dependence of prices but the uncertainty, rate and amplitude of change. Over the past few decades, agricultural commodity markets have undergone periods of extreme volatility, fuelled by a combination of factors of climate change induced production shocks and geopolitical upheaval of trade routes combined with an accelerating process of financialisation of commodity markets.

There is a direct conversion of price volatility to income volatility to a farmer. Lack of predictability of the output prices with reasonable confidence compromises the farm-management choices with regard to the input allocation, technology investments and debt servicing. The resultant income shock can push households into a phase of temporary or long-term poverty when prices fall in the harvest period when farmers are forced to sell their products to settle the seasonal loan, and then the households face a phase of temporary or chronic poverty.

### 2. The Anatomy of Agricultural Price Volatility

In order to see how price volatility affects the situation, it is necessary to comprehend why agricultural markets are more susceptible to strong price fluctuations. The basic explanation can be due to the characteristics of the agricultural supply and demand curves.

#### 2.1 Inelastic Supply and Demand

The demand for the basic food commodities tends to be price inelastic; people need to eat with or without prices, and when there is a reduction in price, people are not going to consume the food at a large scale. Similarly, there is an inelastic short-term agricultural supply. When a crop has been planted, the potential supply is considered fairly fixed until the following season. Thus, what until recently would have been seen as a small shock to supply, say a drought in one of the largest producer areas, or an unexpected change in demand, necessitates a price change that would be disproportionately large to clear the market.

#### 2.2 Key Drivers of Fluctuation

- a) **Production Shocks and Climate Change:** Weather is still the major factor of supply. Climate change has increased the number of extreme weather events such as drought, floods, El Niño events and other events, which amplify the supply side shock, hence resulting in sudden upward price spikes.
- b) **Input Cost Transmission:** Modernized agriculture is energy-consuming. The prices of diesel, electricity and most importantly, synthetic fertilizers are directly affected by the changes in the prices of crude oil. This volatility of input-costs is usually transferred through to output prices at a lag, which generates a complicated squeeze of margins among farmers.

- c) **Trade Policy and Geopolitics:** The food system of the world is very interconnected. Global price shock can be instigated by export bans imposed by key producers of a given product during crises or by geopolitical disputes that interfere with key trade routes.
- d) **Macroeconomic Factors and Financialization:** Exchange-rate variations influence the domestic price of the commodities that are exported and imported. In addition, the growing interest of financial index funds in commodity futures markets has been discussed as a contributor to unnecessary volatility, in which prices no longer reflect underlying supply and demand facts.

### 3. The Direct Impact on Farmer's Income and Livelihoods

There is no even distribution of global or regional market volatility on the farm gate. It has vast effects depending on the size of the farmer, storage facilities and availability of market information. The essence of this is however income instability which has trickle effects on the farm enterprise.



**Figure 1. Vicious Cycle of Price Fluctuations**

#### 3.1 The Harvest Season Price Slump

The effect is worst among the small holder farmers in emerging economies and the developing economies as a result of liquidity containment. Devoid of access to cheap credit or proper storage facilities on the farm, such farmers are frequently obliged to dispose of all their harvest right after harvesting. This mass selling behaviour causes over supply in the local markets and this lowers the prices to the lowest in the annual cycle. Farmers are selling low, however, in most cases they are forced to buy food later in the year as prices have increased which makes them stuck in a negative terms of trade cycle.

#### 3.2 Erosion of Investment and Capital Formation

Uncertain investment horizon is a result of volatile prices. Modernisation of farms, which may be in the form of drip irrigation, buying mechanisation or those of better-quality seeds, involves the upfront capital investment, the returns of which are subject to accrual in the form of years. In situations where the farmers fail to estimate future income with a fair degree of confidence, they are rational in being risk-averse by investing insufficiently in productive assets. This capital formation stagnation restricts long-term growth in productivity and ensures that farm incomes remain low.

#### 3.3 The Debt Trap Phenomenon

Seasonal credit has been an important source of input to farmers in terms of seeds and fertilisers. These loans are usually borrowed before the season where input prices could be high and then the repayment is supposed to be made at the end of the harvest. The farmer can become incapable of servicing the debt on a sudden fall in output prices during harvest, which results in the sale of assets, distress borrowing at usury rates or out of the agricultural industry altogether.

**Table 1. Income Scenario for Corn Farmer under Stable vs. Volatile Markets (Per Hectare)**

Component	Stable Market Scenario (INR)	Volatile Market Scenario (INR)	% Change in Income
Average Yield (Quintals/ha)	40.0	40.0	0%
Market Price (₹/Quintal)	₹ 2,275 (MSP)	₹ 1,600 (Crash Price)	-29.6%
Gross Income (₹/ha)	₹ 91,000	₹ 64,000	-29.6%
Cost of Cultivation (₹/ha)	₹ 35,000	₹ 35,000	0%
Net Income (₹/ha)	<b>₹ 56,000</b>	<b>₹ 29,000</b>	<b>-48.2%</b>
Risk Factor	Low (Protected)	High (Vulnerable)	High

#### 4. Risk Management Strategies: Building Resilience

##### 4.1 On-Farm Production Strategies

Diversification is the most basic strategy in managing risk as it follows the principle of not placing all the eggs in a single basket.

- **Crop Diversification:** Planting a combination of crops that have diverse market cycles, price determinants and climatic resiliencies. Should the price of a cash crop, e.g. cotton, plummet, income earned on a staple food crop or livestock can stabilise the household.
- **Vertical Integration:** Ascending the value chain by treating raw commodities in the farm. The volatility of prices of processed goods and the profit margins are generally more stable and the farmer is somewhat not attached to the fluctuations of the bulk commodity prices.

##### 4.2 Market-Based Financial Instruments

###### a) Forward and Futures Contracts (Hedging):

- Forward Contracts:** This is a custom-made deal between the grower and the buyer, including a processing company, that involves the sale of a specified amount of produce at a fixed price on a given date in the future. This type of setup erases the downside risk on the farm but at the same time, it erases the potential of positive movements in the case of unexpected market price increases.
- Futures Contracts:** Standardized contracts that are traded on regulated markets and which require the sale or buying of a commodity at a fixed price and the specific date. Farmers can counter possible losses in case the physical market prices decrease by assigning futures contracts with the number of gains being similar to the anticipated yield of the futures contracts as the position nears maturity. This type of implementation demands a degree of financial savvy and an availability of brokerage facilities, factors which have historically limited their ubiquity to bigger and more commercial undertakings.

- Options Contracts:** Under these options, the producer can sell at a certain price but not with the obligation. The farmer is purchasing a put option that serves as a price insurance and, therefore, sets a price floor but retains the flexibility to take advantage of any favourable price changes in case the market recovers.



**Figure 2. Risk management strategies**

**Table 2. Comparative Analysis of Agricultural Price Risk Management Tools**

Strategy Category	Tool / Mechanism	Primary Benefit for Farmer	Key Challenges / Limitations	Target Group Suitability
<b>On-Farm</b>	<b>Crop Diversification</b>	Reduces reliance on a single revenue stream; spreads risk.	May reduce specialization gains; requires diverse agronomic knowledge.	All farmers, especially smallholders.
<b>Market-Based (Hedging)</b>	<b>Forward Contracting</b>	Locks in a guaranteed price pre-harvest; simplifies planning.	Eliminates opportunity to benefit from price rises; counterparty risk.	Commercial and organized smallholders linked to agribusiness.
<b>Market-Based</b>	<b>Futures &amp; Options</b>	Provides sophisticated price discovery and flexible risk transfer.	High complexity requiring financial literacy; margin calls require liquidity; basis risk.	Large-scale commercial farmers.
<b>Institutional</b>	<b>Warehouse Receipt Systems (WRS)</b>	Prevents distress selling at harvest; eases access to credit.	Requires reliable storage infrastructure, grading standards, and trusted legal frameworks.	Small to medium farmers with non-perishable grains.
<b>Financial/Policy</b>	<b>Revenue Insurance</b>	Comprehensive protection against both yield and price shocks.	High premiums often require government subsidies; complex data needs to set baselines.	Farmers in regions with developed insurance markets and government support.

## 5. Challenges to Adoption and Future Outlook

With the growth in uptake of these tools, their use in producers is still low especially in developing situations. The major hindrances involve informational and infrastructural. The more intricate financial derivatives, including futures, are not easily available to a farmer who is not financially literate. WRS also cannot operate in isolation; it needs to be stored in accredited warehouses and have an efficient grading system. In addition, the mismatch, also known as the basis risk, can at times make hedging strategies ineffective to marginal or remote producers between farm-gate prices and the price at the global futures exchange.

Technological convergence is expected to lead to the direction of risks in the agricultural sector. New digital solutions are already providing agronomic guidance to stabilize harvests, broadcasting transparent market prices information to increase bargaining power, and providing access to digital credit and other micro-insurance services. The use of satellite imagery and artificial intelligence is improving the actuarial models of insurance, thus making revenue insurance more accurate and affordable.

## 6. Conclusion

The volatility of market prices is the pathological feature of agricultural economics, which is driven by the inelasticity of food supply and demand and fuelled by modern environmental and geopolitical problems. To producers, uncontrollable volatility is not just an inconvenience, it is a working death Knell to income stability, capital investment and a long-term guarantee of livelihood.

Although it is impossible to prevent price fluctuations, the consequences of these phenomena can be reduced. The advancement necessitates adaptation of the reactive, ex post coping to the proactive, ex ante risk management. This would require a multi-layered solution: producers should implement on-farm diversification policies; the financial sector should develop the available financial hedging market tools; and governments should invest in infrastructure that fulfils key roles like warehousing and information system to facilitate the operation

of these markets. Making the farm viable in the unstable world requires a shift away of the pure pursuit of maximization of yields to the strategic stabilization of returns.

#### References

- Birthal, P. S., & Hazrana, J. (2019). Crop diversification and resilience of agriculture to climatic shocks: Evidence from India. *Agricultural Economics*, 50(6), 707–719. <https://doi.org/10.1111/agec.12518>
- Chand, R. (2017). *Doubling farmers' income: Rationale, strategy, prospects and action plan*. NITI Aayog, Government of India. [https://niti.gov.in/writereaddata/files/document\\_publication/DOUBLING%20FARMERS%20INCOME.pdf](https://niti.gov.in/writereaddata/files/document_publication/DOUBLING%20FARMERS%20INCOME.pdf)
- Food and Agriculture Organization of the United Nations (FAO). (2011). *Safeguarding food security in volatile global markets*. FAO.
- Gulati, A., & Juneja, R. (2022). *Agricultural market reforms: Problems and prospects*. In A. Gulati (Ed.), *Indian Agriculture Towards 2030* (pp. 115–136). Springer.
- Kalkuhl, M., von Braun, J., & Torero, M. (Eds.). (2016). *Food price volatility and its implications for food security and policy*. Springer Open. <https://doi.org/10.1007/978-3-319-28201-5>
- Kumar, A., & Saroj, S. (2019). Contract farming and smallholder income: Evidence from potato farmers in India. *Agribusiness*, 35(1), 1–20. <https://doi.org/10.1002/agr.21588>
- Mishra, P. K. (2020). *Management of agricultural risks in India: The way forward*. Indian Council for Research on International Economic Relations (ICRIER).
- Organization for Economic Co-operation and Development (OECD). (2011). *Managing risk in agriculture: Policy assessment and design*. OECD Publishing. <https://doi.org/10.1787/9789264116146-en>
- Ton, G., Vellema, W., Desiere, S., Weetus, S., & D'Haese, M. (2018). Contract farming for improving smallholder incomes: What can we learn from effectiveness reviews? *White Campbell Collaboration*, 14(1), 1–189.
- World Bank. (2013). *Agriculture risk management team: Risk management assessment*. World Bank Group.



## Influence of crop rotation on soil health and overall productivity



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### 1. Introduction

The development of agriculture through the post-war acceleration, which was driven by mechanization, the use of synthetic fertilizers and pesticides, resulted in unprecedented increases in crop yields. However, this paradigm has habitually relied on simplified agricultural regimes where large acreages are brought under uninterrupted harvest of monocultures of staple crops like maize, wheat, or rice. Although economically efficient in the short run due to economies of scale, the long-term effect of constant monoculture has become more and more associated with the loss of the basic source of the agricultural economy: the soil itself. The degradation of soils, in the form of erosion, the loss of nutrients, loss of organic carbon, and compaction, poses a threat to food security in the long term. Here, crop rotation is re-emerging not as an old custom or even a scientifically confirmed, indispensable element of sustainable agroecosystems. Crop rotation is considered the regular growth of various crop species on the same field in an orderly pattern. Rotation also brings about functional biodiversity in contrast to monoculture, which depletes certain resources in the soil and also picks up certain pests. This article presents the multi-dimensional effect of crop rotation and shows how it is one of the main driving forces of soil health and a requirement of long-term, robust productivity.

### 2. Mechanisms of Soil Health Enhancement through Rotation

Soil health can be described as the remaining ability of soil to be a living ecosystem that is essential to support plants, animals and people. Crop rotation enhances soil health in three main interconnected processes, which are: maximizing nutrient recycling, enhancing physical structure, and increasing biological diversity.

#### 2.1 Nutrient Cycling and Fertility Management

The effect of monocultures is the continuous demand for certain nutrient profiles, which promptly drains a given element in the specific horizons of the soil. As an example, constant maize production is a burdensome source of nitrogen (N) and phosphorus (P).

Rotation systems, especially those including legumes like soybeans, alfalfa or peas, have a fundamental shift in nutrient dynamics. Legumes convert nitrogen in the atmosphere into forms accessible to the plants by a symbiotic association with nitrogen-fixing *rhizobia* bacteria in their root nodules. Upon termination or harvesting of these legumes, residues that remain give organic nitrogen to the soil pool, which is then available to other non-leguminous crops.

More so, crops having varying depths of roots and designs experiment with various soil volumes. The deep-rooted crops, such as alfalfa or forage radishes, may be able to take in nutrients near the surface, such as nitrates that have been washed further down the root zone of more shallow crops, by pumping them back to the surface through biomass development.

#### 2.2 Soil Physical Structure and Aggregation

The good soil structure is that which consists of stable aggregates, which are clumps of soil particles that are maintained together as a result of organic matter, fungal hyphae, and bacterial exudates. These aggregates formed pore space that is critical in the penetration of water, roots and gaseous exchange.

The annual monocultures that come with intensive tillage tend to destroy soil aggregates. Rotations can help restore them in several ways:

- a) **Varied Root Architecture:** Physical enmeshment of soil particles can be enhanced by including crops with dense and fibrous root systems, like grasses or small grains.

b) **Organic Matter Inputs:** Different types of crop residues break down as they have different rates. Microbial activity leads to the decomposition process, which results in polysaccharides and glomalin, a glycoprotein synthesized by mycorrhizal fungi, which are strong biological glues that stabilize the aggregates against water slaking.

c) **Reduced Tillage Opportunities:** Periodic introduction of phases of perennial forage in a rotation results in the restoration of soil structure.

### 2.3 Biological Activity and Biodiversity:

The healthy ground is alive with microscopic organisms. Constant monoculture picks out a simplified food web of soil, typically with pathogens that are particular to that culture. The crop rotation brings a variety of root exudates, a cocktail of sugars, amino acids and organic acids that roots are releasing into the rhizosphere, which sustains a wider range of microbial life.

The rhizosphere effect is also cropping species dependent. A mixed rotation creates an equal society of bacteria, fungi, protozoa, and nematodes. This biodiversity promotes:

1. **Disease Suppression:** A competitive microbiome of soil can be used to suppress soil-borne pathogens.
2. **Nutrient Mineralization:** Diversity in the community of microbes is more effective in the decomposition of organic matter and the release of mineral nutrients.

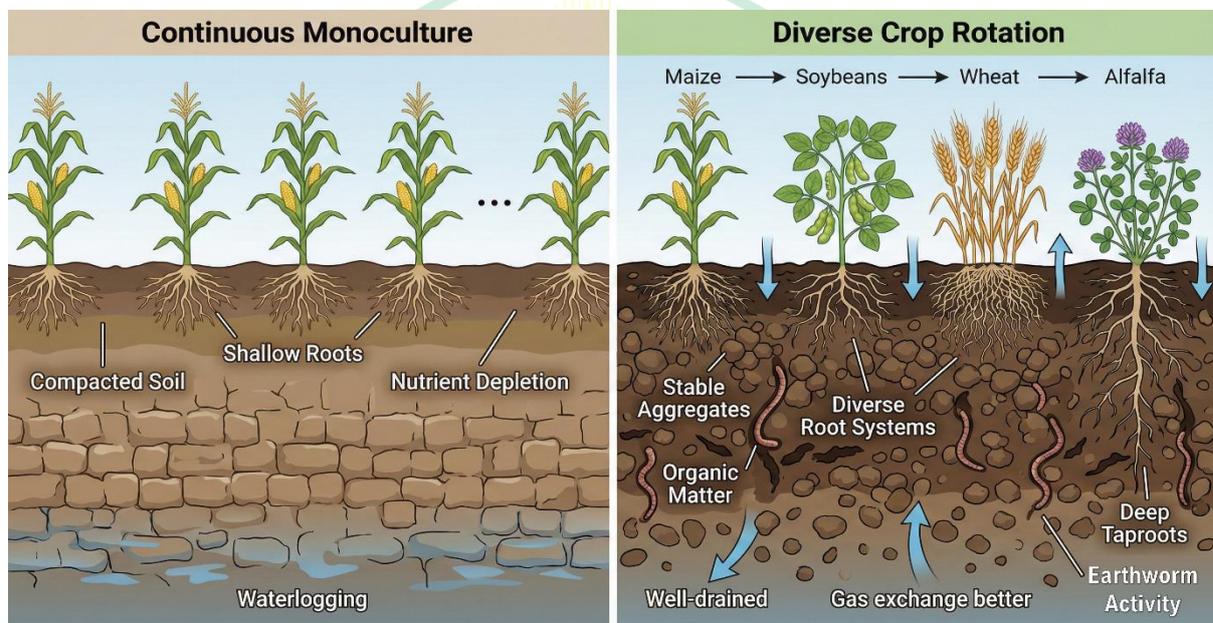


Figure 1. Comparative Soil Profiles under Continuous Monoculture and Diverse Crop Rotation

### 3. Disruption of Pest and Disease Cycles

Among the direct and most cost-effective advantages of crop rotation is the break in the pest cycle as well as the pathogen cycle. A lot of agricultural pests and disease-causing organisms are very host-specific.

The host plant remains present in a continuous monoculture and, therefore, the pest populations may be allowed to grow exponentially between seasons. An example is the corn rootworm (*Diabrotica virgifera virgifera*) commonly referred to as the billion-dollar bug in the Midwestern of the United States, which is a pest of continuous corn fields. Its larvae feed on the roots of corn and it leads to great lodging and loss of yield.

The rotation of a non-host crop like soybeans or oats into the rotation would break the life cycle. The larvae hatch in spring, and they are unable to find any appropriate host roots to feed on and perish due to starvation. The same can be said of soil-borne fungal pathogens, e.g. *Fusarium graminearum* (head blight in wheat/ stalk rot in corn), or nematodes, e.g. soybean cyst nematode.

Rotation does not eliminate the panacea; however, it makes the soil rather less dependent on the chemical control measures by greatly decreasing the number of inoculum loads.

#### 4. Impact on Overall Productivity and Economic Viability

Productivity is the final indicator of any given practice in agricultural activity. Although monocultures can sometimes perform better within one optimal weather year with high inputs, long-term research has always indicated that crop rotations are better in terms of yield stability and, in many instances, better yields on average over a long period.

##### 4.1. The Rotation Effect

The rotation effect is a common phenomenon which is observed by Agronomists; in this phenomenon, a crop that is cultivated in rotation produces more than the crop that is cultivated in the same system, although the limiting factors of crop, e.g. water, nutrients and pests, are apparently under the same control in both systems.

This increment in yield, although typically between 10 and 25 percent, is likely to be ascribed to the overall advantages to the health of the soil reported above: a better microbial community, better soil structure and subsequent improved water-use efficiency, and less sub-clinical pathogen pressures.

##### 4.2. Economic Resilience and Risk Mitigation

Although crop diversification adds new dimensions of management complexity, there are massive economic payoffs associated with it:

- **Reduced Input Costs:** Successful Rotations, especially those that involve the use of legumes, break the cycles of pests, thus leading to less consumption of synthetic nitrogen fertilizers; in addition, the interference with pest cycles will also result in less spending on pesticides and fungicides.
- **Market Buffering:** When a farmer grows only one crop type, he or she will be facing total reliance on that particular commodity market; by diversifying numerous markets, the economic risk will be evenly spread.
- **Climate Resilience:** Soils with better structure and high organic matter in the form of products of a well-performed rotation have a higher water retention capacity, making crops more resistant to temporary drought situations.

#### 5. Designing Effective Rotation Systems

The best rotation does not exist, but it has to be designed in accordance with the local climatic conditions, the types of soil and the market possibilities. However, the successful rotations always follow certain ecological principles.

In order to come up with a system that is effective, producers ought to categorize the crops based on their functional role and not just their market value. The order must be mixed between crops of opposite nature.

**Table 1. Functional Characteristics of Major Crop Groups in Rotations**

Crop Group	Functional Examples	Primary Role in Rotation	Secondary Benefits	Potential Drawbacks/Considerations
<b>Warm-Season Grasses (C4)</b>	Maize (Corn), Sorghum, Millet	High biomass production; high caloric yield; economic backbone.	Builds soil organic carbon via high residue retention.	High nitrogen and water demand; heavy residue can delay soil warming in spring.
<b>Cool-Season Grasses (C3)</b>	Wheat, Oats, Barley, Rye	Excellent erosion control (winter cover); fibrous root systems improve surface aggregation.	Weed suppression via allelopathy (e.g., Rye); scavenges leftover nitrogen.	Can host similar fungal pathogens to warm-season grasses (e.g., Fusarium).
<b>Annual Legumes</b>	Soybeans, Peas, Lentils, Dry Beans	Biological Nitrogen Fixation (BNF); high-value protein crop.	Breaks grass pest cycles; residues decompose rapidly, releasing N quickly.	Leaves relatively little residue cover, increasing erosion risk post-harvest.
<b>Perennial Forages/Legumes</b>	Alfalfa, Clover, Perennial grasses	Deep rooting breaks compaction; significant N-fixation (alfalfa); "soil rest" phase (no tillage).	High-quality livestock feed; massive improvement in soil structure over 3+ years.	Requires a longer-term commitment; removes significant potassium and phosphorus if harvested for hay.
<b>Brassicac/Root Crops</b>	Canola, Radish, Turnips, Sugar beets	Bio-fumigation properties suppress some pests/nematodes; deep taproots alleviate compaction.	Scavenges nitrates from deep soil profiles (radishes); diversifies farm income.	Some are sensitive to common herbicide residues; Do not host mycorrhizal fungi.

### 5.1. Principles of Sequencing

Several rules make it successful when utilizing these functional groups:

- Follow high-N consumers with N-fixers:** Planting corn following fixers will take advantage of the fixed nitrogen.
- Alternate root architectures:** To take advantage of the variable soil profiles and improve aggregation, replace deep taproot systems with fibrous root systems
- Alternate high-residue and low-residue crops:** Follow high-residue corn with lower-residue soybeans to manage surface trash and facilitate planting, provided erosion is controlled.
- Include a perennial phase where feasible:** The introduction of a two-to-four-year perennial forage is perhaps the most effective measure towards restoring destroyed soil structure.

To visualise how these principles are applied in practice, Figure 2 illustrates a typical four-year rotation sequence designed for the US Midwest, highlighting the synergistic interactions between crops.

### 6. Conclusion

With the shift towards intensive monoculture, the natural capital of the world's soils has been undermined, even though it has contributed to the rapid increase in historical achievements in agricultural yield. The facts are indisputable: the use of external chemical inputs solely to complement the biological ecosystem processes cannot be sustained economically and environmentally. Crop rotation is not retrogressive, but an advanced use of ecological science in modern agriculture. The active control of soil fertility, the restoration of damaged soil profiles, and the interruption of harmful pest cycles can be provided by the producers through a strategic sequence of various plant species. The outcome of this is a more productive agricultural system that is also more resistant to climatic extremes and fluctuations in the market. Crop rotation is a key measure to take in changing agriculture, as it is currently a nutrient-mining process, to a regenerative process, which will create the soil base of the future generations.

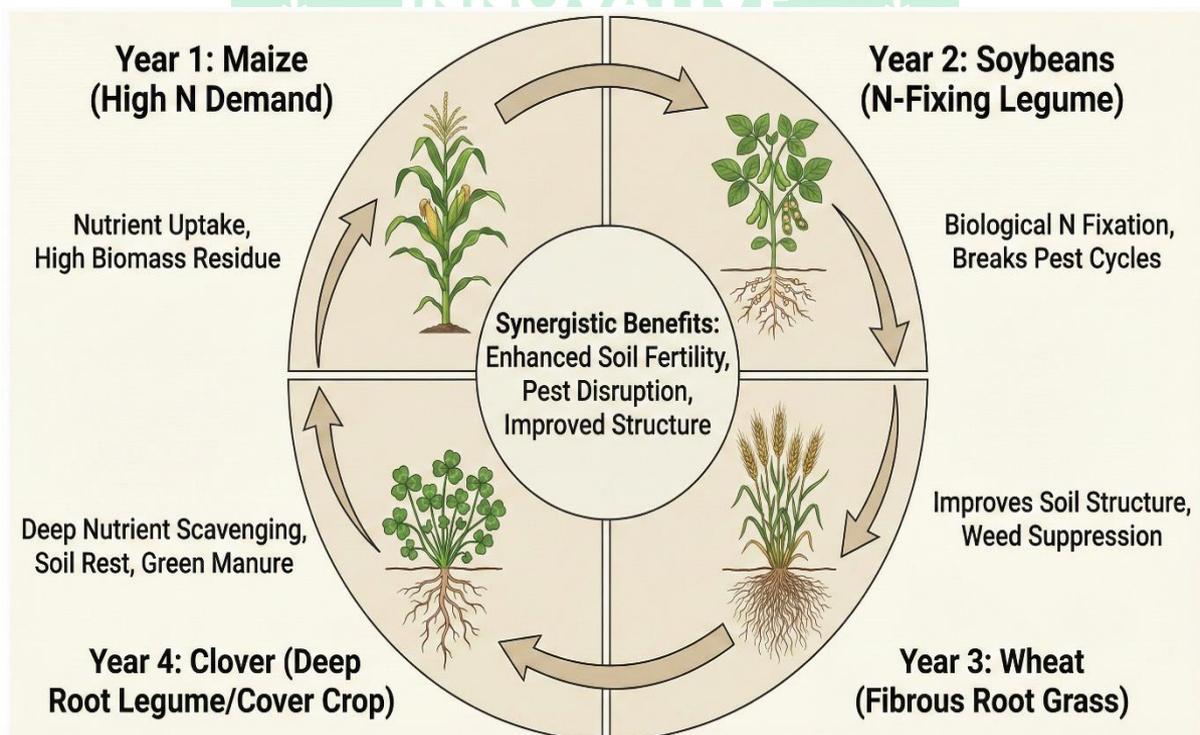


Figure 2. Comparative Soil Profiles under Continuous Monoculture and Diverse Crop Rotation

## References

- Bowles, T. M., Mooshammer, M., Slessarev, Y., Blesh, J., Gaudin, A. C., & Grandy, A. S. (2020). Long-term evidence shows that crop-rotation diversification increases agricultural resilience to adverse growing conditions in North America. *One Earth*, 2(3), 284–293. <https://doi.org/10.1016/j.oneear.2020.02.007>
- Bullock, D. G. (1992). Crop rotation. *Critical Reviews in Plant Sciences*, 11(4), 309–326. <https://doi.org/10.1080/07352689209382349>
- Davis, A. S., Hill, J. D., Chase, C. A., Johanns, A. M., & Liebman, M. (2012). Increasing cropping system diversity balances productivity, profitability and environmental health. *PLoS ONE*, 7(10), e47149. <https://doi.org/10.1371/journal.pone.0047149>
- Karlen, D. L., Varvel, G. E., Cambardella, C. A., & Colvin, T. S. (2013). Soil quality response to long-term yield mapping and crop rotation. *Geoderma*, 202, 3–10. <https://doi.org/10.1016/j.geoderma.2013.03.006>
- Larkin, R. P. (2015). Soil health paradigms and implications for disease management. *Annual Review of Phytopathology*, 53(1), 199–221. <https://doi.org/10.1146/annurev-phyto-080614-120357>
- McDaniel, M. D., Tiemann, L. K., & Grandy, A. S. (2014). Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. *Ecological Applications*, 24(3), 560–570. <https://doi.org/10.1890/13-0616.1>
- Peoples, M. B., Brockwell, J., Herridge, D. F., Rochester, I. J., Alves, B. J. R., Urquiaga, S., Boddey, R. M., Dakora, F. D., Bhattarai, S., Maskey, S. L., Sampet, C., Rerkasem, B., Khan, D. F., Hauggaard-Nielsen, H., & Jensen, E. S. (2009). The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. *Symbiosis*, 48, 1–17. <https://doi.org/10.1007/BF03179980>
- Tiemann, L. K., Grandy, A. S., Atkinson, E. E., Marin-Spiotta, E., & McDaniel, M. D. (2015). Crop biodiversity promotes climatic resilience and soil carbon storage. *Ecology Letters*, 18(8), 767–776. <https://doi.org/10.1111/ele.12453>
- Venter, Z. S., Jacobs, K., & Hawkins, H. J. (2016). The impact of crop rotation on soil microbial diversity: A meta-analysis. *Pedobiologia*, 59(4), 215–223. <https://doi.org/10.1016/j.pedobi.2016.04.001>

## Market Integration, Price Transmission and Volatility in Major Agriculture Commodity Chains



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### 1. Introduction

Complex commodity chains are the distinctive features of global agricultural space, in which market integration, price transmission and price volatility play the key role. In my opinion, market integration is a measure of how the spatially dispersed markets move together, and hence the level of efficiency as well as the level of arbitrage. Price transmission summarizes the occurrence of price flows within the supply chain - e.g., the farm gate to the retail shelf. Price volatility is a significant threat as it assesses how prices vary with time. It is important to have a subtle opinion of these interdependent phenomena; strong market integration will help distribute resources in the best way possible whereas proper transmission of prices will help the price signals to be properly used to guide production and consumption. On the other hand, asymmetric transmission can be a sign of market power and distribution of values that is not fair. Therefore, it is impossible to balance the farm incomes and ensure the food supplies without controlling price volatility. This paper will discuss the theoretical frameworks, empirical approaches, and implications of these three fundamental concepts in terms of policy in the major agricultural commodity chains.

### 2. Theoretical Frameworks

#### 2.1. Market Integration

The Law of One Price (LOP) is the foundation of market integration that states that, as long as there are no frictions, the same goods are supposed to trade at the same price after the transportation expenses and the tariffs have been paid. Whereas full integration is not always witnessed, the level of integration is an indicator of how close a market is to being treated as a single economic entity. The cost of moving goods between places is frequently used by scholars in their relocation as part of the spatial price equilibrium models.

Key theoretical perspectives include:

- a) **Arbitrage Theory:** The argument here is that rational agents will take advantage of the price difference by purchasing in markets with lower prices and selling in markets with higher prices until the price levels even out, and thus destroying the opportunities of arbitrage.
- b) **Cointegration:** In econometrics, cointegration tests the hypothesis that two or more non-stationary price series are in a long-run equilibrium relationship, indicating integration; any deviations will be temporary and self-correcting.
- c) **Market Efficiency Hypothesis:** This hypothesis posits that market prices reflect all available information, implying that arbitrage opportunities are quickly exploited, leading to integrated markets.

#### 2.2. Price Transmission

Price transmission can be described as the process by which price shocks or changes experienced in a single segment of either a market or a supply chain are passed on to the rest. This may be on a vertical channel, that is, where goods are grown at the point of production or in the farm through the wholesale to the retail level or in the horizontal channel, where goods of the same commodity are traded in different geographical markets.

#### 2.3. Price Volatility

Price volatility can be described as the rate of change of the price of a particular commodity rising or falling throughout a given period of time; it is simply an indication of the variance of the returns. Although a certain amount of volatility is part and parcel, too much volatility is harmful.

Theoretical explanations for price volatility include:

- a) **Supply and Demand Shocks:** Agricultural markets are extremely vulnerable to supply shocks like weather strikes or pest strikes, and demand shocks like any income shift or evolving consumer preferences, and can cause an abrupt and large price change due to short-run inelasticity.
- b) **Speculation:** There is a controversial opinion in the role of financial speculation in commodity futures markets, some scholars opine that speculation contributes to volatility, and others believe that it improves liquidity and price discovery.
- c) **Information Asymmetry:** The differences between access and interpretation of information in the market may give rise to price changes as investors react differently to new data.
- d) **Market Structure:** Imperfect competition - such as the oligopolistic or monopolistic nature of processing or retail could influence the absorption or amplification of price shocks.

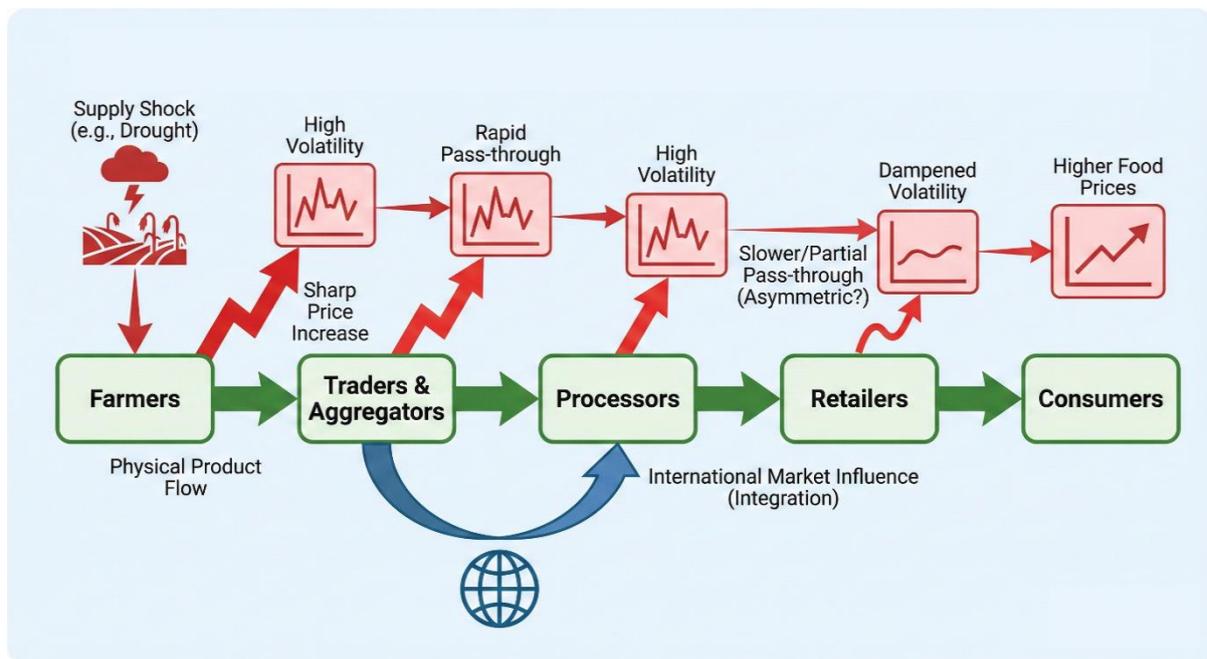


Figure 1. Price shock propagation in an agricultural commodity chain

### 3. Methodological Approaches

#### 3.1. Measuring Market Integration

The common measures of market integration are those based on econometric methods, based on Law of One Price and the theory of arbitrage.

- a) **Correlation and Unit Root Tests:** To test non-stationarity, the first test is the evaluation of simple price correlation, and the second is the use of unit root tests.
- b) **Cointegration Tests:** The main way of identifying a long-run equilibrium relationship is by using Engle-Granger tests or Johansen tests; a cointegrating relationship indicates that there is integration and there is temporary deviation.
- c) **Threshold Cointegration:** More sophisticated methods, like threshold cointegration, use nonlinear adaptation and recommend arbitrage when price variations exceed transaction costs.

#### 3.2. Measuring Price Transmission

Price transmission analysis focuses on the speed and the extent of adjustment between markets or stages of the supply chain.

- a) **Error Correction Models (ECMs):** These models can identify both short-run dynamics and long-run equilibrium, whereby coefficients depict the rate and degree of propagation.

- b) **Asymmetric Price Transmission Models:** To examine the differences in transmission of increases and decreases, more specific nonlinear methods, such as Threshold Error Correction Models (TECMs) and Non-Linear Autoregressive Distributed Lag (NARDL) models, are used.

### 3.3. Measuring Price Volatility

Volatility measures the dispersion of prices over time, often using models that account for time-varying risk.

- a) **Standard Deviation/Variance:** Simple indicators of the average deviation of price.
- b) **GARCH Models:** The Generalised Autoregressive Conditional Heteroskedasticity model series of EGARCH and GJR-GARCH techniques are popular in estimating and predicting volatility, and in particular clustering of periods of high volatility.
- c) **Implied Volatility:** This is calculated based on option prices, and it is an indicator that shows how the market anticipates future volatility.

## 4. Empirical Evidence and Case Studies in Major Agriculture Commodity Chains

The empirical studies done in various agricultural commodity chains have repeatedly shown different levels of market integration, complex transmission of prices and high price volatility.

### 4.1. Cereal Grains

International trade and future markets have largely dominated the highly integrated global markets of cereals like wheat and maize. However, regional markets, especially in developing countries, have low integration due to poor infrastructure.

- **Price Transmission:** Studies often support asymmetric price transmission in which global price increases are passed on to retail mediums- such as the bread prices- faster and more holistically than falls. Processing cost asymmetry and the market power of retailers are often associated with this asymmetry.
- **Volatility:** The prices of cereals are basically prone to volatility, which is mostly caused by extreme weather conditions, geopolitical conflicts (impacting the trade routes) and significant policy adjustments.

**Table 1. Summary of Market Integration in Cereal Markets**

Commodity	Geographic Scope	Integration Level	Key Influencing Factors
Wheat	Global	High	Futures markets, international trade, supply shocks
Maize	Global	High	Biofuel demand, livestock feed, and weather events
Rice	Regional/Global	Moderate	Export restrictions, government interventions, and regional preferences

### 4.2. Livestock and Dairy Products

Integration is diverse: live animal markets are usually regional, but processed dairy products have more global connections.

- **Price Transmission:** Asymmetry is the rule of the day, and farm-gate price rises are easily transferred to consumer prices.
- **Volatility:** The volatility in feed prices and disease outbreaks is a major cause of sharp supply shocks.

### 4.3. Horticultural Products

Such markets tend to be less integrated across long distances because perishability and high cold-chain costs make this difficult, but global integration is increasing for high-value products.

- **Price Transmission:** Pass-through is usually associated with smooth and high marketing margins. Retailers can iron out farm-gate volatility against consumers, and this may not be in favour of farmers in times of price increases.
- **Volatility:** The horticultural industry is characterized by price volatility due to seasonality, high speed of weather changes and high variability of demand.

## 5. Determinants and Implications

### 5.1. Determinants of Market Integration, Price Transmission, and Volatility

Several factors influence these market dynamics:

- Infrastructure:** The market should have good transportation networks, storage facilities, and communication systems. Lack of adequate infrastructure increases the cost of conducting transactions and secluding markets.
- Information Asymmetry:** Lack of timely and correct market information may hinder arbitrage, slow down price transmission and increase volatility.
- Market Structure:** The degree of competition or concentration at different levels of the supply chain (e.g., processing, retail) significantly impacts price transmission and the distribution of market power. Monopolistic or oligopolistic structures can lead to asymmetric price transmission.

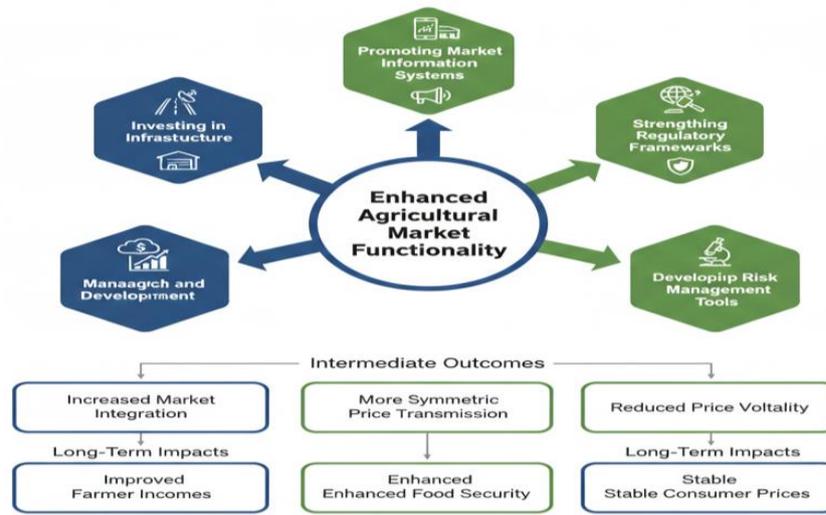


Figure 2. Policy Levers for Enhancing Market Functionality

- Trade Policies:** Tariffs, quotas, export bans, and subsidies can fragment markets, distort price signals, and exacerbate volatility.
- Technology:** Innovations in logistics, storage, and information technology (e.g., mobile apps for market prices) can enhance integration and improve price transmission.
- Macroeconomic Factors:** Exchange rates, inflation, and interest rates influence input costs, consumer demand, and trade competitiveness, impacting all three phenomena.
- Climate Change and Environmental Factors:** Increasingly frequent extreme weather events directly impact agricultural supply, leading to greater price volatility.
- Financialization of Commodities:** The involvement of financial investors in commodity futures markets can, in some views, contribute to price volatility, particularly during periods of uncertainty.

### 5.2. Implications for Stakeholders

- Farmers:** Well-integrated markets and perfect price transmission can sustain stable and predictable incomes. On the other hand, low integration, negative transmission, and volatility leads to high risks of income to farmers, which hinders investment and long-term planning.
- Consumers:** here is a direct impact of food volatility on household budgets and food affordability. Consumer welfare can be destroyed by asymmetric transmission of prices in which only increases are conveyed and no decreases.
- Processors and Retailers:** These intermediaries are vulnerable to the risks of fluctuation in input prices but may be able to use market strength to influence price transmittance, which may be favourable to asymmetric pass-through.

- d) **Policymakers:** These dynamics are critical in understanding the formulation of successful policies concerning agricultural trade, market infrastructures, food security and risk management.

## 7. Conclusion

Market integration, transmission of prices, and volatility are essential notions of the operation and issues of the large agricultural commodity chains. The markets in staple commodities have high levels of integration in the global market, but the regions have unequal disparities in differences and complexities in the transmission of prices. The volatility of prices due to a combination of supply, demand, and macroeconomic variables is always a threat to the stability of agricultural systems.

The empirical studies have always highlighted the fact that asymmetric transmission of prices is common and unpredictable negative impacts of the excessive price volatility especially on the vulnerable farmers and consumers. To resolve these, a holistic policy framework that focuses on investment in physical and digital infrastructure, enhances transparency by ensuring information systems that are robust and uphold fair competition along the supply chain are requisite. Policymakers can improve incomes of farmers significantly, stabilise the prices of consumers, and eventually boost food security across the world by facilitating more integrated markets, symmetric transmission of prices and reducing volatility. Further studies, particularly those relating to long-term effects of climate change and the changing market forms, will be important in adjusting policies to the changes that might arise in the future in the agricultural commodity markets.

## References

- Baffes, J. (2007). Oil spills on other commodities. *Resources Policy*, 32(3), 126–137. <https://doi.org/10.1016/j.resourpol.2007.08.002>
- Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. *Journal of Econometrics*, 31(3), 307–327. [https://doi.org/10.1016/0304-4076\(86\)90063-1](https://doi.org/10.1016/0304-4076(86)90063-1)
- Conforti, P. (2004). *Price transmission in selected agricultural markets* (FAO Commodity and Trade Policy Research Working Paper No. 7). Food and Agriculture Organization of the United Nations.
- Engle, R. F., & Granger, C. W. J. (1987). Co-integration and error correction: Representation, estimation, and testing. *Econometrica*, 55(2), 251–276. <https://doi.org/10.2307/1913236>
- Fackler, P. L., & Goodwin, B. K. (2001). Spatial price analysis. In B. L. Gardner & G. C. Rausser (Eds.), *Handbook of agricultural economics* (Vol. 1, pp. 971–1024). Elsevier.
- Gilbert, C. L., & Morgan, C. W. (2010). Food price volatility. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365(1554), 3023–3034. <https://doi.org/10.1098/rstb.2010.0139>
- Huchet-Bourdon, M. (2011). *Agricultural commodity price volatility: An overview* (OECD Food, Agriculture and Fisheries Papers, No. 52). OECD Publishing. <https://doi.org/10.1787/5kg0t00nrthc-en>
- Johansen, S. (1988). Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control*, 12(2-3), 231–254. [https://doi.org/10.1016/0165-1889\(88\)90041-3](https://doi.org/10.1016/0165-1889(88)90041-3)
- Meyer, J., & von Cramon-Taubadel, S. (2004). Asymmetric price transmission: A survey. *Journal of Agricultural Economics*, 55(3), 581–611. <https://doi.org/10.1111/j.1477-9552.2004.tb00116.x>
- Minot, N. (2011). *Transmission of world food price changes to markets in Sub-Saharan Africa* (IFPRI Discussion Paper 1059). International Food Policy Research Institute.
- Peltzman, S. (2000). Prices rise faster than they fall. *Journal of Political Economy*, 108(3), 466–502. <https://doi.org/10.1086/262126>

## Mulching Techniques for Improving Crop Yield and Soil Moisture Conservation



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### 1. Introduction

In the context of modern agriculture, there is a two-fold problem of feeding the ever-increasing of people in the world, and at the same time preserving the diminishing natural resources, especially freshwater. Currently, nearly 70 per cent of the global freshwater abstractions are conducted in the food production sector, which is estimated to be unsustainable in the scenario of climate change characterized by unpredictable precipitation and high-evapotranspiration rates. This makes the field-scale strategies to improve water-use efficiency (WUE) inalienable.

Mulching is one of these techniques and an agronomic strategy. Defined as the use of a protective layer of material on the surface of the soil, mulching essentially alters the energy and mass balance on the soil-atmosphere interface. The use of it has also expanded historically, and is currently utilized in large-acreage cereal and vegetable systems due to mechanization and material science innovations.

The main tasks of mulching are varied: they include preservation of soil moisture due to the reduced evaporation, stabilization of soil temperature, inhibition of competition between weeds, and, depending on the material, the increase of soil organic matter. This paper analyses the effectiveness of the different mulching systems in achieving these goals and also discusses their resulting effect on crop growth.

### 2. Mechanisms of Action

The positives of mulching are based on its ability to uncouple the surface of the soil and the immediate atmospheric situation.

#### 2.1 Soil Moisture Conservation

The most significant contribution of mulching is the reduction of direct water loss from the soil surface through evaporation. In un-mulched soil, capillary action draws water to the surface, where solar radiation converts it to vapor. A mulch layer acts as a physical barrier, breaking this capillarity and insulating the soil from incident solar radiation. By reducing the vapour pressure gradient between the soil surface and the atmosphere, evaporation is significantly curtailed.

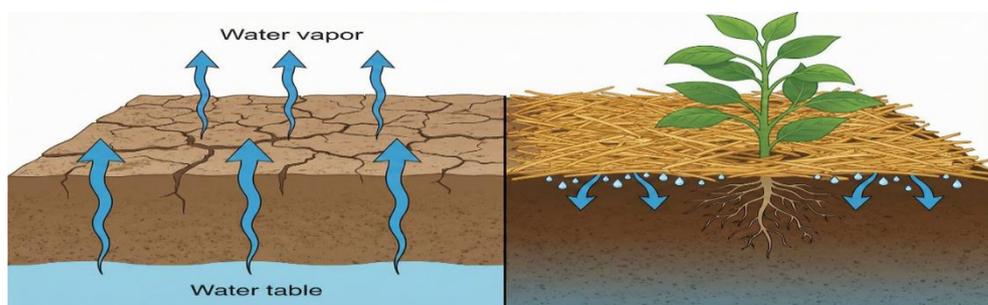


Figure 1. A schematic cross-section of soil illustrating the moisture-conserving effect of mulching. The left panel shows high rates of water vapor loss from bare, cracked soil. The right panel shows a straw mulch layer trapping moisture and condensing it back in

## 2.2 Soil Temperature Regulation

Mulches regulate the thermal regime of soil. This modulation is strongly dependent on the optical characteristics of the mulch material in power and direction.

- a) **Organic Mulches:** such materials have poor thermal conductivity and a large albedo. They therefore have the effect of reducing maximum daytime temperatures and increasing minimum temperatures at night so as to create a stable and moderate root-zone environment which is most favourable during periods of heat stress.
- b) **Inorganic Mulches:**
  - I. Transparent films can pass solar radiation, thus warming the soil considerably via the greenhouse effect; this will be beneficial in the early warming of soil in cooler climate areas.
  - II. Black films absorb solar radiation, conductively transfer heat, providing moderate warming and blocking light needed by the weed to germinate.

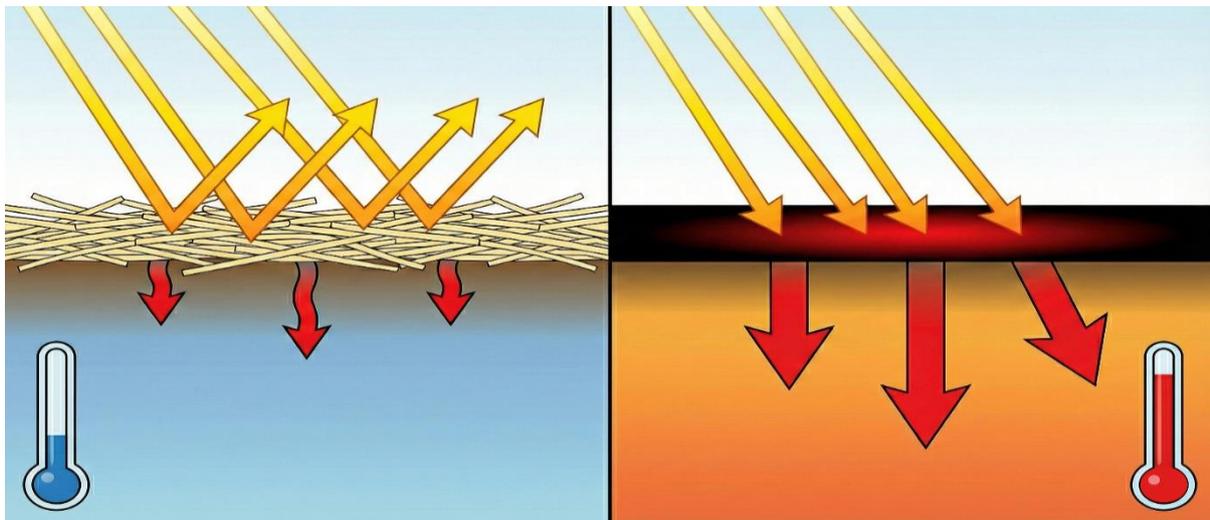


Figure 2. A comparative diagram of soil temperature regulation by different mulches. The left panel shows straw mulch reflecting most incoming solar radiation, keeping the underlying soil cool. The right panel shows black plastic mulch absorbing solar radiation

## 2.3 Weed Suppression

The main mode of action of mulches is to cover the photosynthetically active radiation (PAR) and this inhibits the growth and germination of weed seeds which are dependent with light, as the radiation is not reaching the soil surface. Furthermore, most mulches as a physical layer do not allow the green weed seedlings to penetrate the surface.



Figure 3. A photograph demonstrating the weed-suppressing capability of black plastic mulch in a tomato field. The rows on the left, covered with black plastic, are virtually weed-free. The adjacent bare soil on the right is heavily infested with weeds competing

### 3. Types of Mulching Materials: A Comparative Analysis

The selection of appropriate mulch is contingent upon crop type, climate, cost, and long-term soil health objectives.

#### 3.1 Organic Mulches

Derived from plant and animal residues, organic mulches include straw, hay, compost, wood chips, sawdust, and crop residues.

- **Advantages:** In addition to saving moisture, these materials also break down with time, supplying soil organic matter (SOM), improving microbial activity, improving soil structure due to low bulk density, and acting as a slow source of nutrients.
- **Disadvantages:** They are usually cumbersome in terms of transport and installation. Otherwise, they can bring weed seeds or phytopathogens. High carbon-to-nitrogen (C:N) ratios (e.g. sawdust) might temporarily bind nitrogen in the soil, which might require additional fertilisation.

#### 3.2 Inorganic Mulches

Polyethene (PE) films are the leading type of vegetable and fruit packaging; the thickness and optical properties are the characteristic features of the packaging.

- **Advantages:** They offer high quality, consistent moisture saving and accurate temperature regulation compared to organic choices. Black plastics offer almost complete protection of weeds, which minimizes herbicides dependence.
- **Disadvantages:** They are petrochemical products that absorb a large amount of carbon and they do not add organic matter to the soil. Most importantly, the disposal of residual plastic fragments at the end of the season leads to the long-term pollution of the soil and leads to impediments in future farming.

#### 3.3 Biodegradable Mulch Films (BDMs)

A new solution that is aimed to alleviate the pollution problem that is related to the traditional plastics. The BDMs are supposed to be added to the soil upon harvest and then mineralised by soil microorganisms to carbon dioxide, water, and biomass of microorganisms.

- **Status:** Despite the promise, it still has some difficulties in the predictability of the degradation rates in different soil moisture and temperature conditions, and the increased initial costs compared to standard PE films.



Figure 4. A visual comparison of common mulching materials. From left to right: organic wheat straw, inorganic black polyethylene plastic film, and a biodegradable mulch film.

**Table 3. Comparative Analysis of Common Mulching Materials**

Material Category	Examples	Primary Mechanisms	Advantages	Disadvantages
<b>Organic</b>	Cereal straw, grass clippings, compost, bark chips	Insulation, shading, decomposition	Improves soil health/SOM, nutrient cycling, permeable to rain, lower cost (if locally available)	Can immobilize nitrogen, potential pest harbor, labour-intensive application, decomposes rapidly in heat
<b>Inorganic (PE Film)</b>	Black plastic (LDPE), Clear plastic, Woven geotextiles	Vapour barrier, light manipulation (absorption or transmission)	Excellent moisture retention, precise temperature control, superior weed control (opaque films)	Non-renewable, significant disposal challenge (pollution), impermeable to rain (requires drip irrigation)
<b>Biodegradable</b>	Starch-based polymers, PLA/PBAT blends	Similar to PE film initially; microbial breakdown later	Reduces plastic pollution, eliminates removal labour, comparable agronomic performance to PE	Higher cost, unpredictable breakdown rate based on climate, varying mechanical strength

#### 4. Impact on Soil Moisture Conservation

Empirical researches have always shown that mulching has a great effect of increasing water storage in soil. This is determined by the thickness of the mulch (in case of organic) or the permeability (in case of inorganic). Organic mulch (e.g. 510cm of straw) can also help to cut evaporation losses by 30 to 50 per cent compared to bare soil, which is especially important in the first years of crop-growth when the canopy cover is too small to obscure the soil surface.

Plastic films are even more effective for evaporative loss prevention. In plasticulture systems, which almost solely use drip irrigation under the mulch, the water is applied to the root zone, and the plastic film prevents water from evaporating on the surface. Research work in the arid areas has shown that plastic mulching can enhance WUE, which is the crop yield divided by the amount of water used on it, by 25 % to more than 60 %, depending on the crop and irrigation technique.

In addition, the organic mulches enhance water penetration, as they cover the soil surface with the kinetic force of raindrops, which results in a soil crusting and sealing; hence, when it finally rains the water is absorbed by them into the soil profile instead of going into the surface as runoff.

#### 5. Impact on Crop Yield and Quality

Agronomic advantages of mulch, which include increased moisture status, improved root-zone temperature, and decreased weed competition, all add together to produce increased marketable yields and, in many cases, improved crop quality.

##### 5.1 Physiological Basis for Yield Improvement

By preserving a higher level of soil moisture capabilities, the mulching improves plant water stress, thus allowing a longer stoma opening, and increasing CO<sub>2</sub> uptake as well as photosynthetic rate.

Also, the process of temperature regulation is very critical. Plastic mulches of thermophilic cultivars, including tomatoes, peppers, and melons, increased root growth and hastened the occurrence of phenological transitions, producing earlier harvests, which fetch high prices in the market. On the contrary, organic mulches, which lead to shadiness and cooling effects, reduce the root temperature excesses in arid hot climates to protect crops like potatoes against the adverse effects of heat.

## 5.2 Yield Response Evidence

The degree of increase in the yield depends on the crop species and the environmental setting. Usually, the highest relative yield increments are observed in dry and semi-arid environment, or during periods of droughts in the temperate area.

- **Vegetable Crops:** The meta-analytical data indicate that plastic mulching of tomatoes, eggplant, and melons and cucumbers results in increased yields by 20-50% percent compared to bare-soil controls. This improvement can be attributed to the synergies of thermal stimulation during the initial stages of growth and the continuity of soil moisture during fruiting.
- **Field Crops:** Straw mulching used as part of maize and wheat systems with water scarcity has been reported to stabilize crop yields by maintaining penalty soil moisture at times of critical phenological events, e.g., anthesis and grain filling.

**Table 4. Yield Responses to Different Mulching Systems in Semi-Arid Conditions**

Crop	Mulch Type	Average Yield Increase vs. Bare Soil (%)	Key Factor Influencing Yield
Tomato	Black PE Plastic	+45%	Soil warming promoting early growth; excellent moisture stability.
Tomato	Wheat Straw (10cm)	+25%	Moisture conservation and reduced heat stress during peak summer.
Maize	Stover Residue	+18%	Conservation of fallow moisture; reduced evaporation during early growth.
Potato	Straw Mulch	+30%	Soil cooling effect and moisture retention, beneficial for tuberization.

## 6. Challenges, Limitations, and Environmental Considerations

Despite the fact that the benefits are enormous, the broader implementation of mulching requires a wise evaluation of the related minuses.

### 6.1 The White Pollution Crisis

Wide use of traditional polyethene covers has created a serious environmental disaster usually termed white pollution. Lacy plastic film can be recovered after harvest, but this is a labour-intensive process and rarely recovers all the film. With time, plastic debris is stored in the soil profile and increases the bulk density, hindering water infiltration and root in-growth and adsorbing agrochemicals, resulting in severe dangers to soil biota. Based on this, there must be a transition to biodegradable alternatives, which is a critical agro-ecological necessity.

### 6.2 Agronomic Constraints of Organic Mulch

Although organic mulches have virtues as far as environmental ecology is concerned, there are practical limitations affecting them. Adequate biomass to be used in large-scale applications may not be very easy to procure and may be expensive. In cool and moist climatic regimes, heavy organic mulch may cause excessive cooling and saturation of the soil in spring, which may delay the sowing date and increase the proliferation of fungal species and gastropods. In addition, nitrogen can be temporarily locked up by cereal straw mulches, and close monitoring of nutrients is required.

## 7. Conclusion and Future Perspectives

Mulching is an essential tool in the modern agronomic toolkit, which offers a proven route to increase the production of food and mitigate the shortage of water. Mulch helps lower the water-use of the soil and optimize biophysical environments that promote plant development by protecting the soil matrix against atmospheric vicissitudes.

However, the sustainability of mulching procedures needs to be improved. Agronomic efficacy versus environmental stewardship views the future path of mulching.

1. Accelerating the study and commercialisation of certified biodegradable mulch films that rival polyethene using cost-efficient and economically viable prices.

2. The bigger the organic mulching in large-scale cropping systems through conservation farming techniques like no-till farming and cover cropping, thus minimising the reliance on exogenous biomass inputs.
3. Development of site-specific mulching policies, which consider the local weather conditions, soil type and unique physiological needs of the target crops.

### References

- Chakraborty, D., Nagarajan, S., Aggarwal, P., Gupta, V. K., Tomar, R. K., Garg, R. N., Sahoo, R. N., Sarkar, A., Chopra, U. K., Sarma, K. S. S., & Kalra, N. (2008). Effect of mulching on soil and plant water status, and the growth and yield of wheat (*Triticum aestivum* L.) in a semi-arid environment. *Agricultural Water Management*, 95(12), 1323–1334. <https://doi.org/10.1016/j.agwat.2008.06.001>
- Kader, M. A., Senge, M., Mojid, M. A., & Ito, K. (2017). Recent advances in mulching materials and methods for modifying soil environment. *Soil and Tillage Research*, 168, 155–166. <https://doi.org/10.1016/j.still.2017.01.001>
- Kasirajan, S., & Ngouajio, M. (2012). Polyethylene and biodegradable mulches for agricultural applications: A review. *Agronomy for Sustainable Development*, 32(2), 501–529. <https://doi.org/10.1007/s13593-011-0068-3>
- Lamont, W. J. (2005). Plastics: Modifying the microclimate for the production of vegetable crops. *HortTechnology*, 15(3), 477–481. <https://doi.org/10.21273/HORTTECH.15.3.0477>
- Prosdocimi, M., Cerdà, A., & Tarolli, P. (2016). The immediate effectiveness of barley straw mulch in reducing soil erodibility and surface runoff generation in Mediterranean vineyards. *Science of The Total Environment*, 547, 323–330. <https://doi.org/10.1016/j.scitotenv.2015.12.076>
- Steinmetz, Z., Wollmann, C., Schaefer, M., Buchmann, C., David, J., Tröger, J., Muñoz, K., Frör, O., & Schaumann, G. E. (2016). Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation? *Science of The Total Environment*, 550, 690–705. <https://doi.org/10.1016/j.scitotenv.2016.01.153>

# Nano-Fertilizers for Improving Nutrient Uptake and Crop Performance



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## 1. Introduction

The Green Revolution realized a record of increased food production in the world, which was largely based on the high-yielding varieties of crops and heavy application of agrochemicals. But the ruling paradigm is near the biophysical cutoff point. Traditional synthetic fertilizers, which are, nevertheless, indispensable, are particularly inefficient: at present, it is estimated that only 30-50% of applied nitrogen (N), less than 45% of phosphorus (P), and about 40% of potassium (K) is absorbed by the crops. The proportion of residuals forms one of the major sources of pollution of the environment. Nitrogen from nitrate leaching is leached into groundwater, and gaseous emissions of nitrous oxide (N<sub>2</sub>O) significantly contribute to climate change. Similarly, phosphate runoff is still the major contributor to eutrophication in fresh and marine habitats. The solution to these inefficiencies is to shift to precision farming, matching the plants with nutrient provision. Nanotechnology - the control of matter on a molecular and atomic level - is one alternative route to this synchronization. Nano-fertilisers are deliberately developed to be efficient nutrient delivery systems to the tissues of plants, reduce environmental losses, and finally improve yields and nutritional quality of crops and reduce the total rate of fertilizer use.

## 2. Defining Nano-Fertilizers: Classification and Characteristics

Nano-fertilizers are not just conventional fertilizers that have been subjected to micronization to smaller sizes but rather tailor-made substances whose nanoscale dimensions give them unique properties, including high surface-area-volume ratios, high solubility, or optical/magnetic behaviours. Their essential characteristic is exceptionally high specific surface area, and it allows more interactions with soil particles, plant roots and microbial consortia and leading to sorption mechanisms and enhancing metabolic integration.

Table 1. Classification of Nano-Fertilizers in Agriculture

Classification Category	Description	Examples	Primary Function
1. Nanoscale Nutrients (Nano-particles)	The nutrient itself is engineered at the nanoscale.	Nano-ZnO, Nano-Fe <sub>2</sub> O <sub>3</sub> , Nano-CuO, Nano-Hydroxyapatite (P)	Direct supply of macro- or micronutrients with high bioavailability due to size and reactivity.
2. Nano-enabled Bulk Fertilizers	Conventional bulk fertilizers coated or mixed with nanomaterials.	Urea coated with nano-polymers; Nano-clays mixed with NPK	Controlling the release rate of bulk nutrients to match crop demand curves.
3. Nano-carriers (Host-Guest Systems)	Nanomaterials act as vehicles to load and deliver nutrients.	Zeolites, Chitosan nanoparticles, Mesoporous silica nanoparticles (MSNs)	Protecting nutrients from premature degradation in soil and facilitating targeted cellular delivery.

The defining characteristic of these materials is their extremely high specific surface area. This allows for greater interaction with soil particles, plant roots, and microbial communities, facilitating sorption processes and enhancing metabolic integration.

## 3. Mechanisms of Enhanced Nutrient Uptake

The excellence of nano-fertilizers lies in their ability to overcome the physical and biological repellence of uptake of conventional ionic nutrients. Mechanisms of action are complex and involve interactions between the soil and root as well as interactions inside plant tissues.

### 3.1. Increased Bioavailability in the Rhizosphere

Throughout the soil solution, the standard nutrients often precipitate to insoluble forms (especially phosphorus and micronutrients like iron and zinc), or they are strongly adsorbed at the soil colloids, and thus they are no longer available to plants. Due to their small size and adjustable surface charges (zeta potential), nanoparticles can penetrate smaller pores of soils and stay longer in suspension. They therefore have lesser fixation tendencies, hence have a greater concentration of bioavailable nutrients in the rhizosphere right around root hairs.

### 3.2. Enhanced Root Uptake Pathways

Traditional nutrient ions are absorbed into roots through specially designed ion channels and transporters that are incorporated in root cell membranes. Nanoparticles take advantage of these routes in addition to getting access to other routes via their tiny size. They enter cell-wall pores and are carried into them via:

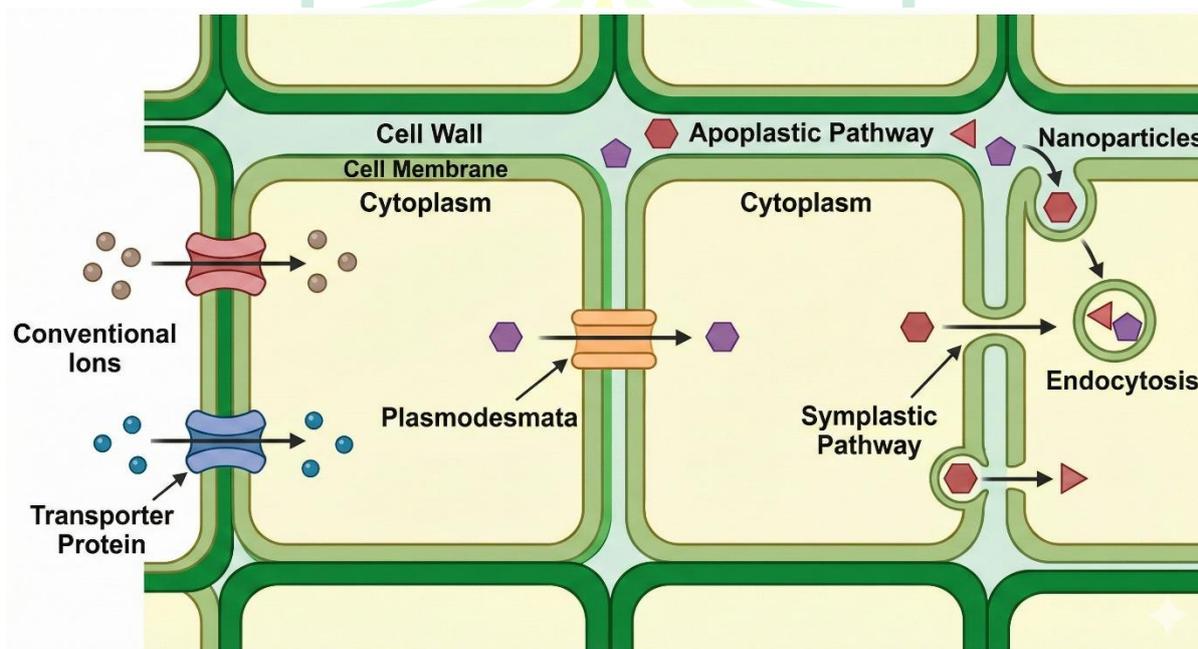
- **Apoplastic Transport:** transport across the extracellular spaces between the cell walls.
- **Symplastic Transport:** cell-to-cell movement through plasmodesmata.
- **Endocytosis:** a process during which the nanoparticle is absorbed by the plant cell membrane and translocated actively to the cytoplasm. This unique benefit over passive ionic diffusion allows absorption even against concentration gradients.

### 3.3. Foliar Penetration Efficiency

The waxy cuticle of leaf usually prevents foliar application of conventional fertilizer solutions because the waxy structure repels hydrophilic solutions. With more effective penetration of the cuticle through stomatal opening and cuticular fissures, nano-fertilizers, especially those having lipophilic coating or surfactants, are easily penetrated by the cuticle. After being fixed into the leaf tissue, they are translocated through the phloem to other parts of the plant hence giving a quick solution to nutrient deficiency.

### 3.4. Controlled and Targeted Release

Controlled release may be the most impactful benefit. Traditional fertilizers release nutrients quickly upon hydration and often are in excess of direct plant needs, leading to wastage. Nano-carriers (e.g. Systems of chitosan or zeolites) can be designed to release nutrients gradually throughout the growing season. Smart nano-fertilizers that are more developed are triggered by certain environmental factors. An example is polymer coatings that can be programmed to degrade and liberate nutrients only when the pH of the soil changes, or when root exudates (organic acids) are released to indicate nutrient requirements, and which can be programmed to match supply to physiological requirements.



**Figure 1. Mechanisms of Nanoparticle Interaction and Uptake in Plant Cells**

#### 4. Impact on Nutrient Use Efficiency (NUE) and Environmental Sustainability

The first tool of appraising fertilizer performance is the Nutrient Use Efficiency (NUE) as the proportion of output (nutrient in harvested crop) to the input (fertilizer spread). Sustainable agriculture revolves around the increase of NUE. Nano-fertilizers significantly enhance NUE by alleviating the three major loss pathways of nutrients:

Nano-fertilizers significantly improve NUE by mitigating the three primary avenues of nutrient loss:

1. **Reduced Leaching:** Since nano-nano-formulations can be designed to release slowly, and they have better retention in the root zone due to the interactions of surface charges, less of the nutrients will be washed under the root zone into the groundwater- which is one of the key features of using nano-formulations in the management of nitrogen in sandy soils.
2. **Decreased Volatilization:** urea is likely to be transformed to the gaseous form of ammonia, particularly during warm alkaline environments. Nano-coated urea or nano-composites slow down the urea hydrolysis rate by blocking the urease enzyme, and thus drastically suppressing the losses of ammonia volatility.
3. **Minimized Fixation:** nano-fertilizers reduce fixation of phosphorus and micronutrients in the soil by reducing the rate at which these compounds precipitate into insoluble soil forms.

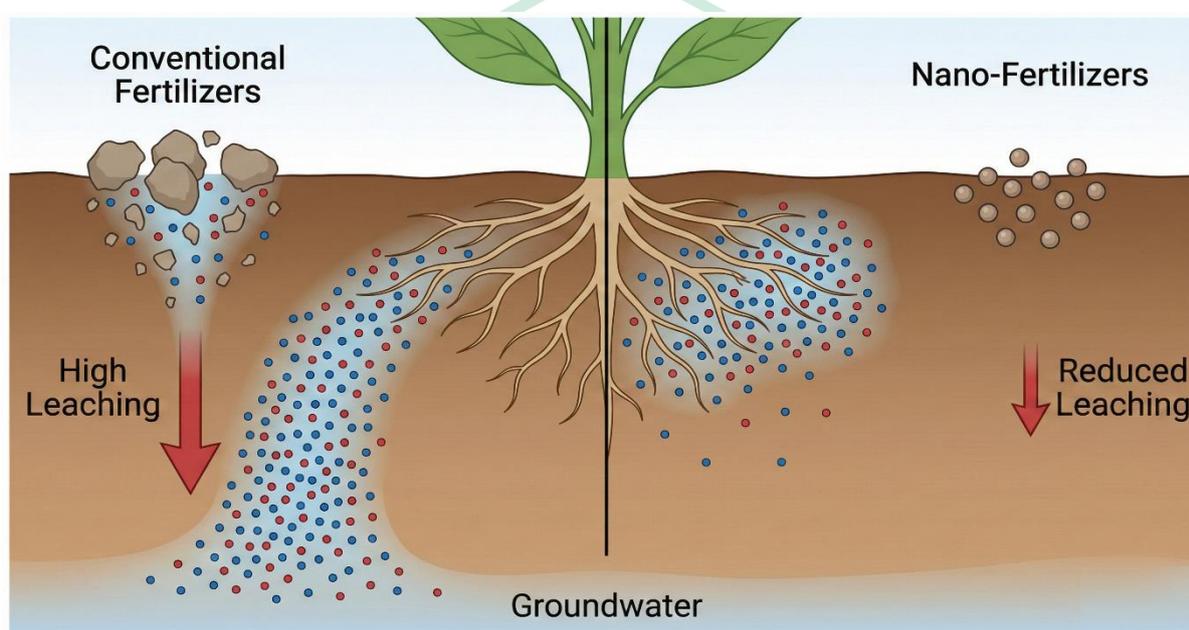


Figure 2. Impact of Nano-Fertilizers on Crop Physiology and Stress Tolerance

Recent meta-analyses indicate that nano-fertilizers can increase NUE by 20–40% compared to conventional counterparts, allowing farmers to reduce overall application rates without sacrificing yield.

Table 2. Comparative Analysis of Conventional vs. Nano-Fertilizers

Feature	Conventional Fertilizers	Nano-Fertilizers
<b>Size</b>	Bulk materials (>1000 nm)	Nanoscale (1–100 nm)
<b>Solubility &amp; Dispersion</b>	Variable; often rapid dissolution	High solubility/dispersibility due to surface area
<b>Release Mechanism</b>	Rapid, uncontrolled hydrolysis/dissolution	Slow, controlled, or triggered release
<b>Nutrient Use Efficiency (NUE)</b>	Low (30–50%)	High (Potentially 70–90%)
<b>Mode of Uptake</b>	Passive ionic diffusion/active transport	Endocytosis, apoplastic/symplastic penetration
<b>Environmental Footprint</b>	High (leaching, eutrophication, GHGs)	Reduced due to lower application rates and targeted delivery
<b>Cost per Unit</b>	Low	High (currently)

## 5. Effects on Crop Performance: Yield and Quality Physiological Impacts

Yield and Quality Physiological Effects.

The enhanced absorption due to nano-fertilizers will translate into transparent physiological advantages and have gains in yield.

### 5.1. Enhanced Photosynthesis and Metabolic Activity

Micronutrients are important catalysts in enzymes in plants. Indispensable compounds in chlorophyll synthesis and photosynthetic electron transport are nano-forms of iron (Fe), magnesium (Mg) and manganese (Mn). Empirical evidence shows that foliar application of nano-Fe or nano-Mg show significant increases in chlorophyll content, photosynthetic rate and biomass accumulation when compared to chelated or salt forms of the same elements.

### 5.2. Stress Tolerance Mitigation

Abiotic stresses like drought and salinity are increasing the occurrence of the specter of climate change. Nano-fertilizers (especially nano-silicon (Si) and nano-zinc oxide (ZnO)) have demonstrated the ability to alleviate these stresses. They do so by balancing osmotics, increasing the activity of antioxidant enzymes (e.g., superoxide dismutase) in order to combat the products of reactive oxygen species in response to stress, and stomatally by regulating stomata to minimise water loss.

### 5.3. Yield Improvements and Biofortification

The end result of the progress in the field of plant physiology is reflected in significantly increased yields. Regional research studies carried out on various crops, including cereals, vegetables, and legumes, indicate a consistent yield increase of between 15-30 per cent in cases where nano-fertilizer regimes are used compared to the traditional agricultural management procedures.

Besides, nanofertilizers are creating highly fertile possibilities of agronomic biofortification, which improves the nutritional quality of food staples. Zinc deficiency is an endemic issue in the world. Nano-ZnO has been shown to be used to enrich Zn levels in wheat and rice, for example when applied to wheat, it was shown to enrich grain levels of zinc significantly more than traditional ZnSO<sub>4</sub> fertilisation, thus directly overcoming hidden hunger in human populations.

## 6. Challenges, Risks, and Future Perspectives

Although nano-fertilisers have an impressive potential, their large-scale use is restrained by huge challenges and uncertainties that should be carefully examined scientifically and regulated by the government.

### 6.1. Ecotoxicity and Soil Health Concerns

These very properties that make nanoparticles highly reactive and penetrative to the cell also welcome environmental dangers. The fate of nanomaterials in the soil matrix in the long run has not been fully characterised.

- **Impact on Soil Microbiome:** Do nano metal-oxide nanoparticles (i.e. nano-Ag or nano-CuO) suppress useful nitrogen-fixing bacteria or mycorrhizal fungi? In several studies, dose-dependent toxicity has been reported in these crucial microbial communities.
- **Trophic Transfer:** It is credible to consider that nanomaterials can be accumulated in soil organisms, such as earthworms, and thus be passed on to the food chain. Moreover, the translocation of nanoparticles into edible foods (grains, fruits) is an aspect of food safety that should be exhaustively tackled by conducting in-depth toxicological studies.

### 6.2. Economic Viability and Scalability

Currently, the production of engineered nanomaterials is both energy-demanding and expensive compared to the massive scales of the industrial processes of Haber-Bosch nitrogen generation or phosphate mining. To ensure that nano-fertilisers become economically viable to use in producing staple crops in developing economies, synthetic processes that are more cost-effective have to be up-scaled.

### 6.3. Regulatory Gaps

There has been an approach in regulatory frameworks of agriculture that bulk chemicals are in mind, and not nanomaterials. An overt lack of standardised procedures to describe nano-fertilisers and assess their impact on

the environment is apparent. A clear set of guidelines as to what a given compound qualifies as a nano-fertiliser and an acceptable level of soil-accumulation is a condition to commercial application.

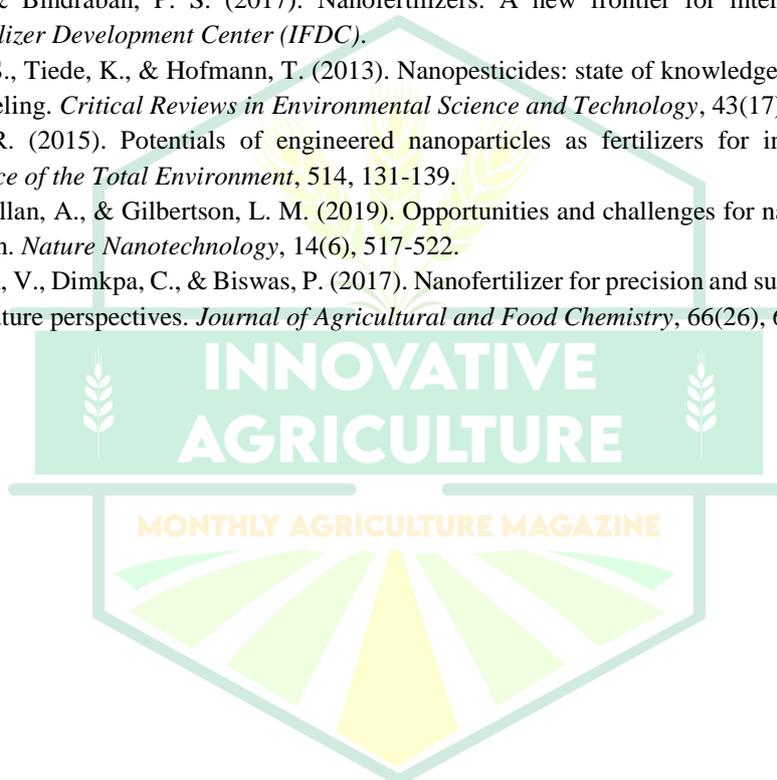
## 7. Conclusion

Nano-fertilisers are another groundbreaking technological advancement that promises to revolutionize the field of agriculture. Using the unique characteristics of the nanoscale, these materials provide a scientifically proven solution that allows decoupling food production and the use of excess chemicals. They provide the avenue to improve the nutrient-use efficiency, lower the environmental pollution, and enhance crop resistance and nutrition.

Nonetheless, there should be a careful shift from conventional to nano-enabled agriculture. The academic and research society should place a priority on long-term and field-scale ecological risk assessments in order to make sure the mitigation of one environmental catastrophe does not create another. It is a combination of a healthy dose of science and preventive policy that will make or lose nano-fertilisers the backbone of the next Green Revolution.

## References

- Dimkpa, C. O., & Bindraban, P. S. (2017). Nanofertilizers: A new frontier for international agriculture. *International Fertilizer Development Center (IFDC)*.
- Kah, M., Beulke, S., Tiede, K., & Hofmann, T. (2013). Nanopesticides: state of knowledge, environmental fate, and exposure modeling. *Critical Reviews in Environmental Science and Technology*, 43(17), 1823-1867.
- Liu, R., & Lal, R. (2015). Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions. *Science of the Total Environment*, 514, 131-139.
- Lowry, G. V., Avellan, A., & Gilbertson, L. M. (2019). Opportunities and challenges for nanotechnology in the agri-tech revolution. *Nature Nanotechnology*, 14(6), 517-522.
- Raliya, R., Saharan, V., Dimkpa, C., & Biswas, P. (2017). Nanofertilizer for precision and sustainable agriculture: current state and future perspectives. *Journal of Agricultural and Food Chemistry*, 66(26), 6487-6503.



## Performance Assessment of Krishi Vigyan Kendras (KVKs) in Technology Dissemination and Capacity Development



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### 1. Introduction

The dynamics of the Indian agriculture, the development of subsistence farming to excess excess-focused but environmentally fragile industry, requires an effective knowledge-delivery system. In this sense, the Krishi Vigyan Kendras (KVKs), which are the Farm science centres of the Indian Council of Agricultural Research (ICAR), occupy a strategic niche in the National Agricultural Research and Extension System (NARES). The KVK network was created in 1974 and started to cover almost all the rural districts of the country.

Unlike the top-down technology transfer that was usually the cornerstone of traditional extension paradigms, KVKs were designed under a special institutional design that was based on the philosophy of learning-by-doing, and on the adage that see is believing. Their main goal is to experiment with location-specific agricultural technology and develop the capacity of the farmers and rural entrepreneurs to embrace sustainable and profitable practices.

This network is huge in terms of the amount of money invested by the populace, and the growing complexity of agriculture challenges, such as a changing climate and unstable markets, requires a stringent performance evaluation. This paper assesses the effectiveness of KVKs in their core mandates, as well as taking it a step further to include qualitative and quantitative effects of KVK interventions in technology dispersion and human resource growth within the rural sector, rather than just reporting physical and financial achievements made.

### 2. The Theoretical Framework: Mandate and Operational Mechanism

In order to analyze the performance in an objective manner, the benchmarks set by the KVK mandate should first be established. The KVK system works with the participatory model involving research, extension, and education. The core operational framework of a KVK rests on four functional pillars:

1. **Technology Assessment and Refinement (TAR):** On-Farm Testing (OFT) to determine the location specificity of agricultural technologies in different farming systems.
2. **Frontline Demonstration (FLD):** To determine the production potential of technologies in the field of farmers, and it produces feedback information.
3. **Capacity Development:** Vocational training of the farmers, farm women, and rural youth and in-service training of the extension personnel.
4. **Knowledge and Resource Centre:** This serves as a centre of supporting the agricultural technologies in the district to assist the people, the private and voluntary sector in enhancing the agricultural economy of the district.

The effectiveness of any KVK is defined by the seamlessness of these functions. Assessment of technology should be used to inform demonstrations, and outcomes of demonstrations should be used to inform training curricula.

### 3. Performance Assessment in Technology Dissemination

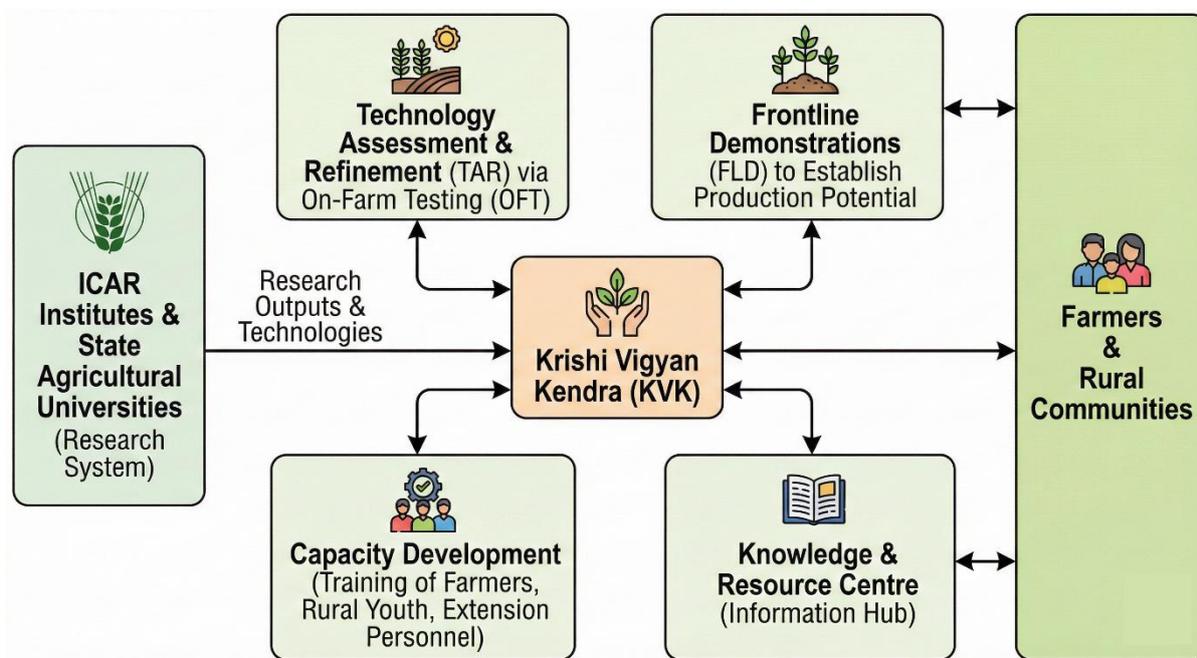
Technology transfer through KVKs is not just the intervention of distribution of inputs but the verification of scientific research in the context of the micro-farms and proving the efficiency of its use. On-Farm Testing (OFT) and Frontline Demonstrations (FLDs) are the major tools to this.

#### 3.1 Efficacy of On-Farm Testing (OFT)

OFTs form the hearth on which generic research-station advice is refined by local reality. According to the data of performance assessments, KVKs have played a crucial role in the fine-tuning of technologies related to integrated pest management (IPM), integrated nutrient management (INM) and varietal assessment.

The success of the OFTs is not judged only by the increased yields, but it includes the aspect of refinement, adjusting a technology in accordance with the local agro-climatic conditions or economic limitations of farmers.

As an example, the KVKs in arid regions effectively optimized the geometry of planting and micro-irrigation timing plans that had been created in research centres with a greater amount of water. Nonetheless, there is a common criticism of the performance of the OFT in the form of a varietal bias wherein the emphasis put on a new type of seed in testing at the cost of natural resource management or farm mechanisation technologies is overemphasised.



**Figure 1. KVK Operational Framework & Mandate.**

### 3.2 Impact of Frontline Demonstrations (FLDs)

FLDs are the flagship intervention of KVKs. They are designed to demonstrate the maximum genetic potential of a technology. The Krishi Vigyan Kendras (KVKs) are based on Frontline Demonstrations. They are carefully tested to demonstrate the highest genetic production capability that a technology can attain when under the direct instruction of scientific professionals. The benchmark performance with regard to this is the yield gap, which is the difference between potential yield in FLDs and the average yield achieved by farmers who use conventional agronomic practices. Investigations at the national level always indicate a high level of yield enhancement that is linked with FLD plots in a range of crops. The monetary effect is normally expressed as the Benefit-Cost Ratio (BCR).

**Table 3. Illustrative Performance Indicators of KVK Frontline Demonstrations (FLDs) across Select Crop Groups**

Crop Group	Technology Intervention	Average Increase over Farmer Practice (%)	Yield over Practice	Benefit-Cost Ratio (BCR) - FLD Plot	Benefit-Cost Ratio (BCR) - Check Plot
<b>Cereals</b>	Improved variety + INM + IPM	18 - 25%		2.45 : 1	1.65 : 1
<b>Pulses</b>	Short duration variety + seed treatment + micro-nutrients (Sulphur)	28 - 35%		3.10 : 1	1.90 : 1
<b>Oilseeds</b>	Improved variety + raised bed planting + IPM	22 - 30%		2.85 : 1	1.75 : 1
<b>Vegetables</b>	Hybrid seeds + drip irrigation + fertigation	35 - 45%		4.20 : 1	2.10 : 1

The data in Table 1 illustrates that KVK interventions through FLDs consistently demonstrate superior economic returns. The high BCR in pulses and vegetables indicates successful dissemination of low-input, high-output

technologies. However, the performance assessment also reveals a demonstration-adoption gap. While the demonstrations are successful, widespread adoption beyond the beneficiary farmers often lags due to external factors like input availability, credit constraints, or market volatility, which are sometimes beyond the KVK's direct control.

#### 4. Performance Assessment in Capacity Development

The human aspect of agricultural development is taken care of by the mandate of the KVKs to train and develop capability. This initiative is necessary to transform farmers into active decision makers as opposed to being passive receivers of technology. This area of performance has to be assessed then to the typology of training, the pedagogical practices that are utilized, and the consequent livelihood effects on the trainees.

##### 4.1 Shifting Focus of Training Programs

Training programmes run by KVK have traditionally given much emphasis to crop-production methods. Longitudinal performance analysis shows that there is a positive paradigm shift compared to the last ten years. A shift towards the post-harvest technology, value addition, agricultural mechanisation, and by-products like milk production, chicken and fishing can be identified. This change is in line with the country's goal of increasing the income of the farmers, and not only the farm produce. Moreover, the rural youth targeted by training programmes directly emphasise the development of entrepreneurship, the production of para-extension workers, the operators of the custom hiring centres, or the seed producers, not traditional farming only.

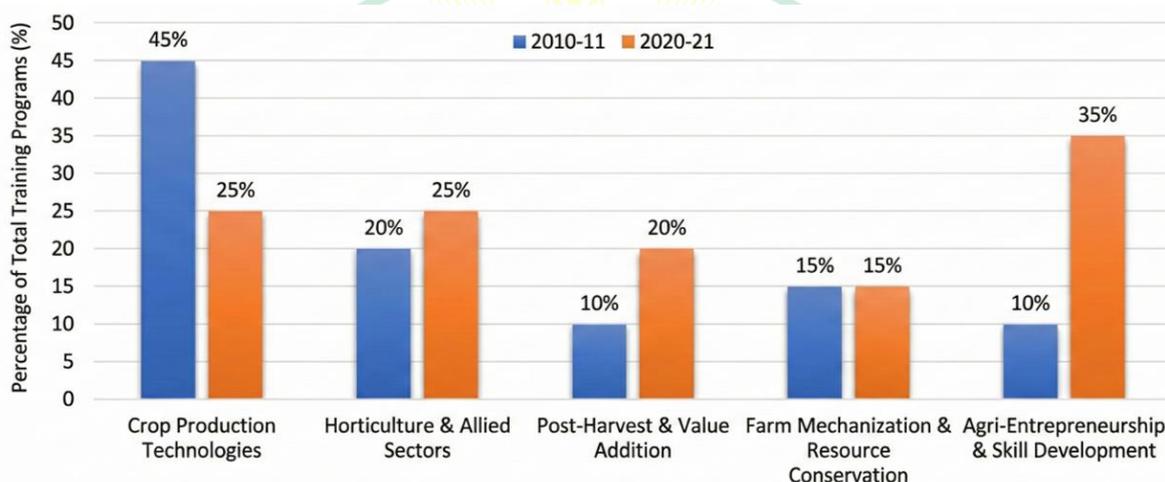


Figure 2. Comparative bar chart illustrating the strategic shift in KVK training focus over a decade, with a marked increase in entrepreneurship and value addition programs

Table 4. Typology and Strategic Focus of KVK Capacity Development Initiatives

Target Group	Strategic Focus of Training	Performance (Desired Outcome)	Indicators
<b>Practicing Farmers/ Farm Women</b>	Productivity enhancement, resource conservation (water/soil), climate-resilient practices.	Adoption of improved practices; reduction in input costs; increased resource-use efficiency.	
<b>Rural Youth</b>	Income generation activities, agri-entrepreneurship (mushroom cultivation, bee-keeping, processing), skill development for service provision (mechanics, drone operators).	Establishment of micro-enterprises; self-employment; reduction in distress migration.	
<b>Extension Personnel (State Dept.)</b>	Knowledge updation on recent research advances, ICT usage in extension, new government schemes.	Improved technical competence of line department staff; better convergence of schemes.	

#### 4.2 Evaluating Training Effectiveness

Although it is clear that the quantitative goals (number of trainings, number of participants) are achieved in general, the qualitative measurement is not totally positive.

- **Strengths:** KVKs are outstanding in offering practical and hands-on training because of their instructional farms and demonstration units. The rural youth residential training programmes have been more successful in setting up post-training enterprises.
- **Weaknesses:** The most common criticism of performance audits is that they do not include a stringent follow-up after the training. It is common to have the system to measure the output (people trained) instead of the outcome (skills applied to improve livelihood). In addition, pedagogical approaches are occasionally didactic, but not participatory, though this is currently changing with the incorporation of ICT tools.

#### 5. The Force Multiplier: ICT Integration in KVK Performance

The integration of Information and Communication Technology (ICT) is a paramount parameter in all the modern evaluations of any extension system. KVKs have been increasingly using digital means to defeat the physical limitations of staffing and expand reach. The output in this arena is manifested in:

- Mobile Advisory Services:** almost all KVKs use SMS and WhatsApp groups to receive timely agro-advisories, which are based on weather. This has significantly minimised the response time to crisis management.
- Digital Platforms:** the use of mKisan portal and KVK-specific sites/applications to disseminate information.
- Social Media utilization:** Numerous KVKs have YouTube to post video footage of their successful FLDs and training modules to have their demonstrations have a longer shelf-life and reach.

Nonetheless, there is skewed digital performance. KVKs in areas where digital infrastructure has been developed are far better than those in remote, tribal, or hilly areas, which unwillingly leads to the emergence of a digital divide in extension services.

#### 6. Critical Structural Bottlenecks Affecting Performance

Although a lot has been done, an open-minded analysis should highlight some structural obstacles that limit the optimal functioning of the KVK network.

- Human Resource Deficits:** It is the most crucial bottleneck. There are high rates of vacancy in scientific jobs in most of the KVKs, making it very difficult to carry out the entire mandate. Furthermore, the administration load of scientists in KVK usually takes up time in the main field functions and research.
- Infrastructural Variability:** Although newer KVKs are well furnished, most of the old centres are poorly maintained with old infrastructure, soil-testing labs, and a lack of mobility (vehicles) to access far-off villages.
- Weak Research-Extension Linkages (REL):** KVKs should theoretically provide feedback to State Agricultural Universities (SAUs) and institutes of ICAR to re-focus research. This feedback loop is, in practice, frequently weak or informal. The university research agenda is at times non-communicative with micro-level issues that have been found by KVKs in the course of Operational Field Testing (OFTs).
- Convergence Issues:** KVKs are supposed to be a hub of knowledge, whereas the departments of the state lines (agriculture, horticulture, animal husbandry) are the main execution arm of the government schemes. Inadequate functional convergence between KVKs and these line departments at the district level results in the performance that is most often suboptimal, causing duplication of efforts or conflicting messages to the farmers.

#### 7. Conclusion and Path Ahead

The performance evaluation of Krishi Vigyan Kendras demonstrates that the system is inherently sound in concept and has no substitute in the Indian farming environment. They have managed to establish themselves as reputable sources of agricultural information on the district level. Their role in the spread of superior species, in illustrating

yield potential based on FLDs, is empirically acknowledged and economically valuable. The change to entrepreneurship-based training of the rural youth is a good strategic realignment.

Nonetheless, to ensure that the KVK system is not sidelined in a fast-changing agricultural economy, there is a need to strategically strengthen the system. Knowledge management will be the key to future performance, not only because of the spread of technology but also in managing it. Going ahead, KVKs are supposed to become more than a demonstration centre and become agribusiness incubation centres at the district level. This shift requires the filling of human resource gaps, spending lots of money on digital infrastructure to democratise access to information, and institutionalising greater formal connection to research bodies and market players, including Farmer-Producer Organisations (FPOs). Performance metrics should finally become the volume of demonstrations that have been held against the quantifiable increase in net income and resilience of the farming community that they serve.

### References

- Adhiguru, P., & Devi, S. V. (2012). ICT in Indian agriculture: Trends and way forward. *Journal of Agricultural Extension Management*, 13(1), 1–16.
- Chand, R., & Parappurathu, S. (2012). Historical background, objectives and mandate of Krishi Vigyan Kendra. In *Agricultural research, extension and development in India* (pp. 45–62). Routledge.
- Dubey, S. K., Burman, R. R., Sharma, J. P., Singh, A. K., & Gill, R. (2019). Impact of KVKs on dissemination of improved agricultural technologies in India. *Indian Research Journal of Extension Education*, 19(2), 1–7.
- Indian Council of Agricultural Research. (2021). *Annual report 2020–21*. Department of Agricultural Research and Education, Ministry of Agriculture and Farmers Welfare, Government of India. <https://icar.org.in/content/annual-reports>
- Kumar, A., Singh, A. K., & Singh, P. (2018). Role of Krishi Vigyan Kendras in agricultural development: An analysis. *International Journal of Current Microbiology and Applied Sciences*, 7(3), 256–262. <https://doi.org/10.20546/ijcmas.2018.703.029>
- NITI Aayog. (2015). *Evaluation report on Krishi Vigyan Kendras (KVKs)*. Programme Evaluation Organisation, Government of India. [https://niti.gov.in/writereaddata/files/document\\_publication/KVK-Evaluation-Report.pdf](https://niti.gov.in/writereaddata/files/document_publication/KVK-Evaluation-Report.pdf)
- Roy, M. L., Chandra, N., Mukherjee, A., Jaisi, S., & Kharbikar, H. L. (2013). Impact of frontline demonstrations on yield and economics of pulse production in India. *Journal of Community Mobilization and Sustainable Development*, 8(2), 236–240.
- Sulaiman, R. V., & Hall, A. (2002). Beyond technology dissemination: Can Indian agricultural extension reinvent itself? *International Journal of Agricultural Resources, Governance and Ecology*, 3(2), 114–135. <https://doi.org/10.1504/IJARGE.2004.004839>
- Venkattakumar, R., & Sontakki, B. S. (2012). Producer companies in India: Experiences and implications for KVKs. *Indian Research Journal of Extension Education*, 12(Special Issue II), 154–160.

## From Institutions to Impact: Rural Community Development in Indian Agriculture



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### Abstract

This paper reviews key institutional innovations in India designed to empower rural communities through agriculture. It examines decentralized and participatory models like ATMA, KVKs, and the Farmer FIRST Programme, which strengthen extension systems and place farmers at the centre of technology development. The study also explores the role of ICT tools in delivering real-time advisories and improving market access, alongside specialized initiatives such as ARYA and Student READY for youth entrepreneurship. Programs like Poshan Vatika and Kisan Sarathi 2.0 further illustrate innovations in nutrition security and AI-driven farmer support. The analysis includes the capacity-building functions of EEIs, SAMETIs, and MANAGE in professionalizing extension services. Ultimately, the paper argues that integrating these community-led, digitally enhanced, and institutionally supported models within a cohesive ecosystem is essential for advancing sustainable rural development, boosting farmer incomes, and supporting India's vision of a self-reliant rural economy.

**Keywords:** Institutional Innovations, Rural Empowerment, Agricultural Extension, KVK (Krishi Vigyan Kendra), Digital Agriculture.

### Introduction

Institutional innovations are fundamental to empowering rural communities, driving self-reliance, sustainable development, and inclusive growth. These innovations typically encompass community-led initiatives, the integration of technology, and participatory governance models designed to tackle localized challenges in agriculture, education, and economic access.

Key concepts within this framework include new organizational structures, policies, and collaborative systems that enhance rural populations' ability to access resources and participate in decision-making. Notable examples are self-help groups (SHGs), farmer producer organizations (FPOs), and cooperatives all of which expand equitable access to markets and financial services. In India, large-scale initiatives such as the National Rural Livelihood Mission (NRLM) have successfully expanded SHGs to encompass over ten crore women, significantly raising household incomes through collective enterprise and community-driven economic activity.

### Innovative Approaches in Agricultural Extension: ATMA

The Agricultural Technology Management Agency (ATMA) represents a decentralized, participatory extension model introduced under the National Agricultural Technology Project (NATP). Functioning as an autonomous society at the district level, ATMA integrates research, extension, and farmer needs through a bottom-up, demand-driven approach. Key strategies include promoting Farmer Interest Groups (FIGs) and SHGs, developing location-specific Strategic Research and Extension Plans (SREPs), and fostering collaboration among government departments, NGOs, and private agencies. Capacity building remains central, with training for farmers, women, youth, and extension personnel. Innovative methods such as Farmer Field Schools (FFS), demonstrations, and exposure visits are widely employed, supported by ICT tools like mobile advisories and Kisan Call Centres. ATMA also emphasizes women's empowerment, youth engagement, Agri-entrepreneurship, and market-led extension. Its flexible framework allows for district-specific innovations, while rigorous monitoring ensures accountability and impact assessment. Overall, ATMA has emerged as a sustainable and inclusive model for agricultural development.

### **Institutional Innovations of Krishi Vigyan Kendra's (KVKs)**

Krishi Vigyan Kendra's (KVKs) serve as frontline extension institutions established by the Indian Council of Agricultural Research (ICAR) to bridge the gap between research and farmers. KVKs have introduced several institutional innovations, including On-Farm Testing (OFT) and Front-Line Demonstrations (FLDs), which provide location-specific solutions and build farmer confidence in new technologies. Capacity-building programs for farmers, women, and youth enhance technical knowledge and self-employment opportunities. KVKs also promote collective institutions such as FIGs, SHGs, and FPOs to strengthen bargaining power and market access. ICT-based tools including mobile advisories, WhatsApp groups, and digital apps ensure timely information dissemination. Gender-focused initiatives support women through training, drudgery-reducing tools, and nutrition gardens. Additionally, KVKs encourage Agri-entrepreneurship and seed production systems, facilitate market linkages, and maintain strong partnerships with research and extension agencies. Through participatory approaches and continuous feedback, KVKs have significantly enhanced rural knowledge, skills, and incomes, solidifying their role as a cornerstone of India's agricultural extension system.

### **Farmer FIRST Programme: Farmer-Centric Innovation**

The Farmer FIRST Programme, implemented by ICAR, aims to empower rural communities by positioning farmers as central actors in technology development and dissemination. It strengthens farmer-scientist collaboration and builds sustainable local institutions. The program establishes village-level committees and innovation platforms where farmers jointly identify problems, prioritize research needs, and co-design on-farm trials. These platforms build trust and ensure that technologies align with local resources and market realities. Institutional linkages with ICAR institutes, State Agricultural Universities, NGOs, and panchayats reduce transaction costs and improve access to inputs and markets. Technology assemblage centres integrate multiple interventions such as soil conservation, horticulture, livestock, and mechanization demonstrating improved practices across village clusters. The program also strengthens local organizations by supporting FPOs, women's SHGs, and youth groups in enterprises like seed production and value addition. Through digital tools, training, and continuous feedback, Farmer FIRST enhances adaptive capacity, risk management, and community-led development.

### **ICT-Driven Innovations in Agricultural Extension**

Information and Communication Technology (ICT) has revolutionized agricultural extension by improving access to information, markets, and services. Mobile-based advisories deliver weather forecasts, crop management tips, and market prices in local languages. Interactive platforms allow farmers to submit queries and receive expert responses, reducing dependence on intermediaries. Digital village knowledge centres provide internet access and training, while IVRS and call centres offer 24/7 recorded and live support. E-extension portals host decision-support tools, and social media platforms enable real-time sharing of pest alerts and best practices. Community radio and agricultural channels broadcast localized content, and GIS/remote sensing tools support precision advisories. Digital market platforms like e-NAM enhance price transparency and farmer bargaining power. ICT also strengthens FPO management, e-governance, and grievance redressal, making institutions more responsive and accountable.

### **Youth and Gender-Focused Institutional Innovations**

**ARYA (Attracting and Retaining Youth in Agriculture)** is an ICAR initiative designed to engage rural youth in profitable Agri-enterprises. It provides hands-on training in enterprises such as seed production, dairy, and food processing, coupled with business planning and market linkage support. KVKs serve as nodal institutions, offering mentoring and exposure visits. ARYA promotes group-based models like youth clubs and FPOs to encourage resource pooling and collective marketing. The program also facilitates access to credit, inputs, and technology backstopping, while using ICT tools for continuous guidance. Special attention is given to including young women and marginalized youth through low-investment, high-return enterprises, thereby reducing distress migration and fostering local leadership.

**Student READY (Rural Entrepreneurship Awareness Development Yojana)** prepares agricultural and allied sector graduates for entrepreneurship through immersive rural experiences. Components such as Rural Agricultural Work Experience (RAWEx) and village attachment enable students to understand field-level

challenges and engage with local institutions. Agro-industrial placements provide insights into agribusiness management, while experiential learning modules encourage students to run small enterprises. The program strengthens rural communities through demonstrations, capacity building, and the formation of new SHGs and interest groups. It also establishes a feedback loop between farmers and academia, ensuring that education and research remain relevant to ground realities.

### **Social Empowerment Initiatives**

**Poshan Vatika** (nutrition gardens) represent a convergent model for enhancing food and nutrition security. These community-managed gardens, often linked to Anganwadi centres, promote the cultivation of nutrient-rich crops. Initiatives integrate schemes like POSHAN Abhiyaan and MGNREGA, providing training in horticulture and organic practices. Women's SHGs play a central role in garden management, improving dietary diversity and generating surplus income. By emphasizing sustainability and local resource use, Poshan Vatika supports self-reliance and reduces external food dependency.

**Kshamata**, though initially focused on urban vulnerable women, offers an adaptable model for rural empowerment through holistic rehabilitation. Its pillars transformation, outreach, and micro-enterprise support focus on counselling, skill development, and financial independence. While urban-centric, its trauma-informed, survivor-centred approach holds potential for adaptation in rural settings, particularly for high-risk women and youth.

### **Digital and Institutional Integration: Kisan Sarathi 2.0**

Kisan Sarathi 2.0 exemplifies the integration of AI and digital tools into extension systems. It introduces standardized operating procedures for combining soil health, market, and insurance data to generate predictive advisories. The platform prioritizes inclusivity through multilingual AI chatbots, hyper-local weather alerts, and tailored content for women and tribal farmers. A network of "Kisan Mitras" (farmer champions) helps bridge the digital divide, while a beta app enables multimedia query resolution. This innovation enhances the precision, accessibility, and scalability of extension services.

### **Capacity-Building Institutions**

**Extension Education Institutes (EEIs)** provide targeted training to mid-level extension workers, blending classroom learning with field immersion. Their curriculum covers participatory approaches, climate-resilient farming, and digital tools, strengthening the link between research and practice.

**State Agricultural Management and Extension Training Institutes (SAMETIs)** operate under ATMA to skill field functionaries through certification programs like PGDAEM and DAESI. They integrate ICT, participatory methods, and market-led extension, driving yield and income improvements at the village level.

**National Institute of Agricultural Extension Management (MANAGE)** serves as the apex body for extension capacity building. Its flagship PGDAEM program, Agri-Clinics, and FPO promotion initiatives have professionalized extension services nationwide. MANAGE's digital platforms, research, and partnerships enhance the coherence and impact of the national extension ecosystem.

### **Conclusion**

Institutional innovations such as ATMA, KVKs, Farmer FIRST, ICT tools, ARYA, Student READY, Poshan Vatika, and Kisan Sarathi are transforming rural India by fostering participatory, technology-enabled, and inclusive development. When integrated within a cohesive ecosystem supported by EEIs, SAMETIs, and MANAGE, these models collectively enhance agricultural productivity, livelihood security, and community resilience. Together, they advance India's vision of an *Atmanirbhar* (self-reliant) rural economy, demonstrating the transformative power of institutional innovation in achieving sustainable and equitable growth.

### **References:**

*Extension Education Institutes (EEIs)*. "Consolidated Report on Training and Impact (Hyderabad, Nilokheri, Anand, Guwahati)." *Institutional Innovations for Empowering Rural Community*, 2015. Described in the section "Extension Education Institutes (EEIs)."

*Government of India*. "Central Sector Scheme for Formation and Promotion of Farmer Producer Organizations (FPOs)." 2020–25. Referenced in the context of MANAGE and other sections promoting FPOs.

*Indian Council of Agricultural Research (ICAR).* “ARYA (Attracting and Retaining Youth in Agriculture): Program Modules and Training Framework.” *Institutional Innovations for Empowering Rural Community*, n.d. Described in the section “ARYA (Attracting and Retaining Youth in Agriculture).”

“Farmer FIRST Programme: Implementation Handbook.” *Institutional Innovations for Empowering Rural Community*, n.d. Described in the section “Institutional Innovations under the Farmer FIRST Programme.”

“Operational Modalities of Krishi Vigyan Kendra’s (KVKs).” *Institutional Innovations for Empowering Rural Community*, n.d. Described in the section “Institutional Innovations of Krishi Vigyan Kendra’s (KVKs).”

“Student READY (Rural Entrepreneurship Awareness Development Yojana): Programme Structure and RAWE Guidelines.” *Institutional Innovations for Empowering Rural Community*, n.d. Described in the section “Student READY.”

*Kshamata Foundation.* “Annual Outreach and Impact Report: Kshamata Transformation Program (KTP), Outreach, and KULT.” *Institutional Innovations for Empowering Rural Community*, 2019–20. Described in the section “Kshamata.”

*Ministry of Agriculture & Farmers Welfare.* “Kisan Sarathi 2.0: Standard Operating Procedures (SOPs) and Beta App Features.” *Institutional Innovations for Empowering Rural Community*, 2025. Described in the section “Kisan Sarathi.”

*Ministry of Women & Child Development, in convergence with Ayush and MGNREGA.* “Poshan Vatika (VATIKA) National Rollout Report: Coverage and Impact Metrics.” *Institutional Innovations for Empowering Rural Community*, 2022. Described in the section “Poshan Vatika.”

*National Agricultural Technology Project (NATP).* “Framework for the Agricultural Technology Management Agency (ATMA).” *Institutional Innovations for Empowering Rural Community*, n.d. Described in the section “Innovative Approaches in Agricultural Extension: ATMA.”

*National Institute of Agricultural Extension Management (MANAGE).* “PGDAEM Curriculum and MANAGE Knowledge Network (MKN) Repository.” *Institutional Innovations for Empowering Rural Community*, 2023–24. Described in the section “National Institute of Agricultural Extension Management (MANAGE).”

*State Agricultural Management and Extension Training Institutes (SAMETIs).* “Annual Training Report: Certification Programs (PGDAEM, DAESI) and Skill Training Metrics.” *Institutional Innovations for Empowering Rural Community*, 2016–17. Described in the section “SAMETIs.”

## ‘Roselle’- A Slice of Tribal Life.



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### 1. Introduction:

The red lateritic zone of West Bengal, an extended part of the Eastern Ghat Range comprising the districts Bankura, Purulia, Birbhum, Jhargram and Western Midnapore is the treasure house of many hidden and untapped plant resources and roselle is one of them. It is popularly known as ‘Kudrum’ and ‘Chukai’ among of the local tribal communities. In english it is known as ‘Roselle’ and ‘Redsorrel’ and ‘Patwa’ in Hindi. It is botanically called as *Hibiscus subdarifa* which belongs to the family Malvaceae. Roselle is the native to the India and South East Asia. It is deeply associated with the social and cultural lives of tribal communities of West Bengal.



### 2. Origin & Distribution:

In West Bengal, roselle grows scatterly since long time in the infertile soil of fallow lands, roadsides and raised bunds as tropical and sub-tropical rainfed alternate fiber crop. It is grown as rainfed kharif crop by broadcasting the seed with the onset of rainy season. Roselle grows well in different parts of India including north Eastern India. In West Bengal, it is mainly cultivated as highland tropical crop in the districts of Malda, Birbhum, Purulia, Bankura, Jhargram, West Midnapure and west Bardhaman respectively.

### 3. Climate and Soil:

Presently roselle is cultivated as food and substitute fiber crop in West Bengal. Roselle thrives well under warm and dry climate with adequate sunlight for its growth and development. It is sensitive to frost and cold winds. Roselle plants cannot withstand water logging. It thrives well in areas having the annual rainfall of about 150 to 200 cm. At least six hours of direct sunlight is essential for optimal growth and colouration of calyces. Well drained loam soil rich in organic matter is considered ideal. The pH of the soil should be between 5.5 to 7.0. Roselle requires minimal care and management.

### 4. Plant's Description:

Roselle is a fast growing perennial herbaceous plant which grows upto the height of 2.0-2.5m. The stem is erect and habitually branched. The leaves are 3-5 lobbed which are arranged alternatively. The plant produces large trumped shaped yellow flowers with red centre. The most distinctive part of it is the fleshy red calyx which surrounds the fruit. The flowers are produced in leafaxil as in the terminal raceme. Edible calyces become ready for harvesting 15-20 days after blooming. Roselle is grown mainly for its red coloured fleshy edible calyces. The calyces are plucked when they become tender, plump, fleshy, crispy and deep red in colour. The fruit is a velvety five lobbed capsule. Capsules are green to purplish at unripe stage and change into red colour at maturity. It is propagated by seed.

### 5. Nutritive Value:

The edible fresh calyces are store houses of different phytonutrients and phytochemicals. 100g edible calyces content 12.3g carbohydrates, 1.9g proteins, 2.3g dietary fibres, 0.1g fats, 57mg iron, 150mg calcium, 300microgram beta-carotene, and 14mg Vitamin-C. The pigment and antioxidant anthocyanin is responsible red colouration of calyces which can be a potent source of natural food colour and act as free radical scavenger. Roselle is rich in organic acid including citric, malic, tartaric and alhydroxycitric acid. The anthocyanin pigment content of roselle calyces varies with the varieties, temperature, harvesting and processing. Average content of anthocyanin is 310.8mg to 362.0mg per 100g.

## 6. Medicinal Value:

For ages rosella has been utilised as a medicinal plant. For many decades it has been used as herbal medicine in phytotherapy. Historically it has been used to treat urinary tract infections, cold and even hangovers. Roselle has incredible health benefits. It can help to regulate blood sugar level and decrease high blood pressure. It also aids digestion, cures constipation and promotes urination, weight loss and bowel movement and protects from the cancer. Juice extracted from the fresh leaves is used to treat conjunctivitis and healing of wounds. Roselle also supports kidney and liver health. Being rich in vitamin-C, it helps to strengthen the immunity system of the body. The Crushed leaves are applied to the skin for the treating cracks, ulcer or boils. Roselle can cure liver disorder, pimples, sore throat and diarrhea. The juice obtained from the leaves is used to treat conjunctivitis. This plant has been utilized in folk medicines as a mild laxative and diuretic and in the treatment of nerve and cardiac diseases. Similar to the leaves, the fruits have also antiscorbutic property. The flower extract has food healing property due to be high flavonoid content. The seed capsules of roses has diuretic and tonic effects. It helps to promote urine and bowel movement. Roselle also cures constipation and protects against colorectal cancer.

## 7. Uses:

Roselle is being highly appreciated for its multipurpose uses. Fleshy red calyces can be consumed fresh or it may be used for preparation of delicious pro-health drinks. Being rich in pectin and citric acid content, ripe calyces are also used locally for making a number of food products like liquor, jam, jelly, syrup, wine, beverage and dried calyces may be used later to produce a sweet herbal tea and juice. A very tasty and tangy chutney can be prepared mixing calyces with garlic mustard oil, salt, green chilli and roasted cumin powder. Calyces are also dried under sun and employed as vital ingredients in a variety of recipes. Red calyces are used for providing a vibrant colour and tart flavour to various food products. Powdered made from the sundried calyces are sold commercially in the market by different private companies. The leaves can also be eaten raw as salad for tangy flavour. The edible calyces are used as green tea which is the best for heart's health. Fresh calyces are used to produce pro health drinks due to containing of high amount of vitamin-C and anthocyanin. For preparation of beverage the anthocyanin can be 28.85mg per 500ml of tea made. The leaves are also cooked green with other vegetables or meats to bring a good taste and flavour in the dishes. The leaves are also used in the dishes like stir-fries, curries and soups. In West Bengal the leaves are also cooked with the pulse lentil. Seeds can be roasted and brewed like coffee or ground and added to salads and soups. The stems being the source of fibre can be used for making twines, ropes, fishing nets, and handicrafts. Roselle extract rich in vitamins and antioxidants are used in skin or hair care products.

## 8. Harvesting:

The calyces ripen about 20-25 days after the start of flowering. This time calyces become fleshy, flowers have dropped and the seeds are matured but not yet exposed. Harvesting of calyces is done when they are fresh, tender, crispy and deep red in colour and would have high moisture content (85%). Roselle comes into full bloom from the middle of October and fruits mature from November to third week of December.

Harvesting of calyces is done by plucking of mature roselle fruits from the plants. This can be done by the hand or sharpen knives or clippers. Late harvesting of calyces make them prone to disease attacks and cracking by sunheat. Regular plucking of fruits encourage prolonged flowering which ultimately increases the productivity of roselle plants. A yield of 1.2 to 1.5 kg calyces may be obtained from a mature plant. Fresh calyces yield of 4 to 6.5mt per hectare can be obtained at about 12% moisture content.

## 9. Post-harvesting Management:

As roselle calyces are perishable in nature, they require immediate drying and processing to ensure a longer shelf-life and preserve the inherent nutrient quality. Therefore development of post-harvest management of edible calyces is urgently needed. Roselle calyces can be stored fresh for a short period. But for long period of storage they should be dried. After harvesting the fresh calyces can be dried under the shed and in a well-ventilated environment. This will allow for the removal of excess moisture from the calyces. To avoid contamination with the soil during drying, plastic sheets should be spreaded over the ground. This will help to obtain good quality products. Calyces can also be dried by direct sunlight using solar drier or oven or use of dehumidifiers. The dried calyces are packed in gunny bags for immediate transportation to the processing industries. The dried calyces can also be stored in air tight containers in cool and dark place. Dried calyces can be stored up to 1 year without affecting its quality.

## 10. Value addition:

A number of value added products are being prepared by using different edible parts of roselle plant. Calyces are a significant component of roselle because it is utilized in food industry for making different value added products which

include beverage like juice, syrup and herbal tea. Food items like jam, Jelly, pickle and yoghurt, snacks like fruit leather and candies and baked goods like cookies. Seeds can be processed into edible oil or flour for making baked goods. Roselle clayx extract can be used for commercial preparation of natural food colourants. Compounds like anthocyanin, polyphenol and dietary fiber extracted from rosella can be used to produce health supplements.

#### **11. Future Prospect:**

The prospect for roselle-based industry in West Bengal is promising driven by the plant's diverse applications and growing market demand for natural products. The state established roselle cultivation and existing agricultural infrastructures which provide a strong foundation for developing value added products like beverages, food items and natural colourants. It has already been seen that roselle jam blended with local fruits like aonla and guava have become highly acceptable. To transition from a fibre focused crop to one that creates value-added products, West Bengal needs to invest for establishing new technology driven processing and storage infrastructures. While online platforms and organized redial channels exist, local farmers need support to access these markets effectively. Creating a strong brand identity for West Bengal sourced roselle products is also a key. Now advancement of roselle cultivation practice can enhance the yield and farmer's profitability. Roselle is a type of crop that requires less input and provides more output as compared to traditional crop and helps the farmers to improve their standard of living. The government should take initiative to promote its cultivation and marketing facilities for selling their produce.



## Traditional Knowledge and Indigenous Paddy Varieties in India River Basin



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### Introduction

Since ancient times, local communities have relied on TRADITIONAL paddy varieties (TPVs) to meet their culinary, nutritional, cultural, and economic needs. Because of their genetic diversity and agroclimatic suitability, TPVs can withstand local pressures, swiftly adapt, and endure the whims of nature. They so contribute important genes for stress tolerance. Additionally, they produce a wide range of ecosystem services that are necessary for ecological stability. Additionally, TPVs are inexpensive for smallholders to cultivate and environmentally beneficial due to their low input requirements. For food production systems to be resilient and sustainable, particularly in the face of climate change, they are therefore vital components of agrobiodiversity, or the diversity of crops and varieties in agricultural systems.

One of the highest diversities of both cultivated and wild crops may be found in India. However, the range and diversity of farmed crops, including rice and other cereals, have significantly decreased in recent years. A small number of rice varieties chosen for their ability to produce high yields in response to the use of high doses of fertilizer are being promoted as a result of the Green Revolution's emphasis on increasing yield.

Only high-yielding and other short types are produced as a sustainable food source by the Green Revolution, which results in the loss of its great diversity of rice varieties. The development of high-yielding variations made it possible to cultivate fewer and fewer conventional kinds. India had about 1,10,000 distinct rice types prior to 1970, but the focus of the green revolution on monoculture and hybrid crops has led to the loss of this diversity for future generations. This is a result of people forgetting about decades of traditional variety cultivation.

### Effects of using Traditional Paddy Varieties :

#### For Customers

1. More nutrient-dense than contemporary variants
2. Safer because they require less chemical inputs
3. Appropriate for particular populations (such as expectant mothers and nursing mothers)
4. Appropriate for particular meal preparations
5. Particular therapeutic characteristics
6. Possess a reduced Glycemic Index

#### Regarding the Producer

1. Require less water
2. Require less inputs (fertilizer, seed) than
3. Types appropriate for particular local soils (such as saline, clayey, etc.)
4. More resistant to disease and pests than
5. Resilient to flooding and drought
6. Produce more feed
7. Increased resistance to climate change

#### Social, Cultural, and natural

1. Safe for the soil, water, and environment.
2. A significant component of high biodiversity

### The Potential Market for Traditional Rice Varieties

- The case for business: It is clear from a triple bottom line perspective that traditional rice varieties are good for both the environment and humans (farmers and consumers). This analysis also makes it clear that traditional rice types have a strong business case.
- The supply constraint: According to food companies, retailers, merchants, and millers, this is the main obstacle; they are certain that they can market and sell higher production volumes of the best conventional rice types.  
Volumes: In various parts of Tamilnadu state, retailers, traders, millers, and farmer-aggregators regularly register significant monthly volumes of varieties like Seeraga Samba, Mappillai Samba, and Kitchili Samba; these range from 1.5 tons retailed per month to 10 tons traded per month to 130 tons milled per month.
- Consumer awareness: Awareness levels of consumers are already increasing due to a combination of factors; with the increase in disposable income, this is resulting in a willingness to sample traditional rice varieties and value-added products; working on awareness and adoption can result in more households becoming regular consumers of traditional rice varieties for different consumption occasions.
- Other motivators: Those involved in the promotion of Indian dietary and therapeutic systems, such as naturopaths and Siddha and Ayurvedic vaidyas, also show interest.

**Table 1 : Traditional Paddy Varieties of India**

Adukku Nel	Jil Jil Vaigunda	Kollikaar	Pattaraikar
Ambemohar	Jiljeera	Konakuruvai	Perumkoomvazhai
Anaikomban	Kaatuyanam	Koomvazhai	Perungar
Anandanoor Sanna	Kadaikazhuthan	Kothamalli Samba	Pillai Milagu Samba
Arcot Kitchili	Kaivari Samba	Kottara Samba	Pisini
Arikiravi	Kalabath	Kowni Nel	Poda Perunel
Arubatham Kodai	Kalajeera	Kudaivazhai	Polinel
Arubatham Kuruvai	Kalanamak	Kullakar	Poompalai
Arubatham Samba	Kalarpalai	Kumsala	Poovan Samba
Athur Kitchili Samba	Kaliyan Samba	Kunthali	Puzuthi Samba
Basmati	Kallimadaiyan	Kuruvai	Puzuthikar
Bayakundathan	Kallumuthan	Kuruvai Kalanchiyam	Puzuthikkal
Burma Kowni	Kallundai	Kuruvikar	Rajabhoga
Chengalpattu Sirumani	Kallurundaikaar	Kuzhiadichan	Rajamannar
Chinna Ponni	Kallurundaiyan	Londhan	Rajamudi
Chinnar	Kamban Samba	Mappilai Samba	Ramakalli
Chithiraikar	Kandasalae	Mathimuni or Mathimudi	Rasakadam
Cochin Samba	Kappakaar	Mottakur	Sadakar
Cuddalore Seeraga Samba	Karikalava	Mozhi Karuppu Samba	Salem Samba
Delhi Pogalu	Karungkuruvai	Mullan Kaima	Salem Sanna
Gajejavar	Karuppu Kowni	Murukankar	Samba
Gamgadala	Karuppu Seeraga Samba	Muttakar	Samba Mosanam
Garudan Samba	Karuthakar	Navara	Sandikar
GEB24	Kashmir Dhal	Neelam Samba	Sanna Samba
Gunaparuva	Katcha Koomvazhai	Norungan	Sannaki Nel
Illupaipoo Samba	Katta Samba	Onamattan	Seengini
Iravaipandi	Kattu Ponni	Orissa Vasana Seeraga	
Jawadhu Malai Nel	Kattu Samba	Samba	
Jeeragasalae	Kattu Vanibam	Ottadai	
	Kattukuthalam	Ottu Kitchili	
	Kitchili Samba	Paal Veliyan	
		Paalthondi	
		Pal Kudaivazhai	
		Panangkattu Kudaivazhai	
		Patchaipermal	

### Tamil Nadu Total Paddy Production

Tamil Nadu still conserves 100–150 traditional rice landraces, usually grown in small pockets. Common traditional varieties include Seeraga Samba, Mappillai Samba, Karuppu Kavuni, Kullakar, Karunguruvai, Thanga Samba, Vadan Samba, Iluppaipoo Samba, Kichadi Samba, etc.

**Table 2 : Production and Productivity of Paddy**

Year	Area (lakh ha)	Production (lakh tonnes)	Average Yield (kg/ha)
2021–22	17.8	77	4200
2022–23	18.0	80	4400
2023–24 (approx.)	17–18	82	4500

The above varieties are grown mostly by small farmers and not officially enumerated, the area share is approximate.

**Table 3 : Area of Traditional Paddy varieties**

Category	Estimated Area	Notes
Total traditional varieties combined	25,000 – 40,000 ha	Based on NGO reports, seed networks, KVK surveys, and organic clusters.
Share of total paddy area	1.5% – 2.5%	Still a small portion compared with HYVs & hybrids.

**Districts with the highest concentration of traditional varieties:** Seeraga, Kichadi, and Thanga Sambas in Thanjavur, Thiruvavur, and Nagapattinam (Cauvery Delta) Mappillai Samba, a traditional dryland rice from Ramanathapuram Kullakar, Salem, and Dharmapuri kinds.

Theni-Karuppu Kavuni, Madurai, and therapeutic black rice Red rice and Kullakar derivatives from Villupuram and Cuddalore

### Global Niche Markets Value

- Elevated nutritional value  
Red rice (Kullakar, Mappillai Samba) → high fiber and iron  
Rich in anthocyanins and antioxidants, black rice (Karuppu Kavuni) is in high demand.
- Gourmet and specialty appeal  
Worldwide, premium biryanis are made using Seeraga Samba.  
Worldwide, black rice is promoted as a "superfood."
- Chemical-free and organic farming  
Conventional cultivars flourish in low-input organic environments and are highly exportable to the US, EU, and Gulf markets.
- Increasing demand from the diaspora  
These kinds are specifically requested by a sizable Tamil diaspora in Singapore, Malaysia, the United Arab Emirates, Europe, and the United States.

### Export Potential

Traditional rice varieties fall under categories such as “Specialty Rice,” “Red Rice,” “Black Rice,” “Aromatic Non-Basmati.”

### Estimated Indian exports of specialty prices (all states)

- Red rice: 20,000–30,000 tonnes/year
- Black rice: 5,000–8,000 tonnes/year
- Aromatic small-grain rices (like Seeraga Samba): 10,000–18,000 tonnes/year

Tamil Nadu contributes a significant share in Seeraga Samba, red rice and black rice exports.

**Table 4 : World Demand of Indian varieties of Paddy**

Region	Demand Reason
UAE, Saudi, Qatar	Tamil diaspora + premium biryani restaurants
USA & Canada	Organic & health food stores
Europe (Germany, Italy, Netherlands)	Organic-certified grains preferred
Singapore & Malaysia	Asian gourmet market

**Traditional Rice Varieties with High Export Potential:**

1. Seeraga Samba : TN cultivar that is most exportable ; Superior fragrant tiny grain; High demand for restaurants (biryani chains overseas) ; High retail cost (₹300–500/kg equivalent) abroad
2. Black rice, or Karuppu Kavuni : sold all across the world as "black" or "forbidden" rice; High appeal for superfoods - health stores; One of the niche export markets with the quickest growth
3. Samba Mappillai: Red rice, which is high in energy, is popular in the organic and fitness markets. Growing demand in Singapore and the Gulf
4. Poongar, Kullakar, and other red rices ; Low glycemic index, gluten-free markets; Good export for consumers who are health-conscious.

**Price Advantage in Global Markets**

Traditional rice exports fetch **3–6 times more** than regular non-basmati rice.

**Table 5: Domestic and International Price of Traditional Paddy Varieties**

Variety	Domestic Price (₹/kg)	Export Retail Price Equivalent (₹/kg)
Seeraga Samba	150–250	300–600
Karuppu Kavuni	200–300	500–900
Mappillai Samba	80–150	200–400
Kullakar variants	80–130	180–350

**Production Constraints**

The wider adoption and commercialization of traditional rice varieties in Tamil Nadu are restricted by a number of interrelated production and marketing issues. Due to the fact that many old landraces yield 20–40% less grain than contemporary high-yielding varieties, farmers frequently experience low and irregular yields. Farmers are forced to rely on unofficial seed exchanges due to the scarcity of certified, pure seeds, which raises the possibility of genetic purity loss and mixing. Additionally, many traditional cultivars have longer crop durations—sometimes longer than 140–160 days—which lowers cropping intensity and deters growers looking for rapid returns. Furthermore, some cultivars are vulnerable to lodging, pests, or temperature stress, and their tall plant form makes them unsuitable for robotic harvesting, which raises labor expenditures and production expenses. Irrigation systems and agricultural advisories in the state largely favour modern short-duration varieties, leaving traditional rice without adequate institutional support.

**Marketing Constraints :**

These cultivars' economic potential is further limited by marketing restrictions. Although retail demand for heritage rice is rising, farm-gate prices are still low and price transparency is lacking, and farmers typically lack structured market connections. Grain breakage and quality degradation are frequently caused by inadequate processing, milling, grading, and storage facilities, which lowers market competitiveness. Additionally, traditional cultivars struggle to break into broader domestic and export markets due to poor branding and the lack of defined grades. Their market is further constrained by consumers' ignorance of the cultural and nutritional significance of traditional rice. High obstacles including expensive organic certification, residue testing, and traceability regulations stand in the way of smallholders trying to sell to premium organic markets.

**Conclusion**

There is a need for us to revisit and reassess the value that was attributed traditionally to rice and ensure that we have a correct time balanced assessment of its nutritional value. Some of the tasks that definitely need to be taken up are the following – There has to be an enhancement of the variety and diversity of rice varieties cultivated

from various viewpoints including nutritional and ecological considerations. The consumer must be able to access from the large basket of traditional rice varieties which have a great nutritional and therapeutic value. We need to revisit the cultivation, post-harvest processing, and methods of cooking rice striking a reasonable balance between economic, ecological and nutritional criteria. We also need a better understanding and appreciation of the knowledge and wisdom about the properties of rice that is available to us from our tradition – this is not only from the texts of traditional medicine but also the wide spread cultural and social practices of our people.



## Consumption Patterns and Nutritional Status of Tribal Groups in Public Distribution System (PDS) of India



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### Introduction

Particularly Vulnerable Tribal Groups (PVTGs) constitute the most marginalized and socio-economically disadvantaged sub-category within the Scheduled Tribes (STs) of India. The Government of India classifies certain tribes as PVTGs based on four criteria: (1) a declining or stagnant population, (2) extremely low literacy levels, (3) pre-agricultural level of technology, and (4) subsistence-based livelihoods dependent on forest resources. These characteristics reflect deep structural vulnerability, limited resilience to social and economic changes, and a high risk of chronic food and nutrition insecurity.

In Tamil Nadu, **six tribal communities** have been officially notified as PVTGs:

1. **Irular**
2. **Kattunayakan**
3. **Kurumba**
4. **Paniyan**
5. **Toda**
6. **Palliyar / Palliyan**

According to the *Census of India 2011*, Tamil Nadu recorded a Scheduled Tribe population of **7.94 lakh**, with distinct geographic concentration of each PVTG community. **Irulars** are predominantly settled in **Thiruvallur** district; **Kattunayakans** in **Tirunelveli**; **Kurumbas, Todas, and Paniyans** in **The Nilgiris**, which has the highest tribal population share in the state; and the **Palliyar** community primarily in **Dindigul** district. These locations were historically shaped by forest dependence, isolation, and limited integration into mainstream socio-economic systems.

PVTGs in Tamil Nadu face multiple developmental challenges including inadequate access to health and education services, poor housing conditions, seasonal and unstable livelihoods, and limited participation in government welfare schemes. Nutritional vulnerability is particularly severe due to irregular food intake, low dietary diversity, high dependence on subsidized grains, and limited access to nutrient-rich foods. Despite Tamil Nadu's strong welfare framework including the Public Distribution System (PDS), special tribal schemes, and social protection measures PVTGs continue to remain nutritionally at risk because of geographical barriers, low awareness, and administrative bottlenecks.

### Problem Focus in Public Distribution System of Tribal Community

PVTGs in Tamil Nadu are among the most vulnerable communities, living in remote forest and hill areas with very limited access to markets, jobs, health services, and nutritious food. Because of their low income and difficult living conditions, they depend heavily on the Public Distribution System (PDS) for their basic food needs. Although Tamil Nadu has a strong PDS, many problems still affect these tribal households. These include irregular supply of food grains, poor quality commodities, long distances to Fair Price Shops, fingerprint authentication failures, and delays in receiving smart cards. Misclassification of smart cards also reduces their entitlement to essential food items.

Another major concern is that the PDS mainly supplies rice and wheat, while PVTGs need a more balanced diet that includes pulses, vegetables, fruits, milk, and protein-rich foods. As a result, their diet lacks variety and important nutrients. Very little research has been done to understand how PVTGs consume food, whether the PDS meets their nutritional needs, and what problems they face in accessing the system.

Therefore, the main problem is that PVTGs depend on the PDS, but the system does not fully meet their nutritional needs, and many operational issues prevent them from getting the benefits they are entitled to. There is a need to study their food consumption, dietary diversity, nutrient intake, and difficulties in using the PDS so that better policies can be made to improve their nutrition and overall well-being.

### **Public Distribution System (PDS) and Smart Card Classification**

Tamil Nadu operates one of the most comprehensive and welfare-oriented Public Distribution Systems (PDS) in India. The PDS is a state-supported food security mechanism designed to distribute essential commodities primarily rice, wheat, pulses, sugar, and edible oils at subsidized prices through an extensive network of Fair Price Shops (FPS). Tamil Nadu follows a Universal PDS model, ensuring that almost all households in the state have access to subsidized food grains irrespective of income status, which distinguishes it from the targeted PDS models used in many other states.

To streamline and modernize the distribution process, the Government of Tamil Nadu introduced Smart Ration Cards supported by digital authentication and electronic Point of Sale (e-PoS) systems. These smart cards help classify beneficiaries, prevent duplication, and monitor commodity distribution more efficiently. The earlier classification of households as Above Poverty Line (APL), Below Poverty Line (BPL), and Antyodaya Anna Yojana (AAY) has been replaced with a more detailed smart card-based categorization, ensuring transparency and accountability.

In Tamil Nadu currently uses five major smart card categories, each providing different levels of entitlement:

#### **1. PHH-Rice (Priority Household – Rice Card)**

- Issued to economically vulnerable households.
- Entitled to *all essential commodities*, including rice at highly subsidized rates.
- Considered the most beneficial category in terms of food grain allocation.

#### **2. PHH-AAY (Antyodaya Anna Yojana Card)**

- For the poorest of the poor households under the national AAY scheme.
- Entitled to the *maximum quantity* of subsidized food grains.
- Designed to support households with no stable income source, widows, elderly poor, and destitute families.

#### **3. NPHH-L (Non-Priority Household – Limited Commodity Card)**

- Entitled to receive *limited essential commodities*.
- These households are relatively better off than PHH families but still eligible for partial subsidies.

#### **4. NPHH-S (Non-Priority Household – Sugar Card)**

- Entitled only to *sugar* at subsidized rates.
- Generally issued to households that do not require rice from PDS, especially urban middle-class families.

#### **5. NPHH-NC (Non-Priority Household – No Commodity Card)**

- No entitlement to any PDS commodity.
- Used mainly for households who opt out of PDS benefits but retain the smart card for identification purposes.

This smart card classification plays a crucial role in determining the quantity, type, and price of commodities received by each household. For vulnerable communities such as PVTGs (**Particularly Vulnerable Tribal Groups**), being categorised under PHH or AAY can significantly improve access to subsidized food grains and reduce the risk of hunger and undernutrition.

### **Income Groups of Tribal**

The survey households were post-stratified into three income groups based on their monthly household income. Since household earnings and living costs have increased significantly in recent years, the income classification used in this study is based on 2025 inflation-adjusted values using the Consumer Price Index for Industrial Workers (CPI-IW), which is the standard national indicator for updating socio-economic income thresholds in India. Accordingly, households earning less than ₹10,000 per month were categorized as the Low-Income Group (LIG), those earning ₹10,001 to ₹20,000 per month were classified as the Middle-Income Group (MIG), and households earning more than ₹20,000 per month were grouped under the High-Income Group (HIG). These

updated thresholds reflect current economic conditions and provide a realistic basis for analysing the consumption behaviour, dietary diversity, and nutritional status of Particularly Vulnerable Tribal Groups (PVTGs). Using CPI-IW-based updated income groups ensures that the study captures the true economic status of tribal households and supports accurate, policy-relevant interpretation of results.

### Nutrition quantity

The dietary recall method was used to estimate the food intake of each household per month. Information such as the amount of food consumed, the actual ingredients used, and the amount consumed by each family member was recorded based on the schedule prepared for this purpose. Finally, using a food consumption table presented in Annexure II (Gopalan *et al.*, 1971) the nutrient intake of each food item was calculated in grams per day. In food consumption, the major nutrient intake was calculated in terms of proteins, calories, calcium, fat, and iron. A similar procedure was employed in its regular calorie consumption calculation in NSSO data.

**Table 1 Recommended Dietary Allowance (RDA) for nutrient intake per day**

S. No.	Nutrients	RDA (CU/ day)
1	Energy (Kcal)	2720
2	Carbohydrates (g)	130
3	Protein (g)	54
4	Fat (g)	20
5	Magnesium (mg)	440
6	Calcium(mg)	1000
7	Iron (mg)	29
8	Iodine (µg)	140
9	Vitamin A (µg)	1000
10	Thiamin (mg)	1.4
11	Sodium (mg)	2000

(Source: ICMR, 2020)

### Consumption Quantities of Essential Commodities Purchased from PDS

Essential commodities purchased from the PDS include subsidized items such as **rice, wheat, pulses (such as masoor dal), edible oil, and sugar**. These items are available at highly subsidized prices in Fair Price Shops (FPS), making them accessible to low-income and vulnerable households such as PVTGs. The quantities purchased depend on the **type of smart card** held by the household (PHH-Rice, PHH-AAY, NPHH-L, etc.). Households with Priority Household (PHH) and Antyodaya Anna Yojana (AAY) cards generally receive higher quantities of rice and wheat. Because these items are cheaper through PDS, most tribal households purchase **the majority of their staple cereals** from the PDS. Tracking these quantities helps understand how much of their basic food requirement is met through the government system.

### Issues Associated with PDS System in India

- **Identification of beneficiaries:** Studies have shown that targeting mechanisms such as TPDS are prone to **large inclusion and exclusion errors**. This implies that entitled beneficiaries are not getting food grains while those that are ineligible are getting undue benefits. According to the estimation of an expert group set up in 2009, PDS suffers from nearly 61% error of exclusion and 25% inclusion of beneficiaries, i.e. the misclassification of the poor as non-poor and vice versa.
- **Leakage of food grains:** (Transportation leakages + Black Marketing by FPS owners) TPDS suffers from large leakages of food grains during transportation to and from ration shops into the open market. In an evaluation of TPDS, the erstwhile Planning Commission found 36% leakage of PDS rice and wheat at the all-India level.
- **Issue with procurement:** Open-ended Procurement i.e., all incoming grains accepted even if buffer stock is filled, creates a shortage in the open market.
- **Issues with storage:** A performance audit by the CAG has revealed a serious **shortfall in the government's storage capacity**. Given the increasing procurement and incidents of **rotting food grains**, the lack of adequate covered storage is bound to be a cause for concern.

- The provision of **minimum support price (MSP)** has encouraged farmers to divert land from production of coarse grains that are consumed by the poor, to rice and wheat and thus, **discourages crop diversification.**
- **Environmental issues:** The over-emphasis on attaining self-sufficiency and a surplus in food grains, which are water-intensive, has been found to be **environmentally unsustainable.**
  - Procuring states such as Punjab and Haryana are under environmental stress, including **rapid groundwater depletion, deteriorating soil and water conditions from overuse of fertilisers.**
  - It was found that due to cultivation of rice in north-west India, the water table went down by 33 cm per year during 2002-08.

#### **Way Forward**

PDS is one of the biggest welfare programmes of the government, helping farmers sell their produce at remunerative prices as well as the poorer sections of society to buy food grains at affordable rates. To enhance the nutritional level of masses, **bio-fortified foods** need to be distributed through the PDS that will make it more relevant in the backdrop of prevalent malnutrition in India.



## NEW TRENDS IN AGRICULTURAL BIOTECHNOLOGY: INNOVATIONS, TECHNOLOGIES, AND FUTURE DIRECTIONS



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### Abstract

Agricultural biotechnology is undergoing a rapid transformation driven by breakthroughs in genomics, synthetic biology, genome editing, artificial intelligence, and biological systems engineering. These technologies are enabling precise manipulation of plant and microbial genomes, sustainable crop production, climate-resilient agriculture, and enhanced food security. This article reviews the latest trends in agricultural biotechnology, focusing on genetic engineering, CRISPR-based genome editing, microbiome engineering, smart bio-inputs, bioinformatics, cellular agriculture, and emerging regulatory landscapes. The paper also highlights current challenges, ethical considerations, and future opportunities that will shape the next generation of biotechnology-enabled agriculture.

### 1. Introduction

Global agriculture faces unprecedented challenges: climate change, emerging pests and diseases, depletion of natural resources, declining soil fertility, and a rapidly growing population. Traditional breeding methods, although foundational, are too slow to meet the urgent need for resilient and high-yielding crops. Agricultural biotechnology provides tools for precise, efficient, and sustainable solutions.

Recent advancements—especially in genome editing, omics technologies, AI-assisted breeding, and microbiome manipulation—are revolutionizing how crops are developed and managed. These technologies have matured to the point where they can be integrated into mainstream agricultural practices.

This technical article presents an in-depth overview of **new and emerging trends in agricultural biotechnology**, covering both the technological foundations and real-world applications that are reshaping global agriculture.

### 2. Advances in Genome Editing Technologies

Genome editing is one of the most transformative developments in agricultural biotechnology. While first-generation tools such as TALENs and ZFNs paved the way, modern methods offer unprecedented precision.

#### CRISPR-Cas Systems

CRISPR-Cas9 revolutionized plant genome editing due to its simplicity and high efficiency. Current innovations include:

#### CRISPR-Cas12 and Cas13

- Cas12 enables precise editing with reduced off-target effects.
- Cas13 targets RNA, allowing transient gene regulation without permanent DNA modification.

#### CRISPR Prime Editing

Prime editing introduces targeted changes without double-strand breaks, reducing risks associated with conventional CRISPR.

#### Multiplexed CRISPR Editing

Allows simultaneous editing of multiple genes, accelerating breeding for complex traits such as:

- Drought tolerance
- Disease resistance
- Nutrient use efficiency

#### Epigenome Editing

Rather than altering DNA sequence, epigenome editors regulate gene expression by modifying:

- DNA methylation
- Histone marks
- Chromatin structure

This approach generates stable, inheritable changes without altering the genetic code.

### Base Editing

Base editors (C→T, A→G conversions) enable precise point mutations without double-strand breaks. They are used in:

- Herbicide tolerance
- Improved grain quality
- Enhanced photosynthetic efficiency

### 3. Synthetic Biology in Agriculture

Synthetic biology integrates engineering principles with biology to design novel biological systems.

#### Designer Metabolic Pathways in Plants

Scientists are engineering custom biosynthetic pathways to produce:

- High-value metabolites
- Nutrient-enriched crops
- Natural pesticides

For example, metabolic engineering of carotenoid pathways produces vitamin-A enhanced crops.

#### Synthetic Promoters and Gene Circuits

Artificial promoters allow tight regulation of gene expression in response to:

- Light
- Temperature
- Salinity
- Pathogen attack

Synthetic gene circuits can enable plants to “sense and respond” to environmental stimuli.

#### Synthetic Nitrogen Fixation

Engineering cereal crops to fix atmospheric nitrogen could reduce dependence on chemical fertilizers and lower environmental pollution.

#### Plant-Based Biomanufacturing

Plants are being used as biofactories for:

- Vaccines
- Therapeutic proteins
- Industrial enzymes

This improves production scalability and reduces costs.

### 4. Agricultural Microbiome Engineering

The plant microbiome—comprising beneficial bacteria, fungi, and other microbes—plays a crucial role in plant health.

#### Designer Microbial Consortia

Instead of traditional biofertilizers, modern biotechnology aims to create optimized microbial communities that:

- Enhance nutrient uptake
- Promote root development
- Improve resistance to pathogens
- Tolerate environmental stress

#### CRISPR-Engineered Microbes

CRISPR is used to modify microbes for:

- Improved nitrogen fixation
- Phosphate solubilization
- Biological control of pests

### Phage Therapy in Crops

Bacteriophages are being engineered to target plant-pathogenic bacteria, reducing reliance on chemical pesticides.

### Endophyte Engineering

Genetically engineered endophytes can produce:

- Growth hormones
- Defense compounds
- Stress tolerance factors

and deliver them directly inside plant tissues.

## 5. Bioinformatics and Genomics-Driven Agriculture

### Pan-Genome Analysis

Modern sequencing technologies allow construction of pan-genomes representing the full genetic diversity of a crop species. Pan-genomics accelerates:

- Identification of novel gene variants
- Trait mapping
- Breeding decisions

### Machine Learning in Genomics

AI-driven tools interpret massive genomic datasets to:

- Predict trait performance
- Identify key regulatory elements
- Optimize genome editing targets

### High-Throughput Phenotyping (HTP)

Advanced imaging systems (hyperspectral, thermal, LiDAR) integrated with AI provide accurate phenotypic data.

### Single-Cell Sequencing

Reveals cell-type-specific gene expression in roots, leaves, and developing tissues, enabling precise genetic manipulation.

## 6. Advanced Plant Tissue Culture and Cellular Agriculture

### Speed Breeding

Controlled environment growth chambers accelerate plant generation cycles using:

- High-intensity LED lighting
- Optimized photoperiods
- Automated nutrient systems

This enables up to 5–6 generations per year.

### Somatic Embryogenesis and Artificial Seeds

Somatic cells are induced into embryo-like structures, offering:

- Clonal propagation
- Preservation of elite genotypes
- Rapid multiplication of disease-free plants

### Cellular Agriculture for Food Production

Biotechnology enables production of agricultural products without traditional farming:

- Cell-cultured meat
- Fermentation-derived proteins (e.g., casein, whey)
- Plant cell bioreactors for flavors, pigments, and oils

### Plastid Transformation

Chloroplast genome editing offers:

- High transgene expression
- Reduced gene flow via pollen
- Enhanced biosynthetic pathways

## 7. Novel Bio-Inputs and Eco-Friendly Crop Protection

### RNA Interference (RNAi)-Based Pesticides

Topical RNA sprays silence essential genes in:

- Insects
- Fungal pathogens
- Viruses

They degrade quickly in nature and leave no harmful residues.

### Biostimulants

Advanced formulations containing:

- Seaweed extracts
- Microbial metabolites
- Peptide-based growth enhancers

These improve plant resilience to abiotic stress.

### Biodegradable Nanocarriers

Nanotechnology delivers:

- Nutrients
- Growth regulators
- Genetic material

with improved efficiency and reduced waste.

### Next-Gen Bioherbicides

Engineered microbes or natural compounds selectively target weeds without harming crops.

## 8. Climate-Resilient Biotechnology

### Engineering Drought and Heat Tolerance

Key approaches include:

- Editing ABA-signaling pathway genes
- Improving root architecture
- Modifying cuticle composition

### C4 Photosynthesis Engineering

Transforming C3 crops into C4-like systems improves photosynthetic efficiency and yield.

### Salt-Resilient Plants

Genome editing targets ion transporters to manage salinity stress.

### Cold-Tolerant Germplasm Development

Antifreeze protein genes from extremophiles are used to enhance low-temperature tolerance.

## 9. Regulatory and Ethical Considerations

### Next-Generation Regulations

Modern frameworks focus on product-based rather than process-based evaluation. This makes certain genome-edited crops exempt from GMO regulations if no foreign DNA is introduced.

### Ethical Issues

Key concerns include:

- Gene flow to wild species
- Biodiversity impacts
- Economic inequality among farmers
- Ownership of genetic resources

### Public Perception

Consumer acceptance varies significantly; transparent labeling and communication are essential.

## 10. Challenges and Limitations

- Limited infrastructure in developing countries
- High cost of advanced biotechnological tools

- Intellectual property restrictions
- Environmental risks and ecological uncertainties
- Need for highly skilled personnel

## 11. Future Directions

### AI + Biotechnology Integration

AI will guide:

- Gene discovery
- Predictive breeding
- Digital phenotyping
- Metabolic pathway design

### Quantum Biology in Crops

Quantum computing may accelerate protein folding simulations and trait prediction.

### De Novo Plant Design

Synthetic biology may eventually enable fully engineered plant species optimized for:

- Carbon capture
- Extreme climates
- High nutritional output

### Field-Deployable Genome Editing

Portable CRISPR kits could enable real-time crop improvement directly on farms.

### Space Agriculture Biotechnology

For future missions, engineered crops must survive:

- Microgravity
- High radiation
- Limited resources

Biotechnology is essential for extraterrestrial food systems.

## 12. Conclusion

Agricultural biotechnology is moving into a new era characterized by precision, sustainability, and innovation. Recent trends—from CRISPR editing and synthetic biology to microbiome engineering and cellular agriculture—are redefining how crops are improved and how food is produced. While significant challenges remain, continued research, regulatory refinement, and technological integration will drive the next wave of sustainable agricultural transformation. These advancements promise a future where biotechnology not only enhances productivity but also addresses global challenges such as climate change, food insecurity, and environmental degradation.

## Harnessing Genetic Resistance for Sustainable Control of Viral Diseases in Vegetable Crops



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### Abstract

Plant viruses pose a significant and persistent threat to global vegetable production, often leading to substantial yield and quality losses. The scarcity of effective chemical controls makes the use of genetic resistance the most sustainable and economically viable strategy for disease management. This review synthesizes current knowledge on the deployment of genetic resistance against viruses in vegetable crops. We explore the process of breeding for resistance, from germplasm screening to the introgression of resistance traits into elite cultivars. A major focus is placed on the molecular mechanisms underpinning both passive (recessive) and active (dominant) resistance, detailing how they disrupt critical stages of the viral infection cycle, including transmission, intracellular multiplication and systemic movement. Furthermore, we address the crucial issue of resistance durability, examining the evolutionary arms race between host plants and viruses and discussing the factors that influence the breakdown of resistance. Finally, we highlight future prospects, including high-throughput screening, the exploitation of quantitative trait loci (QTL) and the development of predictive models for resistance management. The integration of these approaches is essential for developing robust and durable virus control strategies in vegetable agriculture.

**Keywords:** Viruses, Genetic Resistance, Resistance Breeding, Diseases, Durability, Sustainable Agriculture

### Introduction

Vegetable crops are indispensable for global food security and nutrition, yet their production is consistently challenged by a plethora of plant pathogens, among which viruses are particularly damaging. Viruses such as *Tomato spotted wilt virus* (TSWV), *Cucumber mosaic virus* (CMV), *Potyvirus* species (e.g., *Potato virus Y*, *Zucchini yellow mosaic virus*) and *Begomoviruses* (whitefly-transmitted geminiviruses) can cause devastating epidemics, leading to complete crop failure in severe cases. The management of these viral diseases is notoriously difficult. There are no direct chemical treatments that cure infected plants and control measures often rely on the inefficient and environmentally detrimental practice of spraying insecticides to reduce vector populations.

In this context, the use of genetically resistant cultivars stands out as the most promising, sustainable and cost-effective control strategy. Resistant cultivars provide continuous protection throughout the growing season without additional input costs for farmers and are entirely safe for consumers and the environment. The foundation of this approach lies in identifying and incorporating heritable traits that suppress virus multiplication, movement, or transmission.

This review aims to provide a comprehensive overview of the strategies and mechanisms for achieving genetic resistance to viruses in vegetable crops. We will cover the pipeline of resistance breeding, delve into the molecular dialogues that define susceptible and resistant interactions and confront the challenge of ensuring the long-term durability of deployed resistance genes in the face of evolving viral populations.

### Breeding for Virus Resistance in Vegetables

The development of a virus-resistant vegetable cultivar is a multidisciplinary and iterative process involving plant breeders, pathologists and molecular biologists. The standard pipeline, while consistent in its overarching goals, requires specific considerations when the target pathogen is a virus.

#### *Germplasm Screening: The Quest for Resistance Sources*

The initial and critical step is the identification of sources of resistance within available genetic resources. Resistance can often be found in:

- **Commercial cultivars:** Already selected for agronomic quality.

- **Landraces:** Locally adapted, genetically diverse populations.
- **Wild relatives:** Often a rich source of major resistance genes but may require specialized techniques for introgression due to reproductive barriers.

Screening can be conducted in the field under high inoculum pressure or under controlled conditions (greenhouses, growth chambers). Field screening is economical and tests resistance under realistic conditions, including vector pressure, but is confounded by environmental variability and mixed infections. Controlled screening allows for precise inoculation with specific virus strains, ensuring reproducible and interpretable results. A key consideration is the choice of virus strain, as resistance is often strain-specific; using a strain that is representative of field populations is crucial.

#### **Phenotyping: Beyond Symptom Observation**

Accurate phenotyping is essential to distinguish true resistance from tolerance (infection without severe symptoms). Reliable diagnostic methods, such as Enzyme-Linked Immunosorbent Assay (ELISA) or reverse transcription-polymerase chain reaction (RT-PCR), are used to detect and quantify virus accumulation. Furthermore, resistance expression can be influenced by non-genetic factors, including plant developmental stage, inoculation method (mechanical vs. vectored), inoculum dose and environmental conditions, particularly temperature. A comprehensive resistance screen should assess symptom severity, virus presence in inoculated and systemic leaves and viral titers over time.

#### **Genetics and Marker-Assisted Selection (MAS)**

Classical genetic analysis through crosses between resistant and susceptible lines reveals the inheritance pattern of the resistance trait. In vegetable-virus interactions, resistance is often monogenic (78% of cases), with dominant and recessive traits being almost equally common. While monogenic resistances are easier to handle in breeding programs, polygenic (quantitative) resistances are also valuable, potentially offering greater durability.

The advent of molecular markers has revolutionized plant breeding. Marker-Assisted Selection (MAS) allows breeders to select for resistance genes based on their genetic linkage to molecular markers (e.g., SNPs, SSRs), without the need for laborious and season-dependent pathogen challenge tests. This accelerates the introgression of resistance into elite backgrounds and facilitates the pyramiding of multiple resistance genes into a single cultivar.

#### **Molecular Mechanisms of Virus Resistance**

Resistance mechanisms can be categorized based on their mode of action and the stage of the viral cycle they inhibit. Fraser (1990) classified them as passive or active.

##### **a) Passive (Recessive) Resistance**

This form of resistance is conferred by the absence or alteration of a host factor that the virus requires for its infection cycle. Consequently, it is typically recessive in genetic terms. Many of these susceptibility factors have been identified as translation initiation factors.

- ✓ **eIF4E and eIF4G Families:** These are the best-characterized susceptibility factors for a wide range of viruses, particularly potyviruses. The viral genome-linked protein (VPg) of potyviruses interacts directly with eIF4E (or its isoform, eIF(iso)4E) to facilitate viral translation and/or replication. Mutations in *eIF4E* genes that disrupt this interaction confer resistance without compromising plant viability, as the plant has redundant translation factors. This mechanism is the basis for resistance in pepper (*pvr2*), tomato (*pot-1*) and lettuce (*mo1*) against various potyviruses.
- ✓ **Resistance to Melon necrotic spot virus (MNSV):** A classic example in melons. The recessive *nsv* gene encodes a mutated eIF4E. Resistance breakdown by the MNSV-264 strain is determined by a sequence in the 3' untranslated region of the viral RNA (3'-CITE), which alters the translation initiation complex's requirement for the specific eIF4E variant.
- ✓ **Other Susceptibility Factors:** Proteins like TOM1 and TOM2A in *Arabidopsis* are required for the replication of tobamoviruses like *Tobacco mosaic virus* (TMV). Mutations in these genes create a cellular environment where the virus cannot replicate.

## b) Active (Dominant) Resistance

This form of resistance involves a direct recognition of the pathogen by the plant, triggering a defence response. It is typically conferred by dominant Resistance (R) genes, most of which encode nucleotide-binding site leucine-rich repeat (NBS-LRR) proteins.

- ✓ **NBS-LRR Mediated Resistance:** These proteins act as immune receptors, directly or indirectly recognizing specific viral "avirulence" (Avr) factors, often the coat protein (CP), replicase, or movement protein. This recognition initiates a robust defence cascade, frequently culminating in a hypersensitive response (HR) a localized programmed cell death that confines the virus to the infection site.
  - **Examples:** The Tm-2<sup>2</sup> gene in tomato confers resistance to *Tomato mosaic virus* (ToMV) by recognizing the viral movement protein. The Rx gene in potato confers extreme resistance to *Potato virus X* (PVX) by recognizing the coat protein, effectively blocking virus accumulation at the single-cell level.
- ✓ **Resistance to Vectors:** Some R genes provide indirect virus resistance by targeting the insect vector. The Mi-1.2 gene in tomato confers resistance to root-knot nematodes and also to the aphid *Macrosiphum euphorbiae* and the whitefly *Bemisia tabaci*, reducing the ability of these vectors to transmit viruses. Similarly, the Vat gene in melon provides resistance to the aphid *Aphis gossypii* and the viruses it transmits non-persistently.

## c) RNA Silencing and Recovery

RNA interference (RNAi) is a fundamental, innate antiviral defence mechanism in plants. It involves the sequence-specific degradation of viral RNA guided by small interfering RNAs (siRNAs) derived from viral double-stranded RNA replicative intermediates. The phenomenon of "recovery," where a plant shows severe symptoms in initially infected leaves but then produces new, symptom-free growth with low virus titers, is a visible manifestation of a potent RNAi response that has systemically silenced the virus.

**Table 1: Key Resistance Genes and Their Mechanisms in Vegetable Crops** (Gómez *et al.*, 2009)

Crop	Gene	Virus (Pathogen)	Mechanism / Gene Type	Viral Avirulence Factor
Tomato	Tm-2 <sup>2</sup>	<i>Tomato mosaic virus</i> (ToMV)	NBS-LRR (Dominant)	Movement Protein
Tomato	Mi-1.2	Aphids, Whiteflies, Nematodes	NBS-LRR (Dominant)	Insect/Nematode Effector
Tomato	pot-1	<i>Potato virus Y</i> (PVY)	Recessive mutation (eIF4E)	VPg
Pepper	<i>pvr2</i>	<i>Potato virus Y</i> (PVY)	Recessive mutation (eIF4E)	VPg
Pepper	<i>L<sup>4</sup></i>	<i>Tobacco mosaic virus</i> (TMV)	NBS-LRR (Dominant)	Replicase
Melon	<i>nsv</i>	<i>Melon necrotic spot virus</i> (MNSV)	Recessive mutation (eIF4E)	3'-CITE RNA structure
Melon	<i>Vat</i>	<i>Aphis gossypii</i> (aphid)	NBS-LRR (Dominant)	Aphid Effector
Lettuce	<i>mo1<sup>1</sup></i>	<i>Lettuce mosaic virus</i> (LMV)	Recessive mutation (eIF4E)	VPg
Bean	bc-3	<i>Bean common mosaic virus</i> (BCMV)	Recessive mutation (eIF4E)	VPg

## The Challenge of Resistance Durability

The deployment of a resistant cultivar exerts immense selection pressure on the virus population, favouring any variant that can overcome (break) the resistance. Durability is defined as resistance that remains effective after widespread deployment in environments conducive to the disease.

### The Process of Resistance Breakdown

The breakdown of a resistance gene involves three sequential steps driven by evolutionary forces (Fig. 1):

1. **Mutation/Recombination:** A virulent mutant arises in the viral population through point mutation or recombination between viral strains.

2. **Accumulation:** The virulent variant must accumulate sufficiently within the infected plant, competing with the avirulent population. Mutations conferring virulence often carry a fitness cost, which may hinder this step.
3. **Dissemination:** The virulent variant must be efficiently transmitted to new host plants by vectors or other means to initiate an epidemic.

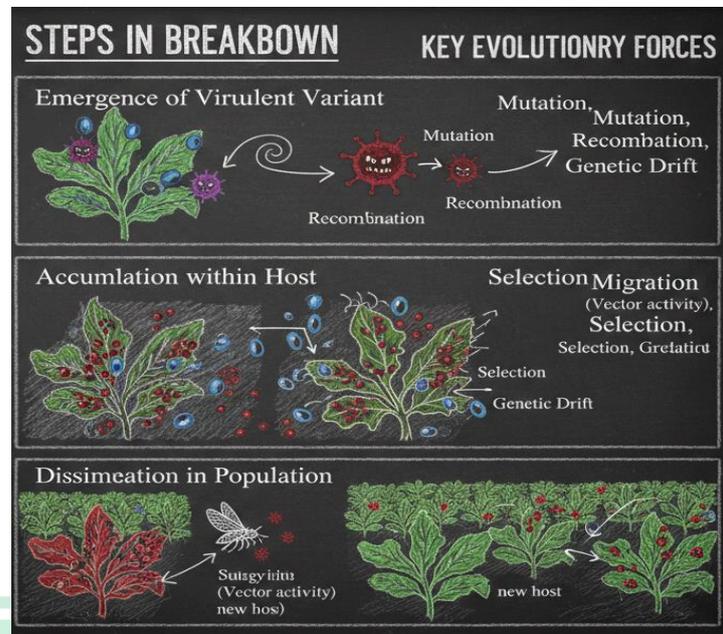


Figure 1: Steps and Evolutionary Forces in Resistance Breakdown

#### Factors Influencing Durability

- **Genetic Nature of Resistance:** No single type of resistance is universally more durable. However, "extreme resistance" (complete suppression without HR) and polygenic resistance are often considered more durable than monogenic hypersensitive resistance, as they present a more complex barrier for the virus to overcome. Pyramiding multiple R genes into one cultivar is a key strategy to enhance durability.
- **Virus Biology:** Viruses with large population sizes, high mutation rates, efficient vector transmission (especially by airborne vectors) and the capacity for recombination have a higher "evolutionary potential" (EP) and are more likely to break down resistance.
- **Number of Mutations Required:** Resistance genes that can be overcome by a single amino acid change in the viral Avr factor are generally less durable than those requiring two or more simultaneous mutations.
- **Agronomic and Environmental Factors:** Large-scale monoculture of a single resistant cultivar, high vector pressure and human activities like the global trade of infected plant material can dramatically accelerate the emergence and spread of resistance-breaking variants.

#### Conclusion

Genetic resistance remains the cornerstone of sustainable virus management in vegetable production. Significant advances have been made in identifying resistance sources, understanding their molecular mechanisms and deploying them via modern breeding tools like MAS. The dissection of recessive resistance based on eIF4E has been particularly transformative, providing robust and often broad-spectrum resistance.

#### References

- Fraser, R. S. S. (1990). The genetics of resistance to plantviruses. Annual Review of Phytopathology, 28, 179–200. Doi: <https://doi.org/10.1146/annurev.py.28.090190.001143>
- Gómez, P., Rodríguez-Hernández, A. M., Moury, B. and Aranda, M. A. (2009). Genetic resistance for the sustainable control of plant virus diseases: breeding, mechanisms and durability. European journal of plant pathology, 125(1), 1-22. Doi: <https://doi.org/10.1007/s10658-009-9468-5>

## How climate induced vegetation change alters soil nutrient cycling



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### Abstract

Climate change is significantly altering soil biogeochemical cycles, with major consequences for soil health and global food security. A synthesis of 755 field observations combined with ecosystem-level reviews shows that rising temperatures act as a metabolic accelerator in soils, increasing nitrogen mineralization by 21.8% and nitrification by 20.9%, largely due to shifts in soil moisture and microbial abundance. Higher precipitation also enhances nitrogen turnover by about 10%, though these gains are often lost through erosion and nutrient leaching. Reduced precipitation, however, shows little immediate effect on nitrogen transformation rates, indicating short-term microbial resilience despite long-term drought-driven changes in microbial community structure. Critically, microbial immobilization the main mechanism for nitrogen retention remains unchanged under warming or altered rainfall, creating a “leaky” nitrogen system where nutrient production exceeds retention capacity. Overall, these findings reveal a growing imbalance between nutrient availability and plant uptake, emphasizing the need for adaptive soil management strategies such as minimum tillage and organic amendments to prevent fertility loss and maintain agricultural productivity under a changing climate.

**Keywords:** Climate change, Soil biogeochemical cycles, Nitrogen transformation, Nitrification, Soil moisture shifts, Precipitation change, Nutrient leaching and Agricultural productivity.

### Introduction

When we imagine the impacts of climate change, we typically look to the sky: the gathering storm clouds, the rising smog, or the sun beating down on melting glaciers. We focus on the atmosphere, where carbon dioxide accumulates. However, a transformation just as profound and potentially more dangerous to our immediate survival is taking place in the top 20 cm of the Earth’s crust. Soil is not merely dirt; it is a living, breathing ecosystem. It functions as a biological engine responsible for recycling organic matter into the nutrients that plants and by extension, humans need to survive. Recent research from 2025 has revealed that this engine is reacting to global warming in complex and volatile ways. By combining broad ecosystem reviews with a rigorous global meta-analysis of 755 field observations, scientists have determined that the soil’s metabolism is racing out of control. As temperatures rise and rainfall patterns become erratic, the fundamental chemical cycles beneath our feet are accelerating, threatening to disrupt ecosystem sustainability and agricultural production worldwide.

### The Heat Factor

#### A Hyper-Active Nitrogen Cycle

The core of soil health is the nitrogen cycle, a process where microorganisms break down dead organic matter (mineralization) and convert it into forms plants can use, such as ammonium and nitrate (nitrification). New quantitative data reveals that global warming is hitting the accelerator on this process. According to a global meta-analysis, warming has a statistically significant, positive impact on soil nitrogen transformations

**Mineralization Spike:** The rate at which organic nitrogen is converted into ammonium increases by **21.8%** when soils are warmed.

**Nitrification Surge:** The subsequent conversion of ammonium into nitrate jumps by **20.9%**.

While faster nutrient release might appear beneficial for plant growth initially, it represents a dangerous “hyper-metabolism.” Rising temperatures amplify microbial activity, causing organic matter to decompose much faster than usual. This rapid breakdown can deplete the soil’s long-term reserves of organic carbon, potentially releasing more CO<sub>2</sub> back into the atmosphere and creating a feedback loop that worsens climate change.

### The Ecosystem Divide:

Not all soils react the same way. Forest ecosystems appear to be the most sensitive to this warming, showing strong increases in mineralization. In contrast, agricultural croplands showed less sensitivity to warming alone, likely because these soils are already heavily manipulated by human activity.

### The Water Paradox (Feast and Famine in the Soil)

Climate change is also violently disrupting the global water cycle. The research highlights a diverging path for our soils depending on whether they face the "feast" of floods or the "famine" of drought.

### The Deluge (Increased Precipitation)

In a wetter world, the soil's nutrient cycle spins even faster. Increased precipitation was found to boost nitrogen mineralization by **10.2%** and nitrification by **9.4%**. Water acts as a solvent and transport medium, allowing microbes to access organic matter more easily. However, this chemical acceleration is often negated by physical destruction. Heavy rains and extreme weather events lead to:

**Nutrient Leaching:** The excess nitrates produced by the faster cycle are highly water-soluble. Intense rainfall washes these nutrients out of the root zone before plants can capture them.

**Environmental Pollution:** These leached nutrients eventually flow into water bodies, causing eutrophication a process that leads to toxic algae blooms and degrades aquatic ecosystems.

**Soil Degradation:** Heavy rain compacts the soil, reducing water infiltration and physically eroding the fertile topsoil layer.

### The Drought Surprise (Decreased Precipitation)

One of the most counter-intuitive findings involves drought. While it is generally assumed that dry conditions shut down soil life, the meta-analysis found that decreased precipitation did not significantly alter the overall rates of nitrogen mineralization or nitrification. This suggests a surprising biological resistance; soil microbes may be tougher than previously thought, maintaining metabolic functions even when water is scarce. However, this resilience has limits. Prolonged dry conditions can stress microbial communities, shifting the population toward drought-resistant species that may not cycle nutrients as efficiently. Furthermore, even if the chemistry continues, the lack of water means nutrients cannot physically move to plant roots, effectively starving the vegetation.

### The "Leaky Bucket" Effect (Production Without Retention)

A healthy soil ecosystem requires balance. It needs Mineralization (to release nutrients) and Immobilization (where microbes store nutrients in their own biomass to prevent loss). Crucially, the research identified a major disconnect. While warming and rain increased the release of nutrients significantly, they did not alter microbial immobilization rates. This creates a "leaky bucket" effect:

- **High Input:** The soil produces available nitrogen faster (21.8% under warming).
- **Static Storage:** The capacity of microbes to hold onto that nitrogen remains unchanged.
- **The Result:** The system leaks. Excess nitrogen that is not immediately used by plants is lost to the environment, leading to a decline in soil fertility over time.

### The Microscopic Drivers

#### Who is Driving the Bus?

The drivers of these changes are the billions of microorganisms living in every handful of soil. The research identified specific biological mechanisms controlling these rates:

- **Substrate Availability:** The increase in nitrogen mineralization under warming is primarily driven by soil moisture and the total nitrogen content of the soil. Essentially, if the soil is wet and rich in organic matter, heat acts as a catalyst for massive nutrient release.
- **Bacterial Regulators:** The nitrification rate is tightly regulated by the abundance of Ammonia-Oxidizing Bacteria (AOB). These bacteria thrive in warmer temperatures: as their populations grow, they convert ammonium to nitrate more aggressively, increasing the risk of leaching.

### Consequences for Humanity

#### Food Security at Risk

These microscopic shifts have macroscopic consequences. The global food system relies on a predictable synchronization between soil nutrient release and crop demand. Climate change is breaking this synchronization.

**Yield Declines:** If nutrients are released in a "pulse" during early spring warming and then washed away by spring rains, they are gone by the time crops need them most. This leads to decreased soil fertility and reduced crop productivity.

**Global Inequity:** The impact is severe in developing regions where agriculture is often rainfed. Farmers in these areas rely on the natural mineralization of soil organic matter. If this natural fertility is degraded by erosion or hyper decomposition, food safety is directly threatened.

**Conclusion:**

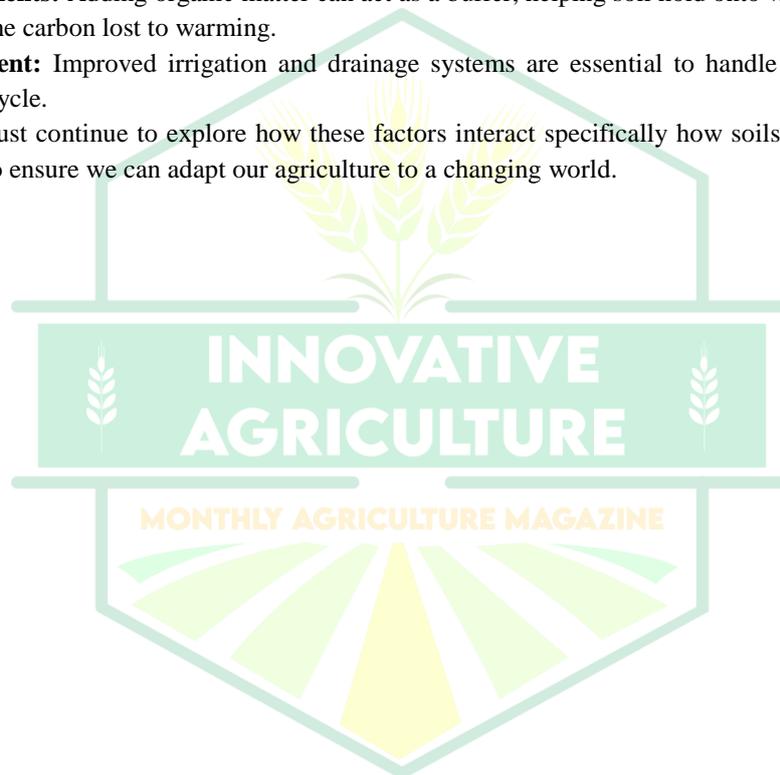
The soil is not a passive victim of climate change; it is an active participant. The evidence shows that rising temperatures and altered rainfall are rewiring the biogeochemical cycles that sustain life. We are facing a future where soil nutrient cycles are faster, leakier, and more volatile. To mitigate these effects, experts suggest we must adopt "climate-smart" soil management strategies:

**Minimum Tillage:** Reducing soil disturbance helps maintain structure and protects organic carbon from rapid decomposition.

**Organic Amendments:** Adding organic matter can act as a buffer, helping soil hold onto water during droughts and replenishing the carbon lost to warming.

**Water Management:** Improved irrigation and drainage systems are essential to handle the extremes of the intensified water cycle.

Future research must continue to explore how these factors interact specifically how soils react when they are both hot and dry to ensure we can adapt our agriculture to a changing world.



## Microbial Resilience Dynamics in Soils Under Long-Term Organic vs. Inorganic Nutrient Inputs



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### Abstract

Soil microbiomes represent complex, functionally diverse assemblages that regulate biogeochemical cycling and underpin ecosystem productivity. Long-term nutrient management profoundly influences microbial community structure, functional capacity, and resilience. This study investigates the comparative impacts of chronic organic amendments (compost, manure, and lignocellulosic residues) and inorganic NPK fertilization on microbial diversity, enzymatic activity, and stress-response dynamics. Organic inputs enhanced soil organic carbon, improved aggregation, and provided sustained energy substrates, promoting higher taxonomic and functional diversity and faster post-disturbance recovery. In contrast, prolonged inorganic fertilization reduced organic matter pools and increased acidification, resulting in community simplification, decreased metabolic potential and diminished resilience. The findings demonstrate that organic nutrient management strengthens microbial network stability and ecological resistance, supporting long-term soil health and sustainable agroecosystem functioning.

**Keywords:** Organic fertilizers, synthetic fertilizers, soil microbiome, resilience, microbial diversity

### Introduction

Soil represents a highly complex biological matrix inhabited by diverse microbial taxa that mediate key biogeochemical processes, including organic matter decomposition, nutrient mineralization, and soil aggregate stabilization. These microbial assemblages collectively form the soil microbiome, whose resilience is defined as the capacity to resist perturbations, recover functional integrity, and sustain ecological processes. Agricultural fertilization regimes exert strong selective pressures on microbial composition and activity. Organic fertilizers such as compost, manures, and plant-derived residues supply slowly available nutrients and substantial organic carbon inputs that promote microbial proliferation and functional diversity. Conversely, synthetic fertilizers, particularly NPK formulations, deliver readily soluble nutrients but may induce long-term shifts in soil pH, organic matter content, and microbial metabolic potential. Assessing how different fertilizer inputs influence microbial resilience is fundamental for optimizing nutrient management strategies and supporting sustainable agroecosystem productivity.

### Effects of Organic Fertilizers on Soil Microbes

Organic fertilizers enhance soil microbial diversity, activity, and overall biomass by supplying a steady source of organic carbon and nutrients. These inputs serve as an energy-rich substrate for a broad range of microorganisms, promoting their growth and metabolic functions. Over time, organic amendments improve soil structure, increase enzymatic activities, and foster functional redundancy allowing microbial communities to maintain key processes even when certain taxa are stressed. Soils receiving organic inputs generally exhibit stronger resilience to environmental disturbances such as drought, fluctuations in pH, and nutrient stress. Beneficial microbial groups, including nitrogen-fixing bacteria, decomposers, and mycorrhizal fungi, tend to flourish under organic fertilization, contributing to more stable and robust soil ecosystems.

### Effects of Synthetic Fertilizers on Soil Microbes

Synthetic fertilizers deliver readily available nutrients that promote rapid plant growth, but prolonged application can deplete soil organic matter and significantly shift soil pH. These changes often result in reduced microbial diversity and destabilized microbial interaction networks. Soils managed exclusively with chemical fertilizers typically show diminished recovery capacity following stress events, indicating lower long-term resilience. Over extended use, synthetic inputs can impair soil structure, suppress beneficial microbial taxa, and disrupt natural

nutrient-cycling pathways. This decline in microbial functionality weakens the soil's ecological balance and ultimately limits its capacity to sustain productive and regenerative agriculture.

### **Fertilizer Impacts on Microbes**

Soils enriched with organic fertilizers generally support higher microbial diversity and more stable microbial communities than soils treated with synthetic fertilizers. Organic inputs help preserve critical soil qualities such as organic matter content, pH balance, and sustained nutrient availability, all of which promote healthy microbial functioning. In contrast, long-term application of chemical fertilizers often reduces microbial stability, weakens nutrient-cycling processes, and contributes to overall soil health decline. These contrasting responses directly affect soil fertility, crop productivity, and the soil's ability to endure and recover from environmental stresses.

### **Recovery, Stress Resistance, and Integrated Fertilizer Approaches**

Microbial communities in organically fertilized soils typically exhibit faster recovery from disturbances due to their higher diversity and functional redundancy. These communities are better adapted to withstand stresses such as drought, salinity fluctuations, and abrupt shifts in nutrient availability. Implementing integrated nutrient management combining organic amendments with synthetic fertilizers can harness the advantages of both systems by ensuring a continuous nutrient supply, preserving microbial diversity, enhancing soil health, and supporting sustained crop productivity. However, achieving these benefits requires careful balancing of inputs to prevent soil degradation, nutrient imbalances, or long-term declines in microbial function.

### **Implications for Sustainable Agriculture and Recommendation :**

The research shows that organic fertilizers improve microbial resilience and long-term soil health, while excessive reliance on synthetic fertilizers can weaken soil ecosystems. For sustainable agriculture, farmers should:

- Apply organic amendments regularly to support microbial diversity.
- Use synthetic fertilizers carefully and in moderation.
- Monitor soil health and microbial activity regularly.
- Adopt integrated nutrient management strategies to balance productivity and ecosystem health.

### **Conclusion**

Soil health depends on the resilience of its microbial communities. Organic fertilizers enhance diversity, activity, and recovery capacity, making soils more resilient to stress and long-term degradation. Synthetic fertilizers provide immediate nutrient benefits but can reduce microbial diversity and weaken soil resilience if used alone for extended periods. Sustainable soil management requires balancing organic and synthetic inputs to maintain productive, resilient, and healthy soils for future agricultural sustainability. By focusing on microbial health, farmers can ensure long-term soil fertility, crop productivity, and environmental protection.

## Enhancing Soil Health and Agricultural Sustainability through Crop Rotation Practices



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### ABSTRACT

Crop rotation is an ancient agricultural practice that dates back to the Roman and Greek civilizations. It remains one of the most cost-effective and efficient methods for enhancing crop yield and maintaining soil fertility. By systematically alternating different crops on the same piece of land, farmers can reduce production risks and uncertainties while promoting long-term soil and ecological sustainability. This practice significantly improves soil health by enhancing both its physical and chemical properties. Additionally, crop rotation helps suppress the incidence of pests, weeds, and diseases due to the varied structure, function, and interactions each crop has with the soil ecosystem. Through the strategic diversification of crops over time, crop rotation contributes effectively to restoring and maintaining soil fertility levels.

**Keywords:** Crop rotation, soil fertility, soil health, sustainable agriculture, pest and disease management, ecological sustainability.

### Introduction

Crop rotation is a time-tested agricultural practice aimed at improving soil health, enhancing organic matter, and minimizing soil erosion. By cultivating different crops in a planned sequence over successive seasons or years, farmers can significantly broaden beneficial microbial activity in the soil, resulting in improved crop yields and sustained agricultural productivity.

Incorporating leguminous crops within the rotation plays a vital role, as these plants naturally fix atmospheric nitrogen, enriching the soil and supplying essential nutrients for subsequent crops. This practice not only boosts soil fertility and nutrient availability but also helps prevent soil-borne diseases, contributing to a healthier and more resilient cropping system.

Crop rotation involves the systematic use of both legume and non-legume crops of varying root depths and growth habits. For example, farmers often grow pulse crops after shallow-rooted varieties and follow cereal crops with deep-rooted plants to maximize nutrient utilization and maintain soil structure.

Overall, crop rotation offers numerous advantages, including better nutrient distribution, improved soil properties, easier soil management, and effective weed control. As a superior and sustainable farming strategy, it serves as an invaluable resource for farmers striving for long-term productivity and ecological balance.

### Principles of Crop Rotation

- Crop rotation enhances the population of beneficial soil microorganisms, including bacteria that support soil health and nutrient cycling.
- Rotation reduces natural and market risks by diversifying crops, thereby protecting farmers against unexpected crop failures.
- Diverse crops improve the overall stability of the farming system and help boost enzymatic activities within the soil.
- Crop rotation helps control weed populations and prevents the dominance of any particular weed species.
- Crops are grown in a specific sequence to maintain and preserve soil fertility over time.
- After cultivating cereal crops in the kharif season, it is recommended to plant non-cereal crops in the rabi season to maintain nutrient balance.

- Farmers should select crops that suit their financial capacity and resource availability.
- Selected crops must be compatible with the soil type, climatic conditions, and local agro-ecological environment.

#### Advantages of Crop Rotation

- **Supports farmers' economic growth:** By cultivating a variety of crops, farmers can diversify their income sources, achieve higher returns, and maintain better financial stability.
- **Reduces production risk:** If one crop fails due to unfavorable conditions, the next crop in the rotation can compensate for the loss. Thus, crop rotation minimizes overall production risk.
- **Increases crop productivity:** Crop rotation enhances soil health, improves nutrient availability, and promotes stable farming systems. These factors collectively lead to increased crop yields.
- **Improves soil fertility:** This practice boosts soil fertility by supporting root development, improving nutrient uptake, and enhancing microbial activity. Healthy soil results in improved crop performance and long-term sustainability.
- **Controls pests and diseases:** Rotating crops increases the diversity of soil organisms, including beneficial microbes that help suppress pests and soil-borne diseases, leading to a healthier cropping environment.
- **Controls weeds:** Crop rotation disrupts weed growth cycles, reduces weed density, and minimizes competition with primary crops, thereby improving overall crop yield.

#### Conclusion

Crop rotation plays a vital role in strengthening the stability of farming systems by improving soil health and boosting enzymatic activity within the soil. By cultivating different crops in the same field across various seasons, farmers can maintain ecological balance, conserve nutrients, and enhance overall field productivity.

- This sustainable practice effectively reduces pest and weed pressure while ensuring long-term soil fertility. Strategic sequencing of legumes, cereals, and root crops enriches the soil with essential nutrients, supports healthy plant growth, and minimizes the risk of soil-borne diseases.
- Overall, crop rotation remains an essential and beneficial approach for achieving sustainable agriculture, improved crop performance, and enhanced resilience of farming systems.

#### Challenges of Crop Rotation in Agriculture

- **Land fragmentation:** In many farming regions, land is divided into small and scattered parcels, making it difficult to implement systematic crop rotation and complicating overall land management.
- **Lack of awareness:** A significant number of farmers are unaware of the principles and benefits of crop rotation. This lack of knowledge leads them to rely on traditional farming practices and prevents them from fully benefiting from rotation systems.
- **Inadequate monitoring:** Poor monitoring of crop growth, soil conditions, and pest populations can result in decreased yields and increased susceptibility to diseases and insect infestations, reducing the effectiveness of crop rotation.
- **Poor crop selection:** Selecting inappropriate crops for the rotation cycle can lower soil fertility, reduce productivity, and increase pest and disease risks. Incorrect crop choices may also cause financial losses for farmers.

#### References

1. Boincean, B., & Dent, D. (2019). *Crop rotation*. In Farming the black earth: Sustainable and climate-smart management of chernozem soils (pp. 89-124). Cham: Springer International Publishing.
2. Shah, K. K., Modi, B., Pandey, H. P., Subedi, A., Aryal, G., Pandey, M., & Shrestha, J. (2021). Diversified crop rotation: An approach for sustainable agriculture production. *Advances in Agriculture*, 2021(1), 8924087.
3. Tariq, M., Ali, H., Hussain, N., Nasim, W., Mubeen, M., Ahmad, S., & Hasanuzzaman, M. (2019). Fundamentals of crop rotation in agronomic management. In *Agronomic Crops: Volume 1: Production Technologies* (pp. 545–559). Singapore: Springer Singapore.

4. Selim, M. (2019). A review of advantages, disadvantages and challenges of crop rotations. *Egyptian Journal of Agronomy*, 41(1), 1–10.
5. Al-Musawi, Z. K., Vona, V., & Kulmány, I. M. (2025). Utilizing different crop rotation systems for agricultural and environmental sustainability: A review. *Agronomy*, 15(8), 1966.
6. Rudell, E. C., Zanrosso, B. A., Frandaloso, D., Giacomini, A. J., Spadotto, D. V., Vargas, L., & Santos, F. M. (2023). Integrated weed management strategies in a long-term crop rotation system. *Advances in Weed Science*, 41, e020220053.
7. Tanveer, A., Ikram, R. M., & Ali, H. H. (2019). Crop rotation: Principles and practices. In *Agronomic Crops: Volume 2: Management Practices* (pp. 1–12). Singapore: Springer Singapore.



## When Technology Meets the Field: The Power of ChatGPT in Modern Agriculture



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### What Is ChatGPT and Why It Matters in Agriculture?

ChatGPT is an advanced AI language model developed by OpenAI that can understand questions and generate human-like responses, making it a powerful new tool in modern agriculture. By processing large amounts of weather, soil and crop data, ChatGPT supports precision farming by helping farmers decide when to plant, irrigate, fertilize or harvest. It can also predict yields, detect early signs of pests and diseases and recommend timely interventions that improve both efficiency and sustainability. Farmers benefit from personalized guidance on nutrient management, water conservation and crop protection advice that is simple, clear and available anytime. Research from different countries even shows that AI-supported decisions can increase crop yields by up to 0.87 metric tons per hectare and reduce water use by 230 cubic meters per hectare, demonstrating its real-world impact. With multilingual support and the ability to integrate with sensors and farm tools, ChatGPT empowers even smallholder farmers in areas such as Northern India to adopt data-driven and climate-resilient practices. By improving access to reliable information, promoting the use of modern technologies and simplifying complex knowledge, ChatGPT strengthens decision-making and contributes to smarter, more sustainable and more resilient farming systems.



### AI (ChatGPT): A New Smart Partner for Farmers

AI is emerging as a dependable partner for farmers because it provides clear and timely guidance that supports everyday farming decisions. Tools such as ChatGPT allow farmers to ask questions and receive instant, easy-to-understand explanations about crop care, soil management, weather changes, pest and disease symptoms, and the correct use of fertilizers and other inputs. This immediate access to information helps farmers avoid delays that often occur when they must wait for field visits or expert consultations. AI also analyses available data to alert farmers about upcoming weather conditions, possible pest outbreaks and changes in market prices. These insights help farmers plan their activities with greater confidence and reduce the risks associated with climate uncertainty and market fluctuations. In addition to general information, ChatGPT can offer recommendations that are tailored to the farmer's specific crop, location and field conditions. Such personalized advice supports better decisions on irrigation, nutrient management and crop protection, which ultimately leads to improved productivity and more sustainable resource use. By providing practical solutions, reliable forecasts and simple explanations, AI gives farmers that support they need to manage their fields more effectively and to adopt modern, data-driven farming practices that strengthen both resilience and profitability.

### AI (ChatGPT): A New Smart Partner for Extension Personnel

AI has become an important support system for extension personnel because it helps them work more efficiently and reach farming communities with greater impact. Tools such as ChatGPT assist extension officers in preparing training materials, developing advisories, drafting reports and explaining scientific concepts in simple and farmer-friendly language. This saves considerable time and allows officers to focus more on field-level engagement. AI also provides quick access to updated research findings, information on government schemes and examples of successful farming practices which helps extension personnel offer accurate and relevant guidance. In addition,

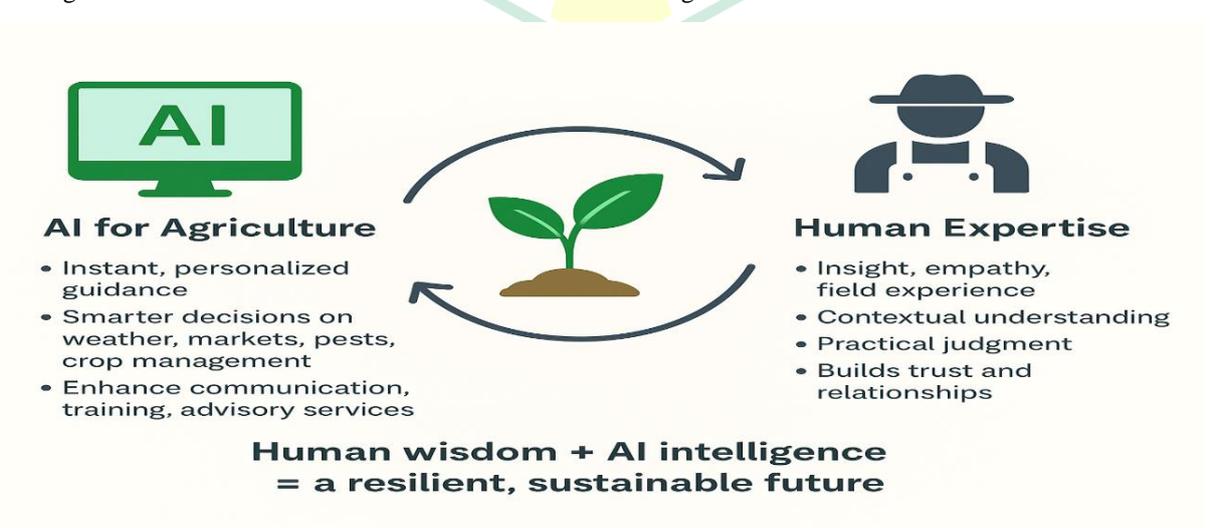
AI contributes to capacity building by helping officers design digital training programs, create engaging demonstrations and stay informed about the latest agricultural technologies and agronomic recommendations. It also supports them in addressing complex issues related to pests, weather, soil health and crop management by offering evidence-based solutions tailored to local conditions. Through better communication, improved knowledge dissemination and enhanced advisory quality, AI empowers extension personnel to deliver more effective services and strengthen the resilience of farming communities in the digital age.

**The Irreplaceable Role of Human Expertise in Farming**

Although AI tools such as ChatGPT provide quick information and timely support, they cannot replace the depth of human experience, understanding and personal connection that agriculture truly requires. Farmers often face complex challenges that depend on local conditions, cultural practices and emotional factors and these situations demand on-ground observation and practical judgment that only human extension personnel can provide. AI systems may sometimes offer incomplete responses, misinterpret local dialects or fail to recognize community norms and socio-economic realities. They also lack the ability to visit fields, observe problems firsthand or build trust through personal interaction. In many rural areas, limited internet connectivity, low digital literacy and restricted access to smartphones create additional barriers to the full use of AI. These limitations make it clear that human expertise remains essential for accurate decision-making, field verification and relationship-building. Human extension agents also play a crucial role in interpreting AI-generated information, adapting it to local needs and providing empathetic guidance that encourages farmers to adopt new practices. As a result, the future of agricultural development depends on a balanced approach where AI enhances advisory services while human extension workers continue to lead with their wisdom, contextual understanding, and personal engagement.

**The Future of Agriculture: When Humans and AI Work Together**

The future of agriculture depends on a thoughtful collaboration between human expertise and artificial intelligence, rather than a choice between the two. AI tools such as ChatGPT offer speed, constant availability and the ability to analyze large volumes of data which supports precision agriculture and timely decision-making. At the same time, farmers and extension personnel bring practical field experience, cultural understanding and the ability to interpret situations that require empathy and nuanced judgment. When these strengths are combined, they create a powerful partnership that can transform farming systems. Human experts can interpret AI-generated insights, adapt them to the specific conditions of each farm or community and guide farmers through complex decisions in a way that builds trust and confidence. Meanwhile, AI can monitor real-time conditions, identify risks, provide early warnings and simplify technical information so that it is easier for farmers to use. This integrated approach ensures that digital agriculture remains innovative while still being centered on people and their lived experiences. By blending the analytical abilities of AI with the practical wisdom and adaptability of human professionals, the agricultural sector can move toward smarter decisions, better resource management, stronger resilience and more sustainable livelihoods for farming communities.



## Conclusion

The integration of artificial intelligence tools, such as ChatGPT into agriculture represents a major transformation in the way knowledge is accessed, shared and applied in everyday farming practices. These tools provide farmers with instant and personalized guidance which helping them make smarter decisions regarding weather conditions, market trends, pest management and crop care. AI has thus become a valuable partner for farmers that supporting them in improving productivity and managing risks more effectively. At the same time, these technologies enhance the work of extension personnel by strengthening communication, facilitating training and improving the quality of advisory services. Despite the many advantages of AI, it cannot replace the insight, empathy and practical experience that human experts bring to agriculture. The true future of farming lies in a collaborative model in which human wisdom and artificial intelligence complement each other. By combining the speed and analytical capabilities of AI with the contextual understanding and judgment of humans, agriculture can move toward a more informed, resilient and sustainable future which ensuring that innovation and traditional expertise work together to strengthen farming communities.



## From Fields to Experiences: Agro-Tourism as a Game-Changing Entrepreneurial Opportunity for Small and Marginal Farmers



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Agro-tourism has emerged as a promising avenue for income diversification, rural entrepreneurship, and sustainable development among small and marginal farmers. By integrating tourism with agriculture, farmers can offer immersive experiences such as farm stays, hands-on participation in farming activities, traditional cooking, cultural demonstrations, and sale of farm products. This approach not only enhances household income but also reduces economic vulnerability caused by fluctuating agricultural yields and market uncertainties. Government support through training, financial assistance, policy frameworks, and promotional initiatives is crucial to address these challenges. By transforming traditional farming into an experiential and entrepreneurial venture, agro-tourism strengthens farmers' social recognition, builds resilient livelihoods, and bridges the gap between agriculture and society. This paper highlights the multifaceted benefits, challenges, and strategies for scaling agro-tourism as a sustainable rural enterprise.

**Key words:** Agro-tourism, Environmental awareness Rural Entrepreneurship. Small and Marginal Farmers.

### **Introduction:**

Agriculture has always been the backbone of rural livelihoods, yet small and marginal farmers continue to face mounting challenges—declining landholdings, rising input costs, uncertain markets, and climate-related risks. For many farmers, agriculture alone no longer guarantees a stable income. In this changing scenario, agro-tourism has emerged as a powerful alternative that blends agriculture with entrepreneurship, offering farmers a new pathway to economic security.

Agro-tourism transforms farms into destinations where visitors can experience rural life, participate in farming activities, enjoy traditional food, and reconnect with nature. For small and marginal farmers, agro-tourism is not just an additional income source—it is an opportunity to redefine farming as an experience-based enterprise.

### **Understanding Agro-Tourism: More Than Just Farm Visits**

Agro-tourism refers to tourism activities conducted on working farms where agriculture remains the primary occupation. Unlike conventional tourism, agro-tourism focuses on authenticity, education, and interaction. Visitors are drawn not by luxury, but by simplicity—green fields, fresh air, traditional lifestyles, and hands-on farm experiences.

Common agro-tourism activities offer visitors an immersive experience of rural life and farming practices. These include farm stays in traditional rural homes, where tourists enjoy local hospitality and simple living, hands-on participation in agricultural operations such as sowing, harvesting, and milking, and traditional cooking and food tasting that showcase indigenous cuisines.

Recreational activities like bullock cart rides and rural games provide cultural entertainment, while nature walks and bird watching allow visitors to connect with the natural farm environment. In addition, the direct sale of fresh produce and farm-based products enables tourists to purchase healthy, locally produced items while supporting farmers' incomes.

For small farmers, agro-tourism leverages what they already have—land, crops, culture, and knowledge—making it a low-cost, high-potential entrepreneurial venture.

### **Why Agro-Tourism Suits Small and Marginal Farmers**

Small and marginal farmers often operate under resource constraints. Agro-tourism fits their context perfectly for several reasons:

#### **Low Initial Investment**

Unlike large agribusiness ventures, agro-tourism does not demand heavy capital. Existing farmhouses, cattle sheds, open fields, and traditional tools can be creatively used to host tourists.

### **Use of Family Labour**

Agro-tourism relies heavily on family participation. Women, elders, and youth all find meaningful roles, reducing dependence on hired labour.

### **Income Beyond Seasons**

Agriculture is seasonal, but tourism can generate income throughout the year, especially during weekends, holidays, and festival seasons.

### **Value Addition Without Land Expansion**

Instead of expanding land area, farmers can increase income by adding value through experiences, hospitality, and direct sales.

### **Income Diversification: Strengthening Financial Resilience**

One of the greatest advantages of agro-tourism is income diversification, as it enables farmers to generate revenue from multiple sources beyond conventional crop sales. Farmers can earn through entry fees for farm visits, accommodation charges for farm stays, and the sale of home-cooked traditional meals.

Additional income is derived from the direct sale of fruits, vegetables, honey, dairy products, and handicrafts, which adds value to farm produce. Moreover, educational tours for schools and colleges create a steady demand while promoting agricultural awareness, making agro-tourism a reliable and sustainable income-supporting enterprise for farmers.

This diversified income reduces farmers' vulnerability to crop failure, price crashes, and climate shocks. Even during poor agricultural seasons, agro-tourism can act as a financial cushion.

### **Agro-Tourism as Rural Entrepreneurship**

Agro-tourism transforms farmers into entrepreneurs rather than mere producers by encouraging direct engagement with visitors and markets. Through agro-tourism activities, farmers interact directly with consumers, gain firsthand feedback, and build trust-based relationships.

They actively market their products and services, focus on customer satisfaction, and continuously innovate farm-based experiences to attract and retain visitors. This entrepreneurial shift enhances farmers' business skills, confidence, and income opportunities while strengthening the connection between agriculture and society.

Through this process, farmers acquire entrepreneurial skills such as communication, planning, branding, and financial management. Over time, many agro-tourism farmers develop strong personal brands rooted in trust, authenticity, and quality.

### **Empowering Women Through Agro-Tourism**

Agro-tourism opens significant opportunities for rural women, who often remain under-recognized in conventional agriculture.

Women play a pivotal role in agro-tourism by contributing their skills and knowledge across various activities. They are actively involved in preparing traditional meals, managing farm stays and maintaining cleanliness, and demonstrating local cultural practices for visitors.

In addition, women engage in the production and sale of value-added products, such as homemade foods and handicrafts, turning traditional household activities into income-generating opportunities and strengthening their economic and social empowerment.

Their skills, which were earlier unpaid or invisible, become income-generating assets. Agro-tourism thus enhances women's economic independence, decision-making power, and social status within the household and community.

### **Attracting Rural Youth Back to Agriculture**

Rural youth often migrate to cities due to limited opportunities in traditional agriculture; however, agro-tourism provides them with a compelling reason to stay, innovate, and engage locally. Young people play a crucial role by managing social media platforms and online bookings, serving as farm guides, and designing creative and engaging tourist experiences.

They also handle digital payments and promotional activities, bringing technological skills and modern marketing approaches into agro-tourism enterprises, thereby strengthening farm entrepreneurship and rural livelihoods.

Agro-tourism aligns well with the aspirations of educated rural youth who seek creativity, technology, and entrepreneurship rather than traditional farming alone.

### **Preserving Rural Culture and Traditions**

Agro-tourism plays a crucial role in cultural conservation. Traditional farming methods, folk arts, local cuisines, festivals, and crafts find renewed value when showcased to visitors.

As tourists show growing interest in rural life and traditions, farmers develop a renewed sense of pride in their cultural heritage, which leads to the revival of indigenous farming practices, preservation of local recipes and traditional seeds, and the continuation of folk arts and customs. In this way, agro-tourism goes beyond income generation and plays a vital role in safeguarding rural identity, knowledge systems, and cultural continuity for future generations.

### **Environmental Awareness and Sustainable Practices**

Agro-tourism promotes environmental consciousness among both farmers and visitors by showcasing sustainable and eco-friendly agricultural practices. Many agro-tourism farms emphasize organic and natural farming methods, efficient water conservation practices, and biodiversity-friendly cropping systems.

By observing and participating in these practices, visitors gain awareness of environmental stewardship, while farmers are encouraged to adopt and promote sustainable approaches that support long-term ecological balance.

Visitors, especially urban children, gain firsthand understanding of food production and environmental stewardship. This educational dimension strengthens public support for sustainable agriculture.

### **Challenges in Agro-Tourism Development**

Despite its significant potential, agro-tourism faces several challenges that hinder its widespread adoption and growth. A major constraint is the lack of awareness, as many farmers are unfamiliar with agro-tourism concepts or remain uncertain about their feasibility. Infrastructure limitations, including poor road connectivity, inadequate sanitation, and insufficient accommodation facilities, further restrict tourist inflow.

In addition, marketing constraints arise from limited access to effective promotional platforms and digital tools among small farmers. Regulatory and licensing issues, such as unclear policies, permissions, and safety requirements, also discourage participation.

Addressing these challenges through targeted support and policy interventions is essential for scaling up agro-tourism in a sustainable manner.

### **Role of Government and Institutions**

Government support plays a crucial role in promoting agro-tourism among small and marginal farmers by creating an enabling environment for adoption and growth. Key interventions include training and capacity-building programmes to enhance farmers' entrepreneurial and hospitality skills, along with financial assistance and subsidies to support infrastructure development.

In addition, clear guidelines and policy frameworks help simplify regulatory processes, while promotion through tourism departments increases visibility and tourist outreach. Together, these measures strengthen agro-tourism as a sustainable rural enterprise.

Agricultural universities, extension agencies, and Farmer Producer Organizations (FPOs) can provide technical guidance, market linkages, and collective branding.

### **Successful Agro-Tourism Models in India**

States like Maharashtra, Karnataka, Tamil Nadu, and Kerala have shown promising agro-tourism initiatives. Farmers offering authentic experiences, cleanliness, and warm hospitality have built successful ventures with repeat visitors.

These examples prove that scale is not a limitation—commitment, creativity, and consistency matter more.

### **Agro-Tourism and the Future of Small Farming**

Agro-tourism represents a fundamental shift in perspective—from farming as mere survival to farming as a meaningful opportunity. It enables small and marginal farmers to reduce economic risk, enhance social recognition, and build resilient livelihoods by diversifying income sources.

At the same time, agro-tourism helps connect agriculture with society by fostering direct interaction between farmers and consumers, thereby strengthening appreciation for farming, rural culture, and sustainable food systems.

As consumer demand for authentic, sustainable, and experiential tourism grows, agro-tourism is poised to become a key pillar of rural entrepreneurship.

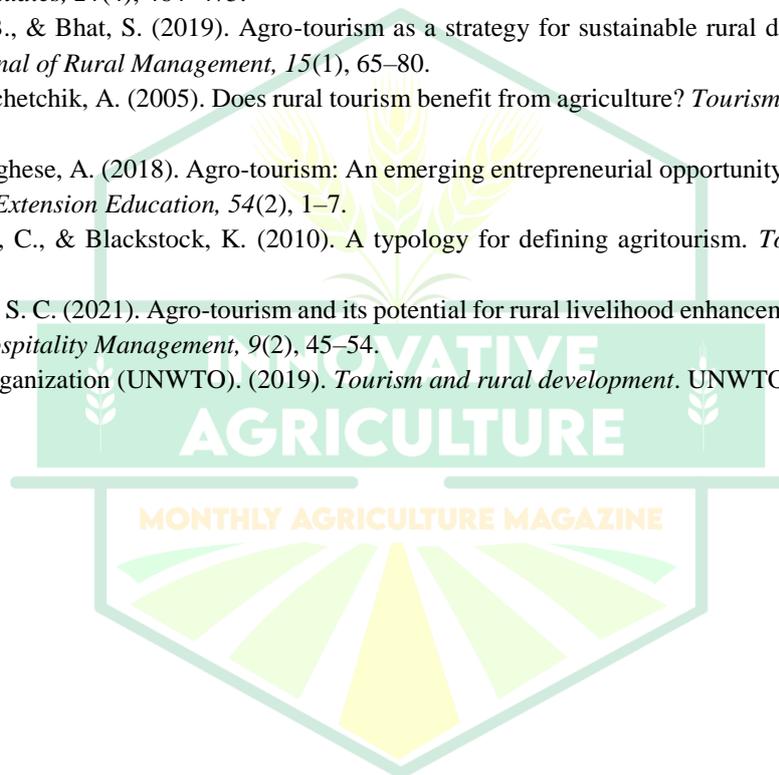
**Conclusion: Cultivating Experiences, Not Just Crops**

Agro-tourism offers small and marginal farmers a chance to look beyond traditional boundaries and reimagine their farms as living classrooms, cultural hubs, and entrepreneurial spaces. By opening their fields to visitors, farmers open new doors for income, dignity, and sustainability.

With the right support, awareness, and innovation, agro-tourism can transform rural landscapes—where farms do not merely produce crops, but cultivate experiences, stories, and sustainable futures.

**References**

- Barbieri, C., & Mshenga, P. M. (2008). The role of agritourism in diversifying farm income and rural economies. *Journal of Rural Studies*, 24(4), 464–475.
- Chandrashekara, B., & Bhat, S. (2019). Agro-tourism as a strategy for sustainable rural development in India. *International Journal of Rural Management*, 15(1), 65–80.
- Fleischer, A., & Tchetchik, A. (2005). Does rural tourism benefit from agriculture? *Tourism Management*, 26(4), 493–501.
- George, H., & Varghese, A. (2018). Agro-tourism: An emerging entrepreneurial opportunity for farmers in India. *Indian Journal of Extension Education*, 54(2), 1–7.
- Phillip, S., Hunter, C., & Blackstock, K. (2010). A typology for defining agritourism. *Tourism Management*, 31(6), 754–758.
- Singh, S., & Bagri, S. C. (2021). Agro-tourism and its potential for rural livelihood enhancement in India. *Journal of Tourism and Hospitality Management*, 9(2), 45–54.
- World Tourism Organization (UNWTO). (2019). *Tourism and rural development*. UNWTO.



## From Spores to Startups: Emerging Opportunities in Mushroom Cultivation



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**Key words:** Startup, vegetable meat, post-harvest losses and semi-urban markets.

Mushroom cultivation is fast emerging as one of the most promising agri-based startup opportunities in India and across the world. With increasing demand for nutritious food, limited land availability, and a growing interest in sustainable farming, mushrooms offer a unique solution. What was once considered a small-scale household activity is now transforming into a profitable and innovative startup venture.

### Need of Mushrooms

Mushrooms are often called the “vegetable meat” because of their high protein content, essential amino acids, vitamins, and minerals. They are low in fat, cholesterol-free, and rich in antioxidants. With growing awareness about healthy diets, vegan food, and functional foods, consumer demand for mushrooms such as button, oyster, milky, and shiitake has increased significantly in urban and semi-urban markets.

### Low Investment, High Potential

One of the biggest advantages of mushroom cultivation is its low initial investment. Unlike conventional crops, mushrooms do not require fertile land or large open fields. They can be grown indoors using unused spaces such as sheds, rooms, or even small backyard structures. Raw materials like paddy straw, wheat straw, sugarcane bagasse, or sawdust are easily available and inexpensive. This makes mushroom farming ideal for startups, rural youth, women entrepreneurs, and small farmers.

### Year-Round Employment

With simple environmental control, mushrooms can be grown throughout the year. This provides continuous employment and income, particularly during the agricultural off-season when rural women have fewer work opportunities.

### High Market Demand and Quick Returns

Mushrooms have a growing market due to their nutritional and medicinal value. Short production cycles (20–30 days) ensure quick returns, making the enterprise attractive and economically viable for rural women.

### Opportunities for Group Enterprises

Mushroom cultivation can be successfully adopted by women self-help groups (SHGs), cooperatives, and farmer producer organizations. Collective production and marketing help reduce risks and improve bargaining power.

### Fast Returns and Year-Round Production

Mushroom cultivation offers quick returns, with some varieties ready for harvest within 20–30 days. Multiple cropping cycles can be taken in a year, ensuring regular income. With controlled environmental conditions, mushrooms can be grown throughout the year, independent of seasonal changes. This stability makes mushroom cultivation an attractive business option compared to traditional agriculture.

### Scope for Innovation and Value Addition

Modern mushroom startups are going beyond fresh produce. There is immense scope for value-added products such as dried mushrooms, mushroom powder, pickles, soups, sauces, chips, and nutraceuticals. Packaging, branding, and online marketing have opened new avenues for entrepreneurs to reach wider markets. Some startups are also exploring eco-friendly products like mushroom-based bio-packaging and compost from spent mushroom substrate.

### Employment and Women Empowerment

Mushroom cultivation is labor-intensive but not physically demanding, making it suitable for women, elderly farmers, and self-help groups. It provides opportunities for self-employment and rural entrepreneurship,

contributing to income generation and livelihood security. Many successful mushroom enterprises have emerged from women-led groups and small collectives.

### **Environmental Sustainability**

Mushroom farming is an environmentally friendly enterprise. It converts agricultural waste into nutritious food and the leftover substrate can be reused as organic manure or cattle feed. This circular approach supports sustainable agriculture and reduces environmental pollution.

### **Economic Feasibility and Profitability Studies**

Many researchers have analyzed the cost–benefit aspects of mushroom cultivation. Findings consistently show that mushroom farming:

- Requires low initial investment
  - Provides quick returns due to short crop cycles
  - Offers high benefit–cost ratios compared to traditional crops
- such studies confirm mushroom cultivation as a viable enterprise for small and marginal farmers.

### **Challenges and Way Forward**

Despite its potential, mushroom cultivation faces challenges such as lack of technical knowledge, post-harvest losses, and market linkages. Proper training, scientific practices, quality spawn, and cold chain facilities are essential for success. Support from agricultural universities, extension agencies, and startups incubators, and government schemes can play a crucial role in promoting mushroom-based enterprises.

### **Conclusion**

From spores to startups, mushroom cultivation offers a viable pathway for aspiring agripreneurs. With minimal investment, quick returns, and vast scope for innovation, it stands out as a sustainable and profitable venture. By adopting scientific methods and entrepreneurial thinking, mushroom farming can contribute significantly to income generation, employment creation, and nutritional security in the years to come.



## PM Dhan-Dhaanya Krishi Yojana (PMDDKY)



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Every year the government comes up with a Budget; a written plan that comes with hopes and aspirations for different sections of the society. It comes up with a blueprint for strengthening economy. It reflects hopes and aspirations wherein national goals, social needs and our vision gets translated into financial allocations with the ultimate aim of empowering all sections of society. An important section of our society is the farming community which is engaged in agriculture sector that is backbone of our economy. This sector has a share of 17-18% in the country's Gross Domestic Product (GDP) and is a source of livelihood for about 50% of the population residing mostly in rural areas. Around 55-65% of India's workforce is engaged in agriculture and various allied activities related to agriculture. According to a report of National Statistical Office NSO entitled Situation Assessment of Agricultural Households 2018-19, the country has 93.09 million agricultural households. Some projections also suggest closer to 40 million full time farmers by 2025. Almost every budget emphasizes agriculture as the foremost engine of India's Development. The allocation to the agriculture sector matters a lot for the farming community of the country. Every year besides the financial allocation, the government also comes up with various new programmes and policies for strengthening the sector.

Agriculture has been receiving a renewed thrust for last decade as is evident from the various government legislations, policies and programmes. The Doubling Farmers' Income programme aimed at doubling the income of farmers' by 2022 was a flagship initiative of the government in a mission mode. Similarly PMKISAN programme aims at financial support of rupees 6,000 for the farming community thrice in a year in installments of 2,000 each. PM Kisan Sinchai Yojana, e-NAM, Soil Health Cards (SHCs), National Mission on Natural Farming (NMNF), PM Matsya Sampada Yojana, Agricultural Infrastructure Fund, PM Fasal Bima Yojana, Kisan Credit Card (KCC) are some of the many schemes of the Ministry of Agriculture & Farmers' Welfare for the welfare of farming community.

**PRIMEMINISTER DHAN-DHAANYA KRISHI YOJANA (PMDDKY):** Despite an abundance of farm related schemes and when benefits of these schemes have already percolated down to the grassroots level; agricultural development across different regions in the country has been uneven. Certain regions in the country have lacked behind in different agricultural growth parameters as compared to other. Many districts, particularly in Uttar Pradesh (Purvanchal, Bundelkhand), Bihar (Seemanchal) and Madhya Pradesh (tribal areas) produce lower yields due to degraded soil, outdated farming methods or lack of desired irrigation infrastructure. For instance, average rice yield in certain districts falling under Seemanchal region of Bihar is 1.8 tonnes / hectare compared to the national 2.7 tonnes. Union Finance Minister Ms. Nirmala Sitharaman in her 2025-26 budget announced a comprehensive development programme for 100 districts of the country which are underperforming in terms of parameters like crop yields, cropping intensity and credit penetration. The new scheme called as Pradhan Mantri Dhan-Dhaanya Krishi Yojana (PMDDKY) was announced on February 1, 2025, during the Union Budget 2025-26 by Finance Minister and approved by the Union Cabinet on July 16, 2025, PMDDKY targets 100 underperforming districts where farming faces challenges like low crop yields, water scarcity, and limited access to resources. PMDDKY has an annual budget of ₹24,000 crore for six years (2025-26 to 2030-31), totaling ₹1.44 lakh crore and it aims to support 1.7 crore farmers, particularly small and marginal farmers owning less than 2 hectares of land, who constitute 86% of India's farming population

The Yojana has consolidated 36 existing agricultural schemes across 11 ministries, including PM-KISAN, PMFBY, PMKSY, and Rashtriya Krishi Vikas Yojana (RKVY), into a unified program to streamline efforts and maximize impact. The Yojana owes its origin from the Aspirational Districts Programme (ADP) of NITI Aayog which transformed 112 underdeveloped districts in health, education, and infrastructure, PMDDKY focuses on regions with low crop yields, cropping intensity below 155% and limited access to credit. By providing

irrigation, storage, loans, training, and modern technology support, PMDDKY seeks to boost farmer incomes, ensure food security and advance *Atmanirbhar Bharat* i. e self-reliant India. The scheme operates under the Ministry of Agriculture and Farmers' Welfare, with oversight from a National Steering Committee, state-level nodal committees, and District Dhan Dhaanya Samitis led by District Collectors. These bodies ensure tailored implementation based on local needs, monitored through a digital dashboard tracking 117 Key Performance Indicators (KPIs) like crop yields, loan disbursements, and storage usage. PMDDKY is ready to launch in October 2025 for the Rabi season, with applications opening in September 2025.

PMDDKY aims to address these challenges by providing high quality inputs and affordable tools, creating modern irrigation infrastructure, strengthening post harvest infrastructure to reduce food losses, ensure easy and timely availability of credit to farming community, promotion of sustainable agricultural practices, diversification through Integrated Farming System (IFS) approach and support to youth for entrepreneurship in agriculture and allied sectors. The ultimate aim is to increase crop yields by 20-30%, through high-quality inputs and technology, reduce dependence on monsoons with advanced irrigation systems like drip and sprinkler, increase mechanization, cut post-harvest losses to under 5%, offer direct market access to double farmer incomes by 2030 and promotion of sustainable practices. Under PMDDKY, there is provision of village and block-level warehouses and cold storages to prevent spoilage of perishables like fruits, vegetables and dairy products. Financial support in the form of subsidies (50-80% off inputs) and loans (short-term: ₹50,000–₹1 lakh; long-term: ₹1–10 lakh) through Kisan Credit Cards or NABARD, market access through digital platforms like e-NAM and new PMDDKY apps to connect farmers directly to buyers and reducing middlemen, support for 10,000 women producer groups with training, loans, and market linkages for activities like dairy or organic farming and global exposure with a fully funded international training for 500 farmers in countries like Israel (expertise in drip irrigation), Japan (precision farming), or the Netherlands (greenhouse technology).

By addressing these challenges, PMDDKY will lead to increase in profits of the farming community by 30-40%, strengthen rural economies, reduce poverty and make farming a viable and attractive profession. KVKs and SAUs will again play a leading role in the implementation of this programme.

**JK UT UNDER PMDDKY:** Of the different states and UTs, Uttarpradesh leads with 12 districts, Maharashtra (09) Madhya Pradesh and Rajasthan (08 each), Bihar (07), Andhra Pradesh, Gujarat, Odisha, Tamilnadu, Telangana and West Bengal (04 each), Assam Chattisgarh and Kerala (03 each), J&K, Jharkhand and Uttarakhand (02 each) and 01 district each in other states. From the Union Territory of Jammu and Kashmir, District Baramulla and Kishtwar have been included in the list of 100 aspirational agriculture districts under the Yojana. The department of Agriculture and Farmers' Welfare in the districts have already been told by the respective district collector to submit plans by including interventions and innovations in agriculture and allied sectors related to climate resilience, area expansion under different crops, cultivation of niche crops, natural resources management, processing and value addition, marketing, mobilization of farming communities especially farm women and youth through SHGs, FPOs and towards entrepreneurship. These should bring tangible benefits for the farming community. Union Agriculture Minister Shivraj Singh Chouhan has described it as a cornerstone for creating a 'poverty-free India' by empowering rural communities through sustainable agriculture.

## Biofortification of Crops: A Sustainable Solution to Nutritional Deficiencies



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Biofortification has emerged as a promising strategy to combat global malnutrition and hidden hunger. It involves the development of crop varieties with enhanced levels of essential nutrients through traditional breeding, genetic modification, or agronomic practices. This innovative approach aims to improve the nutritional quality of staple foods, making them more nutritious from farm to fork.

### What is Biofortification?

Biofortification is the process of increasing the nutrient content of crops during plant growth. Unlike fortification, which adds nutrients during food processing, biofortification occurs naturally within the plant's biology. The goal is to produce crops that naturally contain higher levels of vitamins, minerals, or other beneficial compounds.

### Important of Biofortification

**Addressing Nutritional Deficiencies:** Millions of people worldwide suffer from deficiencies in vital nutrients such as iron, zinc, vitamin A, and iodine. Biofortified crops can help fill these nutritional gaps.

**Cost-Effective and Sustainable:** Once developed, biofortified crops do not require additional costs for consumers. They can be cultivated just like regular crops, ensuring sustainable nutrition.

**Reaching Rural and Poor Populations:** Often, vulnerable populations have limited access to dietary diversity. Biofortified crops are an effective way to improve nutrition in regions where dietary sources of essential nutrients are scarce.

### Biofortified Crops

**Golden Rice:** Enriched with beta-carotene (a precursor of vitamin A), designed to combat vitamin A deficiency.



**Iron-rich Pearl Millet:** Helps prevent anemia, especially in women and children.



**Zinc-enriched Wheat:** Supports immune function and growth.



### **Challenges and Future Prospects**

While biofortification offers many benefits, challenges include regulatory approvals, public acceptance, and ensuring that nutrient levels remain stable during storage and cooking. Ongoing research and awareness campaigns are vital to maximize its impact.

### **Conclusion**

Biofortification is a powerful, sustainable approach to improve global nutrition. By integrating science and agriculture, it provides a practical solution to malnutrition, especially in developing countries. As research advances, biofortified crops are poised to play a crucial role in building a healthier, hunger-free world.



## Biochar: Black Carbon, Bright Future



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### Abstract

A charcoal-like substance that is made up of burnt organic material from agricultural and forestry wastes by a controlled process (pyrolysis) is called Biochar. Although it is similar in appearance to common charcoal, but differs in the production process. It is formed when wood chips, leaf litter, or dead plants are burned in a container at a temperature of 300-500 °C with low oxygen. It is a black, highly porous, lightweight, fine-grained, cleaner material with a large surface area that is more efficient in converting carbon into a stable form. It has approximately 70 % carbon in its composition, plus some amounts of nitrogen, hydrogen and oxygen. This article attempts to brief about the production technology, benefits associated with biochar, along with the linked challenges, with the goal of tackling them and increasing environmental sustainability without harming crop production.

### Biochar: A Game-Changer for Farmers

Usage of biochar in soil would increase its fertility, water holding capacity, thereby boosting crop yield (15-25%) and reducing the release of greenhouse gases. The earlier evidence of biochar as a soil amendment was the "Terra Preta", which is also known as "Indian Black Earth" (a type of soil, initially found in Western Amazonia). It is a dark-coloured earth, has high stability due to a higher amount of carbon, along with high nutrient content that increases the soil biota.

Moreover, the soil application of biochar significantly enhances the soil integrity by providing a growing medium for the plants.

### Biochar Production Technologies

Some institutions have developed low-cost technologies to produce biochar (also known as "black gold") under the condition that the H: C molar ratio of the final product should be less than 0.7. The techniques involved are-

#### 1) Heaping and Charring

This low-cost traditional method of biochar production uses readily available material, is more prevalent in Tamil Nadu. In this method, firstly, small logs, twigs, and woody crop residue are used as a biomass, which is heaped (3-4 ft high) at one place. It is followed by the covering of the entire pile by a mud paste to stop the flow of oxygen. Later on, vents/holes are created in the mud covering (from top to bottom) as a smoke vent, which also permits some air to enter. At last, the heap is put on fire from one end, and left to smoke for a certain number of days. In this way, biomass is transformed into char in the presence of less oxygen.

Though this method is viable for small-scale farmers with respect to investment, but has limited control over the temperature and charring time, which causes production of inferior biochar.

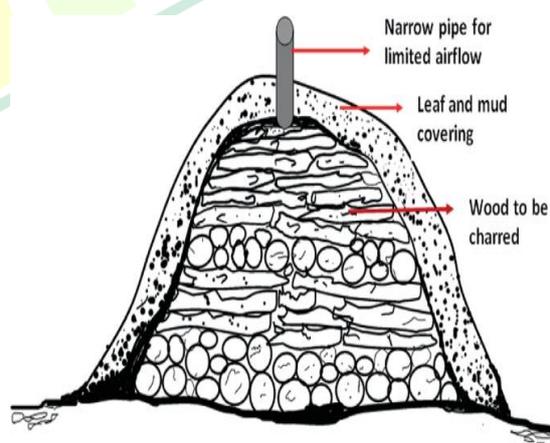


Fig 1: Heaping and charring process

## 2) Thang-Bun Method

Yet another indigenous and traditional ancient method of crop production in jhum lands is the Thang Bun Method. This concept makes use of jhum land, wherein the already available dried plant biomass on land is heaped at a 0.8-1.2 m width and 4-7 m length. It is then coated with a soil layer to make it like a raised bed. At last, the biomass is burnt in low-oxygen conditions to process it into biochar through the carbonization process. This black gold is then added to the raised beds for cultivating crops in the first year of jhum land preparation. This method is more common in Meghalaya ethnic tribal communities, who gave it the name “Thang Bun”.



**Fig 2: In situ biochar preparation cum thang bun method**

### Biochar Production in India

Biochar Production is a recently emerged concept in India; therefore, only a few groups have been associated with its production and application. Two NGOs, namely ARTI (Appropriate Rural Technology Institute) and Janadhar, in collaboration with RaGa LLC, are dealing with biochar production at the village level by making use of sustainable resources like organic solid wastes, waste biomass and bagasse. They primarily use a locally manufactured kiln for biochar production. Moreover, the creation of biochar from the charring kiln also enables the production of compact and uniform briquettes.



**Fig 3: Charring kiln made from an oil drum**

### Advantages of Using Biochar

In addition to being used as a soil conditioner, there are many other properties of biochar by which it can be utilised for other purposes too. Some important applications are given below:

- 1) Helps to improve soil fertility by enhancing its nutrient availability.
- 2) Soil salinity can be reduced by optimisation of the ion exchange capacity.
- 3) Application of Biochar helps in the establishment of soil microbes, thereby strengthening soil health.
- 4) Shows a positive influence on the yield (approximately 10 %) and productivity of the crops.
- 5) A 3-5% application of biochar prevents the occurrence of pests and diseases in the crop field. It also inhibits the growth of weeds in agricultural fields, thereby augmenting crop productivity.
- 6) Due to the stability in the carbon content of biochar, it aids in storing carbon in the soil, thereby boosting carbon sequestration (that would otherwise be composted away in mineral creation) and decreasing greenhouse gas emissions.
- 7) Through the application of biochar, greenhouse gas emissions can be alleviated by 12 %. The combination of biochar and compost improves the decomposing capability of soil via increased stable carbon content.

### Associated Challenges

Although biochar application provides many benefits yet there are still some issues related to it that persist. Since biochar is made up of a wide range of raw materials with different physical and chemical properties, the obtained biochar would show different properties. Hence, the biomass materials should be analysed first, so as to select the one with high carbon content. Furthermore, the production process through which biochar is formed is a little bit complex in nature, as it easily gets influenced by factors like the pyrolysis process, temperature and time regulation, which eventually affect the properties of the produced biochar.

Concerning environmental impact, the long-term stability of biochar is not easy to evaluate due to the paucity of long-term field trials and environmental monitoring. The high production cost is yet another hurdle that limits the large-scale application and promotion of biochar, which should be overcome by designing low-cost production technologies.

### Effect of Biochar on Crops

Incorporating biochar in the vegetable garden's soil increases the stress resistance of vegetables, which includes tolerance to salinity and drought (Akhtar *et al.*, 2014; Usman *et al.*, 2016). Biochar has high porosity, a large specific surface area and a robust cation exchange capacity; therefore, it absorbs Na<sup>+</sup> ions effectively from the soil, and reduces ion toxicity. With regard to the proline level accumulation (which increases under drought and salt stress conditions), the application of 3 % biochar in tomato plants revealed the highest relative leaf water content and decreased proline levels.

Similarly, a significant increase in cauliflower yield has been observed with the application of biochar at 2 t/ha, along with mineral fertiliser, which yields higher curd yield (43.23 t/ha) due to its ability to increase N availability to plants. The height of the radish plant was also found to increase on loamy sandy soil with the incorporation of biochar (Timilsina *et al.*, 2020).

### Conclusion

The easy availability and affordable nature of biochar make it an emerging practical alternative remediation agent for various harmful environmental agents. This carbon-rich compound plays a very important role in improving soil conditions and, hence, crop productivity. Also, it is manufactured from low-cost raw materials obtained from agro-industrial residues, making it cost-effective and farmer-friendly. India generates approximately 500 to 683 million tonnes (MT) of crop waste every year, which, when burned, adversely impacts the environment. The production of biochar from this waste offers a promising opportunity for rural employment, livelihood diversification and ultimately sustainable development. The government, along with agri-tech platforms, should conduct pilot programs and research collaborations to support biochar implementation to balance productivity and long-term resilience. As a result, this transformation of waste into wealth has the potential to bring a revolution in the entire farm ecosystem.

### References

- Allohverdi, T., Mohanty, A. K., Roy, P. and Misra, M. (2021). A Review on Current Status of Biochar Uses in Agriculture. *Molecules*. 26(18): 5584.
- Hombegowda, H.C., Kakhar, P., Madegowda, M. and Marwein, Y. (2021). Thang Bun: Indigenous Practice of In Situ Biochar Preparation-cum-application for Improved Jhum Cultivation in North East India. *Current Science*. 120 (7) :1160.
- Timilsima, S., Khanal, A., Vista, S.P. and Poon, T.B. (2020). Effect Of Biochar Application In Combination With Different Nutrient Sources on Cauliflower Production At Kaski, Nepal. 21: 82-89.
- Wang, Y. (2025). Applications, potential, and challenges of biochar in carbon sequestration. *Highlights in Science, Engineering and Technology*. 125. 23-27.

## From Wild to Wonderful: Unlocking the Value of Ber



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Ber (*Ziziphus mauritiana* L.), commonly known as Indian jujube, is an important dryland fruit crop belonging to the family Rhamnaceae. It is cultivated widely across the arid and semi-arid regions of India, China, Pakistan, Thailand, and parts of Africa due to its exceptional adaptability to harsh climatic conditions. The tree thrives under extreme temperatures (up to 48–50°C), low rainfall (300–500 mm), saline-alkaline soils, and marginal lands, making it a reliable fruit crop for resource-poor regions. India is one of the largest producers of ber, with major growing states including Rajasthan, Gujarat, Haryana, Punjab, Madhya Pradesh, and Uttar Pradesh. Ber fruits are highly nutritious and contain substantial amounts of sugars (10–18%), vitamin C (70–165 mg/100 g), phenolic compounds, minerals (calcium, iron, phosphorus), dietary fibre, and antioxidants. The fruit is consumed fresh at ripe or semi-ripe stages and is also used in traditional Ayurvedic and ethnomedicinal preparations. Despite its high nutritional and medicinal value, ber remains underutilized compared to other tropical fruits. One of the major constraints is its short post-harvest life, typically 3–5 days at ambient temperature, which leads to significant quantitative and qualitative losses during peak harvesting periods. Value addition and processing offer a promising solution to overcome these limitations. Ber is highly suitable for producing a wide range of shelf-stable products due to its favourable physicochemical composition such as high total soluble solids, sufficient natural pectin, desirable acidity, and an attractive flavour profile. It can be processed into dehydrated products (such as ber candy and chuhara), beverages (RTS drinks, squash, nectar), preserves (jam, jelly, murabba), fermented items (wine, vinegar), confectioneries, powders, and nutraceutical formulations. These value-added products not only increase shelf life from a few days to several months but also help stabilize market prices, reduce wastage, promote entrepreneurship, and enhance farmer incomes by two to three times. In recent years, increasing consumer demand for healthy, natural, minimally processed foods has further expanded the scope of ber-based products in both domestic and international markets. Research institutions such as ICAR-CAZRI, ICAR-CIAH, state agricultural universities, and food technology departments are continuously developing improved technologies for ber processing, drying, packaging, and product development. Promotion of value addition in ber also aligns with national priorities such as doubling farmers' income, strengthening rural agro-industries, and diversifying horticultural production systems in arid regions.

Therefore, value addition in Ber is not only a post-harvest management strategy but a holistic approach to improving economic viability, reducing losses, enhancing nutritional availability, and sustaining the cultivation of this climate-resilient fruit crop. This makes Ber processing a highly relevant and impactful area of research, development, and extension in India and other Ber-growing countries.

### Nutritional Attributes of Ber

Ber is a highly nutritious fruit valued for its rich composition of sugars, vitamins, minerals, fibre, and bioactive compounds. The fruit contains 10–20% carbohydrates, predominantly glucose and fructose, which contribute to its sweetness and energy value. It is exceptionally rich in vitamin C, ranging from 70–165 mg/100 g, making it a strong natural antioxidant source, while significant amounts of pro-vitamin A, B-complex vitamins, and minerals such as potassium, calcium, iron and phosphorus enhance its dietary importance. Ber also contains 2–4% dietary fibre that aids digestion and supports gut health. In addition, the fruit is abundant in phenolic compounds, flavonoids, and triterpenoids, which possess strong antioxidant, anti-inflammatory, and therapeutic properties. Its moderate acidity, high pectin content, and balanced sugar–acid ratio not only enhance its nutritional value but also make ber highly suitable for processing into various value-added products

### Processing Attributes of Ber

Ber possesses several favourable processing attributes that make it an excellent raw material for the development of a wide range of value-added products. The fruit contains high total soluble solids (14–22°Brix) and a balanced sugar–acid ratio, which impart natural sweetness and enhance flavour in products such as candy, preserves, and beverages. Its moderate acidity (0.25–0.45% citric acid) improves microbial stability, gel formation, and sensory quality during jam and jelly preparation. Ber also has adequate pectin content (0.5–1.8%), enabling the formation

of stable gels without the need for commercial pectin's, making it suitable for jams, jellies, fruit bars, and marmalades. The firm texture and structural integrity of the fruit allow it to withstand blanching, osmotic dehydration, and drying without disintegration, which is ideal for preparing dehydrated slices, candy, and chhuhara-type products. Different maturity stages of ber can be processed into a variety of products—unripe fruits for pickle and murabba, mature fruits for candy and dehydration, and ripe fruits for beverages, powders, and fermented products—ensuring minimal wastage. Additionally, its natural colour, flavour retention, low fat content, and good drying behaviour further enhance product quality and shelf life.

### Major Value-Added Products of Ber

Ber is a highly versatile fruit that can be processed into a wide range of value-added products due to its favourable composition, firm texture, and attractive flavour profile.

#### 1. Ber Candy / Glazed Ber

Ber candy, also known as glazed ber, is one of the most commercially important value-added products prepared through osmotic dehydration. Mature but firm fruits are blanched and then soaked in progressively increasing concentrations of sugar syrup (40–70°Brix), allowing sugar to replace moisture while retaining the fruit's shape, colour and texture. After syrup infusion, the fruits are drained and dried to obtain a soft, chewy, sweet product with excellent shelf life of 6–8 months. The high sugar content acts as a natural preservative and enhances flavour, making ber candy highly acceptable among consumers of all age groups. It provides an efficient way to utilize surplus seasonal produce while adding significant economic value for processors and farmers.

#### 2. Dehydrated Ber

Dehydrated ber, locally known as *chhuhara*, is a traditional sun-dried or mechanically dried product made from fully ripe fruits. The dehydration process reduces moisture from 70–80% to below 15%, concentrating sugars and enhancing sweetness naturally. The dried fruits have a chewy texture, longer shelf life, and improved storability, making them suitable for transport over long distances. Dehydrated ber is used widely in confectioneries, school snacks, indigenous medicines, and herbal preparations due to its nutrient-dense composition rich in vitamin C, minerals and antioxidants. This simple, low-cost value addition method is particularly important in arid regions where fresh fruits are highly perishable.

#### 3. Ber Powder

Ber powder is produced by drying ripe fruits through cabinet drying, freeze-drying or spray drying, followed by grinding into a fine, free-flowing powder. It retains most of the fruit's natural nutrients, bioactive compounds, and flavour, making it an excellent ingredient for instant beverages, health mixes, nutraceutical formulations, bakery products, and confectionery items. The low moisture content ensures long shelf life while preventing microbial spoilage. Freeze-dried ber powder, in particular, has high antioxidant retention and superior sensory quality. This product is becoming increasingly popular due to its convenience, versatility, and ability to incorporate ber's nutritional benefits into various food systems.

#### 4. Ber Jam and Jelly

Ber is well suited for the preparation of jam and jelly because of its moderate acidity, high sugar content, and naturally present pectin, which aids in gel formation. During processing, ripe ber fruits are pulped and cooked with sugar and acid until the desired consistency is achieved. Jam contains fruit pulp, while jelly is made from clarified fruit extract, resulting in a glossy, transparent product. Both products are highly palatable and can be stored for many months due to reduced water activity. Their vibrant colour, pleasant flavour, and spreadable texture contribute to strong consumer acceptance. Ber jam and jelly offer a profitable avenue for small-scale food entrepreneurs.

#### 5. Ber Pickle and Chutney

Ber pickle and chutney utilize immature or semi-ripe fruits, which possess a firm texture and tangy flavour ideal for spiced preparations. The fruits are cleaned, pricked, and mixed with salt, spices, oil, or vinegar depending on the recipe. Spiced ber pickle has strong ethnic and regional demand, particularly in North and Western India. Chutneys prepared with ber, jaggery, and spices offer a sweet-sour flavour and are used as condiments. These products have extended shelf life due to the preservative effect of salt, oil, and natural acids. Pickles and chutneys

provide excellent options to utilize lower-grade fruits while enhancing farmers' income through household-level processing.

### **6. Ber Squash, RTS Beverages and Nectar**

Ber is increasingly used for the preparation of beverages such as squash, ready-to-serve (RTS) drinks, and nectar owing to its refreshing flavour, attractive colour, and high vitamin C content. Squash is a concentrated syrup containing fruit juice, sugar, and acid, which is diluted before consumption. RTS beverages typically contain 10–15% fruit juice and 10–14°Brix TSS, while nectar contains about 20% pulp, offering a thicker, more natural mouthfeel. Pasteurization ensures shelf stability for several months. These beverages are not only nutritious but also highly acceptable among consumers due to their balance of sweetness and acidity. They provide a highly profitable, scalable opportunity for small-scale industries and FPOs.

### **7. Ber Preserve and Murabba**

Ber preserve and murabba are traditional value-added products made from mature, firm fruits cooked in sugar syrup to enhance shelf life, flavour, and texture. In murabba, the fruits are slowly simmered in graded sugar solutions until they become translucent, tender, and richly sweet, making it a popular delicacy with digestive and tonic properties. Ber preserve involves retaining the fruit's shape and natural flavour while providing a glossy, syrup-coated finish ideal for long-term storage. Both products are widely appreciated for their taste, nutritional value, and cultural significance in Indian households.

### **8. Nutraceutical and Medicinal Products**

Ber is increasingly recognized for its high nutraceutical value, owing to its rich content of vitamin C, polyphenols, flavonoids, triterpenoids, and dietary fibre. These bioactive compounds contribute to strong antioxidant, anti-inflammatory, hepatoprotective, and immunomodulatory properties, making ber-based nutraceuticals highly beneficial for health. Products such as ber extract capsules, ber seed oil, dried ber powder, and functional beverages are used to support digestion, improve immunity, regulate blood sugar, and reduce oxidative stress. Due to its medicinal properties documented in Ayurveda and modern research, ber is becoming popular in the development of herbal supplements and natural health products.

### **Value Addition as a Tool for Income Generation**

Value addition in ber provides a significant opportunity to enhance farmers' income while reducing post-harvest losses. Fresh ber is highly perishable and often suffers 20–25% losses during peak harvesting, but processing it into products such as candy, powder, jam, jelly, squash, murabba, or nutraceutical items increases its market value by 3–10 times. For example, 1 kg of fresh fruit selling at ₹20–50 can generate ₹250–600 when converted into processed products like candy or powder. Small-scale processing units, household-level production, and FPO-based initiatives create employment opportunities in rural areas, stimulate entrepreneurship, and ensure better price stability for growers. Moreover, processed ber products have wider market reach, including urban and export markets, making value addition an effective strategy for economic empowerment, sustainable production, and diversification of income sources for farmers in arid and semi-arid regions.

### **Challenges in Ber Value Addition**

- Lack of organized processing units in rural areas
- Limited cold storage facilities
- Inadequate awareness among farmers
- Perishability leads to rapid spoilage before processing
- Market linkage gaps
- Standardized processing protocols need wider adoption

### **Strategies to Strengthen Ber Processing Sector**

- Promotion of FPO-based micro-processing units
- Training through KVKs, ICAR institutions and state horticulture departments
- Use of solar dryers to reduce energy costs
- Branding and GI tagging of regional products
- Development of export-oriented dehydrated ber items
- Public-private partnerships for processing clusters

### Conclusion

Value addition in ber presents enormous potential to reduce post-harvest losses, enhance farmers' profit, promote entrepreneurship and meet growing consumer demand for healthy, natural fruit-based foods. Standardizing product formulations, improving processing technologies, and establishing market linkages can transform ber from a traditional arid fruit into a commercially significant commodity. With increasing demand for nutritious, functional foods, ber-based value-added products can play a vital role in the food processing sector of India and other developing countries.



## Sustainable Livelihood Security through Integrated Farming Systems in India



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### Introduction

Agriculture in India is more than just a source of food—it is the foundation of rural livelihoods. However, farmers today face multiple challenges: shrinking landholdings, climate variability, rising input costs, and environmental degradation. These challenges call for a holistic approach that enhances income, ensures food security, and protects the environment. The Integrated Farming System (IFS) offers exactly that—a pathway to achieve sustainable livelihood security by integrating diverse enterprises and optimizing on-farm resources.

### Integrated Farming System: A Multi-Dimensional Approach

The IFS model blends crops, livestock, fisheries, horticulture, beekeeping, and agroforestry into a single, interdependent system. Each enterprise complements the other—wastes from one become inputs for another, minimizing external costs and maximizing efficiency.

According to ICAR (2023), integrated farms recorded up to 35–50% higher net returns compared to monocropping systems. By combining income generation, employment creation, food and nutritional security, and ecological balance, IFS becomes a comprehensive model of livelihood resilience.

### Economic and Employment Security

For small and marginal farmers, economic stability is a constant struggle. IFS provides multiple income streams across seasons. For example, a farmer combining paddy with fishery and duck rearing can generate steady earnings throughout the year.

Studies from Kerala and Odisha (2022–2024) show that IFS farmers earned 30–45% higher annual income and created 20–25% more on-farm employment compared to non-IFS farmers. Women's participation in IFS—especially in dairy, poultry, and value addition—has further strengthened household-level income security.

### Environmental and Resource Sustainability

Sustainability lies at the heart of IFS. Integration of crop residues, animal waste, and organic matter helps improve soil fertility and water-use efficiency. Composting, biogas production, and vermiculture ensure resource recycling and reduced greenhouse gas emissions.

FAO (2024) highlights that diversified systems can reduce carbon footprints by nearly 20%, while increasing soil organic carbon and biodiversity. In Maharashtra and Tamil Nadu, adoption of solar-powered irrigation and biogas-based energy systems within IFS models has significantly lowered energy costs and improved ecological balance.

### Food and Nutritional Security

IFS also directly addresses food and nutrition challenges in rural India. A single integrated farm can supply cereals, pulses, vegetables, milk, eggs, and fruits for the household—reducing market dependency and improving dietary diversity.

A NITI Aayog (2025) policy brief emphasizes IFS as a cornerstone for achieving Sustainable Development Goals (SDGs) related to zero hunger, poverty reduction, and responsible resource use. By linking income, employment, and food access, IFS ensures true livelihood security.

### Policy and Institutional Support

Government programs such as National Mission for Sustainable Agriculture (NMSA), Rashtriya Krishi Vikas Yojana (RKVY), and Farmer FIRST Programme (FFP) actively promote IFS models across India. ICAR institutes and Krishi Vigyan Kendras (KVKs) are conducting on-farm demonstrations and farmer training to scale up successful models.

Moreover, NABARD supports integrated farm units through its Farm Sector Promotion Fund (FSPF) and Livelihood Enterprise Development Programme (LEDP), focusing on resource recycling, micro-enterprise development, and women empowerment.

### **Success Stories from the Field**

Across India, IFS success stories are emerging:

- In Kerala, smallholders practicing rice–fish–duck systems increased income by 40% and reduced fertilizer use.
- In Punjab, integration of dairy with horticulture and solar energy improved profitability and environmental performance.
- In Madhya Pradesh, vegetable–poultry–vermicompost models under the Farmer FIRST Programme significantly enhanced farm income and employment.

### **Challenges and Future Prospects**

While the potential is immense, challenges remain—limited awareness, inadequate credit, and fragmented extension services often hinder widespread adoption. Strengthening capacity building, ensuring market linkages, and promoting cluster-based IFS models can make the system more scalable.

Public-private partnerships, policy convergence, and digital extension tools can accelerate the spread of IFS technologies to every smallholder's field.

### **Conclusion**

Sustainable livelihood security requires a balance of income, employment, food security, and ecological sustainability. IFS offers a time-tested and climate-resilient pathway to achieve this balance. As India moves towards Vision 2047, the adoption of IFS will be key to building a self-reliant and prosperous rural economy—where every farmer not only survives but thrives sustainably.

### **Reference**

- Billah, M., Sharma, P., & Kumar, R. (2024). Integrated farming systems and sustainable livelihood: Evidence from farmer field studies. *Indian Journal of Extension Education*, 60(4), 45–53.
- FAO. (2024). Climate-smart agriculture and carbon neutrality: Diversification for resilience. Food and Agriculture Organization.
- ICAR. (2023). Impact of integrated farming systems on farm income and resource sustainability. Indian Council of Agricultural Research.
- ICAR–KVK. (2022). Farmer FIRST Programme: IFS-driven agricultural transformation and livelihood enhancement. Krishi Vigyan Kendras, ICAR.
- Meena, M., & Choudhary, K. (2021). Constraints and extension strategies for scaling integrated farming systems in India. *Journal of Agricultural Extension Management*, 22(1), 101–110.
- NABARD. (2023). Livelihood Enterprise Development Programme (LEDP): Micro-enterprise development through integrated farming. National Bank for Agriculture and Rural Development.
- NITI Aayog. (2025). IFS and sustainable development goals: Roadmap for rural livelihood security. Government of India.
- Patel, R., Singh, S., & Yadav, H. (2023). Economic and employment security of smallholders under integrated farming models in central India. *Journal of Community Mobilization and Sustainable Development*, 18(2), 125–134.
- Saxena, A., & Gupta, L. (2020). Productivity and profitability of crop–livestock–vermicompost models for small and marginal farmers. *International Journal of Agricultural Sciences*, 10(1), 88–95.
- Sharma, R., & Reddy, V. (2022). Soil fertility and natural resource conservation through integrated farming practices. *Journal of Agroecology and Resource Sustainability*, 7(3), 71–80.

## Improving Profitability and Productivity of Jute Cultivation in Eastern India



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### Introduction:

Jute (*Corchorus spp.* L.) belongs to the family Malvaceae and has a chromosome number of  $2n = 14$  (*C. capsularis*) and  $2n = 12$  (*C. olitorius*). It is considered one of the cheapest and most important natural fibres in the world, next only to cotton. In South East Asia, India and Bangladesh are the major jute growing countries, where fibre is extracted from two cultivated species, viz., tossa jute or mitha pat (*C. olitorius*) and white jute or titta pat (*C. capsularis*).

Jute, often known as the “Golden Fibre”, remains a major cash crop in eastern India, providing profitable livelihood opportunities for millions of small and marginal farmers across states like West Bengal, Bihar, Assam and Odisha. The climate and soils of this region are highly suitable for jute cultivation and recent advancements in production technologies along with increasing market demand have enhanced its economic importance. Jute and jute-based industries play a pivotal role in the economy of India and Bangladesh in terms of employment generation, foreign exchange earnings, and supporting the livelihoods of vulnerable farming communities. Besides these two nations, China contributes a marginal share to the world’s jute production along with Thailand, Pakistan, Nepal and Bhutan.

A major share of India’s jute production comes from West Bengal, which alone contributes approximately 74.70% of the national area and 81.60% of the national production, helping fulfill the requirements of jute based industries predominantly located within the state. Overall, jute is cultivated in about 7.9 lakh hectares in India with a production of around 102.85 lakh bales.

Although jute is mainly known for its versatile fibre, every part of the plant has unique economic value with low carbon footprint and high ecological sustainability. As the world focuses more on eco-friendly and bio-degradable materials, jute is regaining its importance. The fibre is primarily used for producing 100% food grade gunny bags, household décor and fabrics, shopping and hand bags, floor coverings, geotextiles, composites and various reinforcement materials.

### Economic Benefits and Profitability of jute in India:

- **Significant income source:** Jute cultivation provides a stable and profitable livelihood option for farmers. With domestic raw jute prices reaching record highs in recent years, jute farming has become highly remunerative. Government initiatives such as “**Jute-ICARE**” have successfully enhanced farmers’ income by approximately **₹10,000 per hectare** through improved yield and fibre quality.
- **Low investment, high return:** Jute requires comparatively **lower input costs** than many other cash crops, while offering **high economic returns**, making it a viable option for small and marginal farmers.
- **Employment generation:** The jute sector plays a crucial role in the socio economic structure of Eastern India. It provides **direct employment to about 0.37 million workers** and supports the livelihood of around **4.0 million farm families**. Additionally, a large number of people are engaged in **trade, processing, transportation, and marketing** of jute.
- **Support to allied industries and exports:** Jute acts as a major raw material source for diverse value-added industries, producing **gunny bags, ropes, home decor items, fabrics, shopping bags, floor coverings,**

geotextiles, composites and packaging materials, thereby boosting industrial growth and export earnings.

- **Cash crop with additional non-price benefits:** Beyond fibre, **jute leaves** serve as a nutritious leafy vegetable in many regions, while **jute sticks** are used as fuel and **organic manure**, contributing to **additional income** and sustainable farming practices.
- **Improved soil health and crop rotation benefits:** Jute can be effectively integrated into **rice based cropping systems** in eastern India. It improves soil fertility, **increases soil organic carbon**, enhances **aeration**, and improves soil structure, which positively influences the growth and yield of subsequent crops such as rice. The crop also helps maintain a healthier **C:N ratio** in the soil.

#### Suitability and advantages of jute cultivation in India:

- **Climate match:** Jute thrives in a **warm and humid climate** with an optimal temperature range of **24-25 °C** and **high rainfall** during the growth period. These climatic conditions are naturally prevalent across **West Bengal, Assam, Bihar, Odisha**, and parts of the **North-eastern states**, making the region ideal for jute cultivation.
- **Soil suitability:** Jute grows best in **alluvial and loamy soils** rich in organic matter, with good drainage. It performs well in **slightly acidic to neutral soils**, which are commonly found in the major jute growing belts of India.
- **Short crop cycle:** Jute has a relatively **short duration (110-120 days)** from sowing to harvest, depending on the variety and management practices. This ensures **quick crop turnover**, enabling farmers to fit jute efficiently into multiple cropping systems.
- **Low input and labour intensive:** Jute require **modest input costs** compared to many other cash crops. At the same time, it is **labour intensive**, providing ample **seasonal employment opportunities** in rural areas during land preparation, sowing/transplanting, weeding, harvesting, retting and bundling operations.
- **Market demand and value addition:** There is a strong and growing market demand in India for **natural and biodegradable fibres**, particularly for **sacking materials, geotextiles, composite materials, and handicrafts**. Local level value addition through **retting, fibre processing, and small scale weaving** enhances income opportunities for farmers and rural communities.

#### Constraints and challenges in Jute cultivation:

- **Yield variability:** Under **rainfed conditions**, jute yields are highly dependent on **soil fertility, seed quality** and **retting practices**. Traditional cultivation methods often result in yields **significantly lower** than the potential achievable through improved management.
- **Market price risk:** Fluctuations in raw jute prices may threaten farm income. When market prices **fall below the minimum support price (MSP)** or procurement is weak, farmers are forced to sell at lower rates. For example, in some regions farmers received only **₹4000-4400 per quintal** despite a higher MSP.
- **Cost escalation:** Increasing **labour charges** and **input costs** reduce profit margins. Hence, **mechanization**, adoption of **improved varieties** and best management practices are necessary to minimize costs and increase efficiency.
- **Procurement and marketing issues:** Even with good yields, lack of **procurement centres**, poor **market linkages** and dependence on local traders limit farmers' bargaining power, often compelling them to sell at **distress prices**.
- **Competition and substitutes:** The presence of **synthetic fibres** and **plastic packaging materials** in the market restricts the expansion of jute demand. Any shifts in industrial preference or government policy may affect jute pricing and trade.
- **Labour availability and retting constraints:** Retting is a **labour and water intensive** operation. Seasonal labour shortages and limited water bodies pose serious challenges to fibre extraction and quality, especially in regions affected by **water scarcity** or **climate variability**.

### Best management practices for enhancing profitability in jute cultivation:

- **Selection of good quality seed and varieties:** Use **certified seeds** of high yielding **tossa or white jute varieties** recommended for the specific agro-climatic zone to ensure better productivity and fibre quality.
- **Timely sowing:** Sow jute seeds **during March-April**, immediately after the harvest of winter crops. Ensure proper **land preparation** with 2-3 ploughings and a well-prepared seedbed for uniform germination.
- **Optimal crop management:** Maintain adequate **soil fertility**, adopt effective **weed management** and ensure **timely harvesting (110-120 days)** to avoid deterioration in fibre quality and maximize yield.
- **Improved retting techniques:** Retting is a crucial step in determining fibre quality. Adoption of **improved retting technologies** (e.g., CRIJAF-saviour, ribbon retting) reduces labour, saves water, and enhances fibre colour, strength, and commercial value.
- **Utilization of government schemes and MSP:** Farmers should take advantage of initiatives like **Jute-ICARE** and ensure linkage to **minimum support price (MSP)** and other procurement systems to secure fair returns.
- **Value addition and diversification:** Apart from fibre sale, explore income opportunities through **jute sticks, small scale fibre processing, and production of value added jute products** to improve overall profitability.
- **Strengthened market linkages:** Organizing farmer groups, using local procurement centres, and connecting with cooperatives or industries can prevent **distress sales** and help achieve better market prices.
- **Crop rotation and soil health improvement:** Incorporate jute into **rice based cropping systems** to maintain **soil fertility**, enhance **soil organic matter**, and reduce pest and disease risks, promoting long term sustainability.

### Conclusion:

Jute remains an essential crop in India, sustaining the rural economy of eastern states and providing an eco-friendly substitute for synthetic materials. Owing to its biodegradability and low environmental footprint, jute contributes significantly to India's pathway toward sustainable development. Although the sector faces constraints such as climate dependency and competition from synthetic alternatives, its future prospects are strong. Continued government support, increasing market demand for green products and technological advancements in cultivation and fibre processing are collectively enhancing the crop's relevance and profitability. By strengthening sustainable practices, fostering innovation, and improving policy interventions, India's jute industry has immense potential to meet rising domestic requirements while also expanding its presence in the global market.

# Pollinator Decline and the Expanding Role of Pollinator-Friendly Landscaping: A Critical Review and Emerging Perspectives



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## Abstract

Pollinators—including bees, butterflies, moths, and other insects—play a crucial role in global ecosystems and agricultural productivity. Recent decades have witnessed alarming declines in pollinator abundance, diversity, and distribution. These declines are driven by a suite of interacting factors, including habitat loss, pesticide exposure, climate change, and landscape fragmentation. This article reviews the evidence for pollinator decline, assesses the rationale and principles of pollinator-friendly landscaping, evaluates global and regional initiatives, and discusses challenges and future directions for research and policy.

## 1. Introduction

Pollination services provided by animals remain foundational to both wild ecosystems and agricultural systems. A significant proportion of flowering plants rely on pollinators for reproduction, and many of the crops grown for human consumption depend on these services (Potts et al., as cited in global reviews). However, in recent years, mounting empirical and modeling evidence has flagged a steep decline in pollinator populations worldwide (Goulson et al., as reviewed in global decline studies; see also Sadafale et al., 2025).

In response, the concept of **pollinator-friendly landscaping**, the intentional design and management of green spaces to support pollinator forage, nesting, and movement has gained attraction among ecologists, urban planners, and policy-makers. This article synthesizes current research on the drivers of pollinator decline, evaluates landscaping-based mitigation strategies, and proposes a framework for advancing this approach within a scientific and policy context.

## 2. Drivers of Pollinator Decline

The decline in pollinator populations is not attributable to a single cause but arises from an interplay of several stressors:

### 2.1 Habitat Loss and Fragmentation

Habitat loss through agricultural intensification and urban expansion remains central to pollinator decline. Fragmentation reduces availability of floral resources, nesting substrates, and connectivity between habitat patches (Cornell CALS, 2025). The loss of wildflower-rich meadows and hedgerows, replaced by monocultures or paved surfaces, has constrained pollinator movement and reproduction (Cornell CALS, 2025).

### 2.2 Pesticide Exposure

The pervasive use of insecticides, herbicides, and fungicides poses both lethal and sub-lethal risks to pollinators. Neonicotinoids and other systemic insecticides accumulate in pollen and nectar, reducing foraging efficiency and immunity (Cornell CALS, 2025). Theoretical and empirical modeling also indicates that high levels of pesticide application can trigger critical transitions in plant–pollinator networks, potentially leading to irreversible collapses (Chattopadhyay & Samadder, 2023).

### 2.3 Climate Change

Rising temperatures, increased drought frequency, and altered precipitation regimes interfere with phenological synchrony between pollinators and floral resources (USGS, 2023; Brunet & Frago, as reported in science reviews). In particular, warming may push certain pollinator species beyond their thermal tolerance, reducing population viability (Datta, Dubey, Gouhier, Ganguly, & Bhatia, 2025).

### 2.4 Pathogens, Invasive Species, and Pollution

Disease and pathogen pressures (e.g., viruses, mites) exacerbate pollinator decline. In addition, the introduction

of invasive species, both floral and faunal can disrupt native plant–pollinator networks. Pollution, including air pollutants and light pollution, further impairs pollinator foraging behavior (Brunet & Fragoso, as reviewed in climate threat studies).

### 2.5 Synergistic and Feedback Effects

These drivers do not act in isolation. For example, pesticide exposure may weaken pollinator immune systems, making them more vulnerable to pathogens; habitat fragmentation can amplify temperature stress; and local extinctions of pollinators reduce pollination services, leading to vegetation changes that further impair pollinator persistence (Sadafale et al., 2025).

## 3. Ecological and Agricultural Implications

### 3.1 Ecosystem Service Disruption

Pollinators sustain reproductive processes in wild flora, contributing to genetic diversity, ecosystem resilience, and the stability of food webs. Their decline can lead to reduced seed set, altered species composition, and weakened resilience to environmental perturbations (Sadafale et al., 2025; USGS, 2023).

### 3.2 Impact on Crop Production

Many crops including fruits, nuts, oilseeds, and vegetables are heavily dependent on pollinators. Declines in pollinator populations may thereby compromise yield, quality, and economic return, affecting both smallholder and commercial agricultural systems (Sadafale et al., 2025).

### 3.3 Socioeconomic and Food Security Risks

Reduced pollination services have direct economic consequences. A planetary risk index developed by researchers indicates that pollinator losses threaten food security, particularly in regions where agriculture is heavily dependent on animal pollination (University of Cambridge, as summarized in a risk-index report; ScienceDaily, 2021).

## 4. Pollinator-Friendly Landscaping: Rationale and Concept

**Pollinator-friendly landscaping** aims to integrate ecological function into managed green spaces by prioritizing floral diversity, nesting resources, connectivity, and reduced chemical exposure. The practice aligns horticultural aesthetics with conservation objectives. Key motivations include:

1. **Scalability and accessibility:** Landscapes ranging from private gardens to agricultural fields can be modified for pollinator use.
2. **Cost-effectiveness:** Compared to large-scale restoration, pollinator-friendly designs often require modest investment but yield rapid ecological benefits.
3. **Ecological responsiveness:** Pollinators frequently recolonize enhanced habitats within weeks to months, demonstrating swift return when conditions improve.
4. **Co-benefits:** Such landscapes may enhance soil health, sequester carbon, reduce urban heat, and improve human well-being.

## 5. Principles of Pollinator-Friendly Landscape Design

Research and practice converge on a set of design principles that optimize landscapes for pollinator support:

### 5.1 Native Plant Emphasis

Native species are strongly preferred because they co-evolved with local pollinators, offering nutritionally appropriate pollen and nectar. They also tend to be more resilient in local climatic and soil conditions (Butters & Murrell, 2022).

### 5.2 Temporal Bloom Continuity

To sustain pollinators year-round, landscapes must include species that flower across seasons. Early, mid, and late-season bloomers ensure continuous nectar sources.

### 5.3 Habitat Structure and Nesting

Effective pollinator landscapes provide not just blooms, but structural features such as bare ground for ground-nesting bees, deadwood and hollow stems for cavity nests, leaf litter for overwintering insects, and microclimatic diversity (Butters & Murrell, 2022).

### 5.4 Reduced Chemical Inputs

Minimizing synthetic pesticide and fertilizer use is critical. Biological control, organic amendments, and

integrated pest management (IPM) help maintain pollinator-safe conditions.

### 5.5 Water and Microclimate

Water features like shallow basins and sand patches, along with windbreaks or shaded zones, enhance microhabitat suitability for pollinator species.

### 5.6 Connectivity

Connecting floral patches through corridors (hedgerows, roadside plantings, green belts) supports movement, foraging, and genetic exchange among pollinator populations.

## 6. Evidence and Case Studies

### 6.1 Enhanced Border Strips in Agriculture

A two-year empirical study demonstrated that native flowering border crops (e.g., prairie mix, Silphium species) significantly increased pollinator abundance and richness compared to conventional border types (Butters & Murrell, 2022). Bloom duration and floral area strongly correlated with pollinator density.

### 6.2 Garden Enhancements Across Urban Gradients

A recent study evaluated pollinator visitation in 32 gardens across urban, suburban, and rural contexts. Floral enhancements (diverse pollinator plants) increased pollinator visitation, network diversity, and modularity in urban and suburban gardens; they also altered pollinator community composition in suburban and rural gardens (Landscape Ecology, 2025). These findings underscore how landscape context mediates the effectiveness of pollinator-friendly interventions.

### 6.3 Floral Richness and Private Gardens

In Great Britain, research found that increasing floral richness in private gardens drives higher pollinator diversity, independent of surrounding landscape context (Urban Ecosystems, 2025). Interestingly, both native and non-native plants contributed to this richness, though native species may be more critical for specialist pollinators.

## 7. Policy Frameworks and Institutional Efforts

Various policy and institutional interventions support pollinator-friendly landscaping:

- Conservation agencies (e.g., USGS) have identified climate change, pesticide use, and habitat loss as priority threats, integrating pollinator considerations into land management on public reserves (USGS, 2023).
- National and regional pollinator protection strategies increasingly incorporate habitat enhancement, native planting incentives, and pesticide regulation (Sadafale et al., 2025).
- Institutional landscapes (e.g., universities, corporate campuses) are adopting ecological planting schemes, reducing mowing regimes, and establishing pollinator corridors.
- Citizen science and community programs also contribute through monitoring, garden conversion, and public education.

## 8. Challenges and Constraints

While promising, the scaling of pollinator-friendly landscaping faces multiple barriers:

### 8.1 Knowledge and Awareness Gaps

Many stakeholders lack awareness of pollinator needs, or they hold misconceptions (e.g., fear of bees, preference for high-maintenance ornamental lawns).

### 8.2 Limited Access to Native Plant Material

Nurseries often favour showy ornamental species; native pollinator-friendly plants are under-represented, restricting adoption by gardeners and land managers.

### 8.3 Pesticide Reliance

Despite the known risks, many agricultural and urban systems remain heavily dependent on chemical pesticides. Transitioning to low-toxicity alternatives requires training, incentives, and regulatory support.

### 8.4 Fragmented Urban Planning

Urban development often proceeds without ecological connectivity planning, leading to isolated pollinator patches that are less effective at sustaining populations.

### 8.5 Climate Adaptation Uncertainty

Rapid climate change introduces uncertainty into plant–pollinator synchrony. Landscapes designed today may not remain optimally functional under future climate regimes. Emerging research suggests that tropical ecosystems may require more intensive management to buffer thermal stress (Datta et al., 2025).

### 9. Future Research Directions

To enhance the scientific underpinnings and practical implementation of pollinator-friendly landscaping, several research priorities emerge:

1. **Long-term monitoring** of pollinator communities in enhanced landscapes, using standardized protocols across regions.
2. **Optimization of plant–pollinator networks**, identifying which combinations of native species maximize pollinator support under varying ecological contexts.
3. **Adaptive landscape design**, integrating projections from climate models to select plant species resilient to temperature and precipitation shifts (Datta et al., 2025).
4. **Behavioural and social research** on gardener and stakeholder perceptions to accelerate adoption.
5. **Policy evaluation** to assess the effectiveness of incentive mechanisms and regulatory measures in promoting pollinator landscapes.

### 10. Conclusion

The decline of pollinators presents an urgent ecological and socio-economic challenge. Traditional conservation strategies, while necessary, are insufficient in isolation. Pollinator-friendly landscaping offers a scientifically grounded, scalable, and economically viable approach to restoring pollinator habitat across urban, suburban, and agricultural landscapes.

By embracing the principles of native planting, reduced chemical inputs, structural habitat diversity, and connectivity, we can create landscapes that not only support pollinators but also yield co-benefits for ecological resilience, food production, and human well-being. However, overcoming cultural, economic, and institutional barriers will be essential.

Integrating scientific research, public engagement, and policy intervention, pollinator-friendly landscaping holds significant promise as a central pillar of pollinator conservation in the 21st century.

### References

- Butters, J., & Murrell, E. (2022). *Native Flowering Border Crops Attract High Pollinator Abundance and Diversity, Providing Growers the Opportunity to Enhance Pollination Services*. *Environmental Entomology*, 51(2), 492–504. <https://doi.org/10.1093/ee/nvab133> [OUP Academic](#)
- Chattopadhyay, A., & Samadder, A. (2023). *Pesticide Mediated Critical Transition in Plant-Pollinator Networks*. arXiv. <https://arxiv.org/abs/2303.08495> [arXiv](#)
- Cornell CALS. (2025). *Pollinator Conservation*. Cornell University. Retrieved from Cornell CALS website. [Cornell CALS](#)
- Datta, A., Dubey, S., Gouhier, T. C., Ganguly, A. R., & Bhatia, U. (2025). *Warming demands extensive tropical but minimal temperate management in plant-pollinator networks*. arXiv. <https://arxiv.org/abs/2504.19879> [arXiv](#)
- Goulson, D., Nicholls, E., Botías, C., & Rotheray, E. L. (2015). *Global decline of pollinators: Trends, impacts and drivers*. *Trends in Ecology & Evolution*, 30(12), 514–523. <https://doi.org/10.1016/j.tree.2015.07.005> (reviewed in global decline studies) [PubMed](#)
- USGS. (2023). *Pollinator Conservation and Climate*. U.S. Geological Survey Fact Sheet 2023–3026. [U.S. Geological Survey](#)
- Sadafale, G. V. R., Vishnupandi, M., Sami, A., Sudalaiyandi, Y., Subal, B. K., Kamal, P. A., & Shukla, A. (2025). *Global Decline of Pollinators: Drivers, Consequences and Mitigation Strategies*. *Journal of Biology and Nature*, 17(2), 356–379. <https://doi.org/10.56557/joban/2025/v17i29697> [I.K. Press](#)
- USGS. (2023). *Climate change and pesticides imperil a once common pollinator*. U.S. Geological Survey. [USGS](#)
- Landscape Ecology. (2025). *Landscape context mediates the effect of pollinator garden enhancements on pollinator visitation and plant-pollinator interactions*, 40, 116. <https://doi.org/10.1007/s10980-025-02135-8> [SpringerLink](#)
- Urban Ecosystems. (2025). *Supporting pollinators in urban gardens: floral richness and abundance influence flower visitor interactions regardless of the surrounding landscape*. *Urban Ecosystems*. <https://doi.org/10.1007/s11252-025-01848-7> [SpringerLink](#)

## “Lepidoptera Diversity and Conservation in Ecotourism”



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### Abstract

Lepidoptera, comprising butterflies and moths, are among the most charismatic and ecologically significant insect groups, serving as sensitive bioindicators of environmental change. Their aesthetic appeal and close association with habitat quality make them ideal flagship taxa for insect-based ecotourism. For instance, in the Western Himalaya region of India, butterfly gardens and ecotourism trails have successfully engaged local communities in conservation efforts while promoting sustainable livelihoods. By integrating community participation, habitat restoration, butterfly ranching, and citizen science initiatives, Lepidoptera-based ecotourism mitigates anthropogenic pressures on fragile ecosystems and fosters environmental stewardship, even in the face of challenges such as climate change, habitat fragmentation, and deforestation. Ultimately, this conservation-oriented tourism model contributes to pollinator protection, ecological resilience, and sustained public engagement in biodiversity conservation.

### 1. Introduction

Lepidoptera-based ecotourism, often termed entomo-tourism, represents a strategic convergence of environmental stewardship and sustainable development. Lepidopterans function as sensitive bioindicators, with their diversity and population dynamics closely reflecting anthropogenic pressures, microclimatic changes, and habitat integrity (Baral *et al.*, 2025; Bonebrake *et al.*, 2010). Because many species depend on specific host plants and stable environmental conditions, monitoring Lepidoptera assemblages provides a reliable metric for evaluating conservation effectiveness at both local and landscape scales.

Beyond their role as ecological indicators, butterflies and moths provide essential ecosystem services, particularly pollination, which sustains floral diversity and supports agricultural resilience (Arya *et al.*, 2018; Baral *et al.*, 2025). In global biodiversity hotspots, initiatives such as butterfly farming and community-managed conservatories have emerged as high-impact “win-win” models. In these systems, tourism revenue directly supports habitat restoration while providing alternative livelihoods for local communities (Checa *et al.*, 2024). By capitalizing on the charismatic appeal and metamorphic life cycle of Lepidoptera, ecotourism transforms visitors into conservation advocates, effectively bridging the gap between scientific research, public engagement, and long-term biodiversity protection (Arya *et al.*, 2018; Baral *et al.*, 2025).

### 2. History and Evolution of Lepidoptera-Based Ecotourism

The origins of Lepidoptera tourism can be traced back to the 19th century, when naturalists engaged in what is now termed “extractive tourism.” During this period, scientists and collectors traveled extensively to collect, preserve, and catalog exotic butterflies and moths, contributing significantly to taxonomic knowledge and museum collections (Kanaujia *et al.*, 2022). Institutions such as the Royal Entomological Society played a pivotal role in documenting global Lepidoptera diversity, inadvertently identifying regions that later became biodiversity tourism hotspots (Smith & Munroe, 2018). Tourism in this era prioritized specimen collection for scientific and private purposes.

By the mid-20th century, growing conservation awareness prompted an ethical shift from consumptive collection to non-consumptive observation. A landmark example was the discovery of the overwintering sites of the Monarch butterfly (*Danaus plexippus*) in Mexico during the 1970s, which demonstrated that large-scale insect migrations could attract international tourism while supporting conservation initiatives (Urquhart, 1976; Shapiro, 1988). This event firmly established butterflies as flagship species for conservation and environmental education (Lemelin, 2013).

In the late 20th century, butterfly houses, conservatories, and live exhibits gained popularity worldwide. These facilities brought Lepidoptera diversity to urban audiences, providing immersive educational experiences while generating financial support for habitat conservation in tropical regions (Collins, 1987; Bozonet & Hall, 2020). By the 1990s, butterfly gardens, parks, and interpretation centers expanded across Europe, Asia, and the Americas. These sites functioned as educational hubs, integrating biodiversity conservation with tourism and public outreach (Mathew et al., 2011).

Today, Lepidoptera ecotourism has evolved into community-based, conservation-driven models. Practices such as butterfly ranching, habitat restoration, and citizen science programs directly link local livelihoods with biodiversity protection, ensuring that conservation outcomes align with socio-economic development (New et al., 1995; Huntly et al., 2019). These models illustrate the transition from extractive collection to observation-focused, sustainable, and participatory tourism.



**Figure 1.** Timeline of Lepidoptera tourism evolution: From extractive collection to conservation-driven ecotourism.

### 3. Lepidoptera as Bioindicators of Ecosystem Health

Lepidoptera, including butterflies and moths, are sensitive bioindicators due to their short life cycles and dependence on specific host plants and habitats. Changes in their abundance, diversity, or seasonal activity reflect habitat loss, climate change, and human disturbances. Monitoring these insects provides a cost-effective tool for assessing ecosystem health and guiding conservation efforts (Wagner et al., 2021; Sánchez-Bayo & Wyck Huys, 2023).

For example, butterfly surveys in the Western Himalaya, India, have informed forest management and habitat restoration programs (Baral et al., 2025).

**Table 1.** Key Lepidoptera species as ecosystem indicators

Species	Habitat	Indicator Role
<i>Papilio polytes</i>	Tropical/subtropical forests	Sensitive to forest fragmentation
<i>Danaus plexippus</i>	Open fields, milkweed	Reflects pesticide use & habitat connectivity
<i>Eurema hecabe</i>	Grasslands, agricultural edges	Responds to urbanization & land-use change
<i>Troides helena</i>	Lowland & montane forests	Indicates forest quality & canopy health

### 4. Climate Sensitivity

Butterflies and moths are highly sensitive to temperature and seasonal variability, with even minor climatic changes influencing their distribution, phenology, and life cycle dynamics. These rapid and measurable responses make Lepidoptera reliable indicators for monitoring the biological impacts of climate change and habitat alteration across ecosystems (Halsch et al., 2021).

### 5. Pollination Services

Beyond serving as bioindicators, Lepidoptera play a vital role in pollination, supporting both wild plants and crops. Declines in their populations can reduce reproductive success and disrupt ecosystem functioning, with

implications for biodiversity and food security. In ecotourism, observing these interactions helps visitors appreciate the importance of conservation (Artamendi *et al.*, 2025).

## 6. Principles of Lepidoptera-Based Ecotourism and Sustainability

Successful Lepidoptera ecotourism requires integrating ecological conservation, community benefits, and low-impact practices, ensuring that tourism supports biodiversity while providing meaningful visitor experiences (Bricker & Snyman, 2023).

### 6.1 Conservation-Oriented Management

Tourism revenue should be reinvested in habitat protection, restoration, and research, ensuring that ecotourism enhances rather than degrades Lepidoptera habitats (IUCN, 2025).

### 6.2 Low-Impact Practices

Responsible practices such as regulating visitor numbers, following designated trails, and using renewable resources minimize ecological disturbance, carbon emissions, and potential negative impacts like the spread of invasive species or diseases in butterfly houses (Bricker & Snyman, 2023).

### 6.2 Community Empowerment

Local communities should be actively involved through employment, guiding, butterfly farming, and conservation projects. This creates incentives for biodiversity protection while supporting sustainable livelihoods (IUCN, 2025).

**Challenges:** Over-tourism, habitat disturbance, invasive species, and disease outbreaks in captive butterfly facilities remain potential risks, requiring careful monitoring and adaptive management.



**Figure 2.** Schematic of Lepidoptera ecotourism: Interactions between conservation, community benefits, and visitor engagement.

## 7. Socio-Economic Importance and Future Outlook

Uttarakhand, located in the Western Himalaya, is a major hub for nature-based tourism and supports exceptionally rich butterfly and moth diversity across its forest and alpine ecosystems. Lepidoptera-based ecotourism offers a practical conservation response to the documented decline of insect populations in Himalayan landscapes (Dirzo *et al.*, 2014). The visibility and ecological role of butterflies make them ideal flagship taxa for linking biodiversity protection with sustainable mountain livelihoods.

By creating direct economic incentives for habitat conservation, Lepidoptera-focused ecotourism strengthens community participation in conservation initiatives. For instance, butterfly gardens and guided nature trails in forested districts such as Dehradun, Nainital, and Chamoli can attract 5,000-15,000 visitors annually, generating income through entry fees, local guiding, homestays, and native plant nurseries, and supporting 10–20 local jobs. Integrating scientific monitoring, environmental education, and community-based tourism can

enhance pollinator conservation while promoting long-term ecological resilience and livelihood diversification in the Western Himalaya.

## 8. Conclusion

Lepidoptera diversity provides a strong foundation for ecotourism-based conservation by linking biodiversity protection with community livelihoods. As bioindicators, pollinators, and flagship species, butterflies and moths effectively connect science, society, and sustainability. When responsibly managed, Lepidoptera-based ecotourism supports habitat conservation, promotes environmental awareness, and fosters local stewardship. Future research should focus on integrating climate modeling with long-term Lepidoptera monitoring to predict ecosystem responses under global environmental change.

## References

- Biesmeijer, J. C., Roberts, S. P. M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A. P., Potts, S. G., Kleukers, R., Thomas, C. D., Settele, J., & Kunin, W. E. (2006). Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science*, 313(5785), 351-354.
- Bozonet, S., & Hall, C. M. (2020). Insect-based tourism and conservation: A review of emerging practices and challenges. *Tourism Review*, 75(1), 280-295.
- Buckley, R. (2009). *Ecotourism: Principles and Practices*. Wallingford, UK: CABI Publishing.
- Collins, N. M. (1987). The conservation value of butterflies. *Biological Conservation*, 40(1), 1-16.
- Dirzo, R., Young, H. S., Galetti, M., Ceballos, G., Isaac, N. J. B., & Collen, B. (2014). Defaunation in the Anthropocene. *Science*, 345(6195), 401-406.
- Fennell, D. A. (2003). *Ecotourism: An Introduction*. London, UK: Routledge.
- Goulson, D. (2010). Impacts of climate change on Lepidoptera. *Journal of Insect Conservation*, 14(4), 431-440.
- Huntly, B., Redford, K. H., & Adams, W. M. (2019). Biodiversity-based tourism and community livelihoods: Balancing conservation and development. *Conservation Biology*, 33(1), 101-109.
- Kanaujia, A., Kumar, A., & Mishra, R. (2022). Historical perspectives of insect collection and biodiversity documentation in India. *Indian Journal of Entomology*, 84(1), 1-10.
- Lemelin, R. H. (2013). *The Cultural Significance of Insects*. Minneapolis, USA: University of Minnesota Press.
- Mathew, G., Tiple, A. D., & Payra, A. (2011). Butterfly gardens as conservation and education tools in human-dominated landscapes. *Current Science*, 101(12), 1545-1552.
- New, T. R., Pyle, R. M., Thomas, J. A., Thomas, C. D., & Hammond, P. C. (1995). Butterfly conservation management. *Journal of Insect Conservation*, 1(1), 35-43.
- Shapiro, A. M. (1988). The Monarch butterfly phenomenon. *American Scientist*, 76(1), 44-53.
- Smith, C. R., & Munroe, E. (2018). A history of entomological exploration and insect systematics. *Annual Review of Entomology*, 63, 1-17.
- Urquhart, F. A. (1976). Found at last: The Monarch's winter home. *National Geographic*, 150(2), 161-173.
- United Nations World Tourism Organization (UNWTO). (2018). *Tourism and the Sustainable Development Goals – Journey to 2030*. Madrid, Spain: UNWTO.
- Warren, M. S., Hill, J. K., Thomas, J. A., Asher, J., Fox, R., Huntley, B., Roy, D. B., Telfer, M. G., Jeffcoate, S., Harding, P., Jeffcoate, G., Willis, S. G., Greatorex-Davies, J. N., Moss, D., & Thomas, C. D. (2001). Rapid responses of British butterflies to opposing forces of climate change and habitat loss. *Nature*, 414(6859), 65-69.
- Wearing, S., & Neil, J. (2009). *Ecotourism: Impacts, Potentials and Possibilities* (2nd ed.). Oxford, UK: Butterworth-Heinemann.

## “Butterflies on a Mission: How Insects Can Save Forests and Livelihoods”



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### Abstract

Butterflies are key components of Himalayan Forest ecosystems, contributing to pollination, nutrient cycling, and food-web stability. Their reliance on native plants and intact habitats makes them sensitive indicators of forest health. Beyond ecology, butterflies support sustainable livelihoods through conservation, education, and community engagement. Butterfly-focused initiatives in the Indian Himalaya link forest protection with local well-being, highlighting their role as ambassadors for biodiversity conservation and sustainable development.

### 1. Introduction

Butterflies (Lepidoptera) safeguard forest ecosystems and support human livelihoods. Sensitive to climate and habitat change, they act as natural “early warning systems,” reflecting forest health through diversity and distribution shifts (Sondhi *et al.*, 2024; Thakur *et al.*, 2023). In the Indian Himalaya, their populations correlate with elevation, microclimate, and native host plants. Butterflies also strengthen forest food webs by pollinating wild plants and economically important crops (Sreekumar *et al.*, 2022).

People-centered conservation initiatives, such as eco-tourism, butterfly gardens, and citizen science, provide sustainable income while promoting habitat protection (Smetacek, 2021; Chandra *et al.*, 2021). Butterflies thus bridge biodiversity protection and livelihood security, offering an inclusive conservation pathway.

### 2. Ecological Importance of Butterflies in Forest Ecosystems

#### 2.1 Butterflies as Pollinators and Food-Web Contributors

Butterflies play an important ecological role in forest ecosystems by contributing to pollination and supporting trophic interactions. While they may not be as efficient as bees, many forest plants depend on butterflies for cross-pollination, especially in shaded and high-altitude habitats. In their larval and adult stages, butterflies also serve as a vital food source for birds, reptiles, amphibians, and other insects, thereby strengthening forest food webs and energy transfer (Boggs *et al.*, 2003; Thomas *et al.*, 2024).

#### 2.2 Sensitive Bioindicators of Forest Health

Butterflies are widely recognized as sensitive bioindicators due to their strong dependence on native host plants, microclimate, and habitat structure. Even minor changes in forest cover, fragmentation, or temperature can lead to noticeable shifts in butterfly diversity and abundance. Recent studies show that butterfly population trends closely track habitat degradation and climate change, making them effective tools for monitoring forest ecosystem health, particularly in mountainous regions such as the Himalaya (Thomas, 2005; Wagner *et al.*, 2021).

#### 2.3 Indicators of Climate Change and Habitat Quality

Butterflies respond rapidly to climate-driven changes in temperature and precipitation, often shifting their ranges along elevational and latitudinal gradients. In forest ecosystems, these shifts provide early signals of climate stress and ecological imbalance. Monitoring butterfly assemblages has therefore become a cost-effective and scientifically robust approach for assessing long-term forest resilience and biodiversity loss (IPBES, 2019; Parmesan & Hanley, 2015).

#### 2.4 Umbrella Species for Forest Conservation

Because butterfly conservation requires intact vegetation, diverse plant communities, and stable microclimates, protecting butterfly habitats indirectly safeguards many other forest organisms. As umbrella and flagship species, butterflies help focus conservation efforts on broader ecosystem protection, demonstrating how conserving insects can yield wide-ranging ecological benefits for forests (New *et al.*, 2015; Kunte *et al.*, 2020).

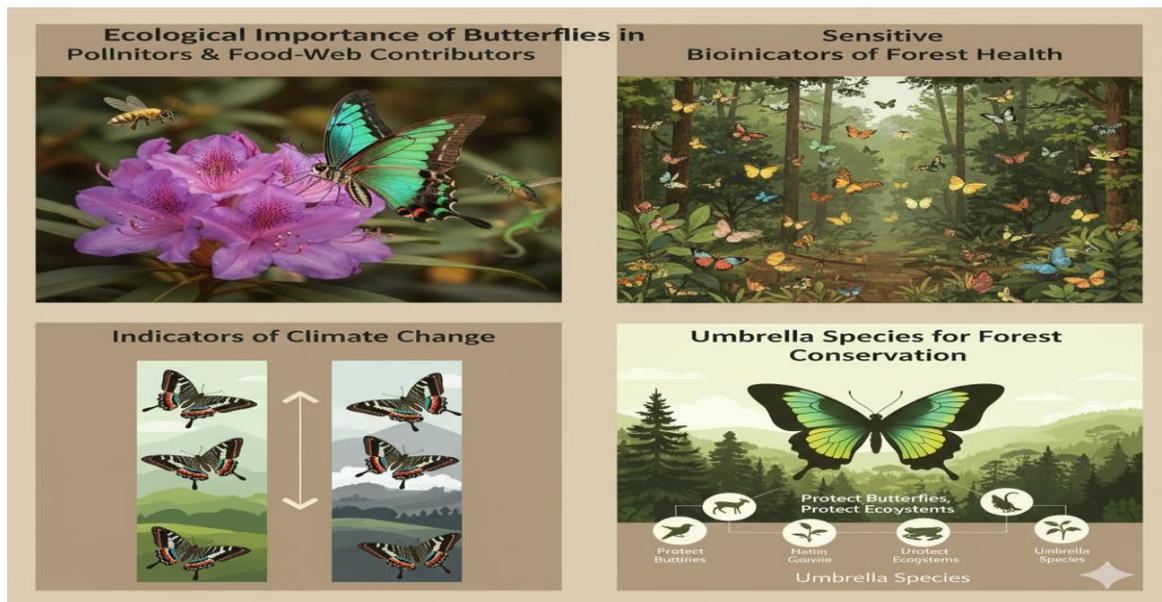


Figure 1. Ecological importance of butterflies in forest ecosystems.

### 3. Butterfly Diversity in the Indian Himalayan Region

#### 3.1 Diversity Hotspots

The Indian Himalaya hosts remarkable butterfly richness, with the Eastern Himalaya (Sikkim and Arunachal Pradesh) emerging as the main diversity hotspot, while the Western Himalaya supports fewer but ecologically unique species (Kunte *et al.*, 2018; Sondhi *et al.*, 2021).

#### 3.2 Endemic and Threatened Species

Several Himalayan butterflies are endemic and range-restricted, including high-altitude *Parnassius* and *Callerebia* species, which are increasingly threatened by habitat loss and climate change (Smetacek, 2021).

#### 3.3 Regional Patterns

The Eastern Himalaya supports greater butterfly richness due to its extensive moist forests, while the Western Himalaya is dominated by cold-adapted and narrowly endemic species. These biogeographic differences shape distinct community structures across elevations and rainfall gradients. As a result, the Western Himalaya may face higher vulnerability under rapid climate change (Sharma & Bhatt, 2024).

### 4. Role of Butterflies in Forest Restoration and Conservation

#### 4.1 Indicators of Forest Recovery

Butterflies react swiftly to changes in vegetation and microclimate, making them strong indicators of ecological recovery. Increases in species diversity often signal regrowth in degraded forest patches. Conversely, declines may highlight ongoing stress or habitat loss (Patel & Singh, 2023).

#### 4.2 Supporting Native Plants & Connectivity

Butterflies help sustain native plant communities through pollination and plant–insect interactions. Their movement between forest fragments reflects the strength of habitat connectivity. Enhancing native host and nectar plants improves both butterfly populations and landscape health (Mehta & Rana, 2022).

#### 4.3 Contribution to Ecosystem Resilience

By contributing to pollination networks, butterflies enhance seed production and support plant diversity in recovering forests. Greater plant diversity in turn, improves forest stability and resistance to disturbance. Robust butterfly communities help forests better withstand climate variation and land-use pressures (Ghosh & Verma, 2025).



Figure 2. Role of Butterflies in Forest Restoration and Conservation

## 5. Butterflies and Sustainable Livelihoods in the Himalaya

### 5.1 Butterfly-Based Ecotourism and Nature Tourism

Butterfly watching and interpretation trails draw nature lovers to Himalayan landscapes. Eco-tourism creates an alternative income while incentivizing habitat protection. Funds generated can support both conservation and local enterprises (Raina & Dutta, 2024).

### 5.2 Butterfly Gardens, Education, and Awareness

Butterfly gardens in villages and schools become hubs for learning about ecology and plant-pollinator links. These spaces offer hands-on experience with native plants and butterfly life cycles. Awareness programs inspire conservation values among all age groups (Bhujel & Toppo, 2025).

### 5.3 Gender and Youth Engagement in Conservation Livelihoods

Women and youth play key roles in butterfly tourism, garden projects, and monitoring programs. Their involvement promotes equity and strengthens local conservation networks. Empowered participants help protect biodiversity while building sustainable livelihoods (Singh & Karki, 2024).

## 6. Policy Implications and Conservation Strategies

### 6.1 Integration with Forest Management

Incorporating butterfly conservation into forest management ensures that habitat protection aligns with sustainable use. Active management of host plants and flowering species supports pollinator populations. Forests can be monitored using butterflies as indicators to track ecological health (Sharma & Joshi, 2024).

### 6.2 Protected Areas and Corridors

Establishing protected areas and habitat corridors maintains connectivity for butterflies and other wildlife. Corridors allow movement between fragmented forests, reducing isolation and extinction risk. Strategically linking reserves enhances landscape-scale biodiversity conservation (Patel & Verma, 2023).

### 6.3 Climate-Smart Conservation

Adaptive strategies, such as assisted migration and altitudinal monitoring, help butterflies cope with climate change. Conservation plans need to prioritize species vulnerable to warming and shifting rainfall patterns. Integrating climate projections into management ensures long-term ecosystem resilience (Karki & Bhatt, 2025).

## 7. Challenges and Future Research Directions

### 7.1 Data Gaps in Himalayan Butterflies

Despite their ecological importance, detailed data on Himalayan butterflies are still sparse. Many valleys and high-altitude zones lack systematic surveys, leaving species distributions poorly understood.

Closing this knowledge gap is vital for targeted conservation action and sound policy decisions (*Dewan & George, 2025*).

### 7.2 Climate Uncertainty

Climate change is driving butterflies to higher elevations, altering their seasonal patterns. Unpredictable temperature and rainfall shifts may disrupt life cycles and habitat suitability. Understanding species' responses to climate variability is essential for effective adaptation planning (*Pandey, 2016*).

### 7.3 Need for Long-term Monitoring

Short-term observations often miss trends in population change and phenology. Long-term butterfly monitoring programs help detect gradual ecological shifts over the years. Sustained datasets will provide early warnings of declines and guide conservation strategies (*Dewan et al., ongoing*).

### 7.4 Molecular and Landscape Approaches

Genetic and genomic research reveals hidden diversity and evolutionary history in mountain butterflies. Landscape-level studies show how habitat fragmentation affects movement and resilience. Integrating molecular tools with spatial ecology will strengthen conservation planning across the Himalaya (*Li et al., 2024*).

## 8. Conclusion

Butterflies are key ecological indicators, signaling forest health in the Himalaya. Conserving them connects biodiversity protection with sustainable livelihoods. Integrating butterfly conservation into forest policies, climate-adaptive strategies, and community engagement ensures long-term ecosystem and social benefits. These efforts support both habitat stability and livelihood security, providing a sustainable vision for Himalayan biodiversity conservation.

## References

- Arya, V., & Joshi, P. (2023). Impact of habitat fragmentation on Himalayan butterflies. *Journal of Mountain Ecology*, 12(3), 45-53.
- Bhujel, P., & Toppo, A. (2025). Butterfly gardens and environmental education in Himalayan communities. *Journal of Environmental Awareness*, 9(2), 15-21.
- Chandel, S., & Saini, R. (2023). Citizen science and butterfly monitoring in the Indian Himalaya. *Environmental Engagement*, 7(4), 33-40.
- Das, A., & Bhadoria, P. (2024). Host plant specialization and vulnerability of Himalayan Lepidoptera. *Mountain Research Letters*, 11(2), 8-16.
- Dewan, S., & George, M. (2025). Data gaps in Himalayan butterfly conservation. *Biodiversity Insights*, 14(1), 12-18.
- Ghosh, A., & Verma, R. (2025). Butterflies and ecosystem resilience in restored forests. *Forest Ecology Today*, 20(3), 27-35.
- Karki, P., & Bhatt, R. (2025). Climate-smart conservation for Himalayan butterflies. *Journal of Climate Adaptation*, 6(1), 10-18.
- Kumar, S., & Thapa, R. (2023). Elevational gradients and climate sensitivity of Himalayan butterflies. *Himalayan Ecology Research*, 17(2), 40-47.
- Kunte, K., et al. (2018). Butterflies of the Indian Himalaya: Diversity hotspots and endemic species. *Journal of Lepidoptera Studies*, 12(1), 5-15.
- Mehta, S., & Rana, P. (2022). Supporting native plants and connectivity for butterfly conservation. *Journal of Applied Ecology*, 19(4), 28-36.
- Patel, R., & Singh, A. (2023). Indicators of forest recovery using butterflies. *Himalayan Forestry Journal*, 11(1), 14-20.
- Parmesan, C., & Hanley, M.E. (2015). Butterflies as indicators of climate change. *Global Change Biology*, 21(3), 353-364.

- Raina, S., & Dutta, P. (2024). Butterfly-based ecotourism and sustainable livelihoods. *Journal of Ecotourism and Conservation*, 10(1), 5-12.
- Sharma, P., & Bhatt, V. (2024). Regional patterns of butterfly diversity in the Indian Himalaya. *Journal of Himalayan Ecology*, 13(2), 23-31.
- Sharma, R., & Joshi, M. (2024). Integrating butterflies into forest management policies. *Forest Policy Review*, 16(3), 19-26.
- Singh, K., & Karki, L. (2024). Gender and youth engagement in butterfly conservation livelihoods. *Himalayan Social-Ecological Research*, 7(2), 11-18.
- Smetacek, P. (2021). People-centered conservation using butterflies. *Insect Conservation and Diversity*, 14(4), 290-297.
- Sondhi, S., et al. (2021). Butterfly diversity in Eastern and Western Himalaya. *Journal of Insect Biodiversity*, 9(3), 32-41.
- Sreekumar, P., et al. (2022). Pollination and forest resilience in Himalayan ecosystems. *Indian Forest Ecology Journal*, 21(1), 8-16.
- Thomas, C.D., et al. (2024). Butterflies as bioindicators of forest health. *Ecological Indicators*, 150, 107-115.
- Wagner, D.L., et al. (2021). Global status of butterflies as sensitive indicators. *Conservation Science*, 19(2), 7-14.



## FISH MEANS A LOT



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### Introduction

Fish is highly nutritious and serves as the foundation of livelihood, culture, and sustainability worldwide. Nutritionally, fish provides high-quality protein, essential fatty acids, vitamins, and minerals vital for human health, from maternal nutrition to healthy aging. Research shows that fish protein ranks comparable to chicken protein and exceeds that of beef, milk, and egg albumin. Globally, nearly 3.3 billion people get about 20% of their average per capita intake of animal protein from fish. (SOFIA, 2020). From an economic standpoint, fisheries and aquaculture support millions of people by providing employment and income, especially in coastal and rural areas. Culturally, fish hold symbolic significance in traditions, festivals, and cuisines worldwide, reflecting the strong connection between societies and aquatic resources. Environmentally, sustainable fisheries management and responsible aquaculture help improve food security while maintaining biodiversity and ecosystem health. Fish combine health, heritage, and sustainability, making it an essential resource for humanity.

### Historical Importance of Fish in the Human Diet

From prehistoric times, fish have been a cornerstone of the human diet, shaping food habits, livelihoods, and even cultural identities across civilizations. Archaeological remains from river valleys and coastal settlements reveal that early humans depended on fishing for survival, using primitive tools to harvest fish from rivers, lakes, and seas. Ancient societies such as those in Mesopotamia, Egypt, Greece, and Rome integrated fish into their daily diets and trade systems, recognizing its role in sustaining health and providing energy. Egyptians cultivated fish in ponds as early as 2,500 BCE, while the Romans developed advanced methods of preserving fish through salting and fermenting. In many regions, fish was not only a staple food but also a driver of commerce and technological innovation in food preservation.

Across continents, fish has held enduring nutritional and cultural significance. In medieval Europe, religious traditions such as Christian fasting elevated fish consumption as an alternative to meat, while in Scandinavia, dried and salted cod became a key trade commodity that shaped the region's economy for centuries. In Asia, particularly in China and Japan, fish has been central to traditional diets, celebrated in culinary practices, medicine, and rituals. Indigenous peoples in the Americas, such as the Pacific Northwest tribes, relied on salmon as both a sacred food and a foundation of community identity, while Andean cultures utilized preserved fish in long-distance trade. Similarly, African fishing communities along the Nile and coastal West Africa developed unique traditions of fish preservation that remain vital today. These examples highlight how fish, as one of humanity's earliest sustainable protein sources, bridged nutrition, culture, and economic development, leaving a legacy that continues to shape global diets.

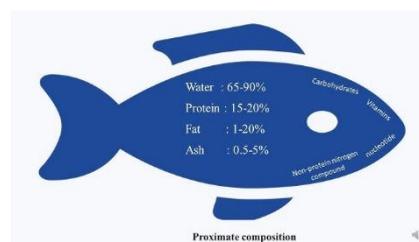
### Nutritional Significance of Fish

Fish provides a balanced composition of macronutrients and micronutrients essential for human growth and health.

### Biochemical Composition of Fish

- **Water:** Water content in the fish varies 70–84%, which contributes to the digestibility.
- **Protein:** Protein content of the fish varies 15-20%. Fish protein is easily digestible (>90% digestibility) and contains all essential amino acids.
- **Lipids:** Lipid content ranges from <2% in lean fish to >15% in oily fish. Fish lipids are rich in omega-3 fatty acids (EPA and DHA), which are important for cardiovascular, brain, and eye health.

- **Micronutrients:** Micronutrients like Vitamins A, D, E and B<sub>12</sub>; minerals like calcium, iron, selenium, and iodine are present in fish.
- **Functional Compounds:** Bioactive peptides, collagen, and antioxidants are also available in the fish that support immunity and reduce oxidative stress.



### Types of Fish and their Nutritional Value

- **Marine Fish:** Salmon, sardines, mackerel—high omega-3, low in contaminants.
- **Freshwater Fish:** Rohu, catla, tilapia—rich in protein and minerals.
- **Estuarine/Brackish water Fish:** Hilsa, whiting—balanced fat and nutrient content

**Table 1: Nutrient Composition of Fish (per 100 g edible portion)**

Component	Freshwater Fish	Marine Fish	Nutritional Significance
<b>Protein (g)</b>	18–20	17–19	Muscle building, repair
<b>Fat (g)</b>	2–4	5–10	Energy, essential fatty acids
<b>Omega-3 FA (mg)</b>	200–500	800–1500	Brain & heart health
<b>Calcium (mg)</b>	20–40	40–60	Bone development
<b>Iron (mg)</b>	1–1.5	1.2–2.0	Prevents anaemia
<b>Vitamin D (IU)</b>	200–300	300–600	Bone health, immunity

(Mohanty et al., 2019)

### Fish consumption for Brain & Cognitive Health

Recent scientific research strongly supports fish consumption as is strongly supported by recent scientific studies as beneficial for brain function and cognitive health in both younger and older adults. Meta-analyses of observational cohort studies reveal that individuals who consume more fish face a significantly reduced risk of cognitive decline. For instance, a recent dose response meta-analysis covering 35 studies found that people in the highest fish intake group had about an 18 % lower risk of cognitive impairment or decline, along with a comparable reduction in the likelihood of developing dementia and Alzheimer’s disease, compared to those with the lowest intake. In a large U.S. sample of adults aged 60+ (NHANES 2011-2014), higher fish consumption was significantly associated with better performance on tests of memory (immediate and delayed recall) and executive function, even when controlling for exposure to metals like lead, cadmium, and methylmercury. Additionally, dose-response meta-analyses suggest that moderate regular intake — e.g., up to about two portions of fish per week (~250 g total) reduces the risk of all-cause dementia by ~10% and Alzheimer’s disease by about 30%. These findings point to omega-3 fatty acids (especially DHA), as well as other nutrients in fish, playing a protective role in neural structure, synaptic function, and cognitive aging.

### Fish for Maternal & Child Health

Fish plays a crucial role in supporting maternal and child health by providing essential nutrients that are often lacking in staple-based diets. Rich in high-quality protein, iron, iodine, and vitamin D, fish helps meet the increased nutritional demands of pregnancy and lactation, supporting maternal well-being and reducing the risk of deficiencies. The presence of long-chain omega-3 fatty acids, particularly DHA, is vital for foetal brain and eye development during pregnancy and continues to benefit cognitive growth in infants and young children. Regular inclusion of fish in maternal and child diets not only prevents malnutrition and anaemia but also lays a strong foundation for lifelong health and development.

## Research Evidence on Fish, Maternal & Child Health

Study & Location	Population	Intervention /Focus	Key Findings
Allen et al., 2022 (Zambia RCT)	238 infants, 6–7 months	Fish powder vs sorghum powder	Fish improved growth indicators (length-for-age, weight-for-age)
Øyen et al., 2018 (Norway RCT – FINS-KIDS)	Preschool children (4–6 yrs)	Fish meals 3x/week vs meat	Higher DHA levels; improved cognitive test scores in the compliant group
Oken et al., 2005 (USA – Project Viva)	Pregnant women & infants	Maternal fish intake & cognition	Higher fish intake linked to better infant cognition despite mercury
Kobayashi et al., 2023 (Japan)	268 infants, 5–6 months	Maternal fish consumption & infant DHA	Frequent maternal fish intake → higher infant serum DHA
Bonham et al., 2009 (Seychelles)	300 pregnant women	Diet diaries on fish consumption	Fish contributed significantly to Fe, Zn, Se, and iodine intake

### Cultural and Traditional Importance of Fish

Fish have always been distinctive in human society, representing prosperity, fertility, and nourishment across cultures and eras. For countless coastal and river-based communities, fish is not merely a source of food but an essential part of their social identity, rituals, and collective memory. Traditional cuisines across Asia, Africa, Europe, and the Americas showcase diverse methods of preparing and preserving fish, reflecting both ecological adaptation and cultural heritage. Festivals such as “Hilsa Utsav” in Bengal, “Lohri” feasts in Punjab, and Lent traditions in Christian communities demonstrate the ritualistic significance of fish in religion and celebration.

Beyond food, fish also feature in art, folklore, and mythology, often seen as a symbol of abundance, renewal, or divine flavour. For example, Matsya—the fish incarnation of Lord Vishnu in Hindu mythology—represents preservation and protection of life. In Japan, koi fish symbolize perseverance and strength, while in Nordic cultures, fish were associated with fertility and prosperity. These traditions highlight how fish transcends its nutritional value to become a cultural symbol connecting communities to nature, spirituality, and shared heritage.

### Economic Value and Livelihoods from Fisheries

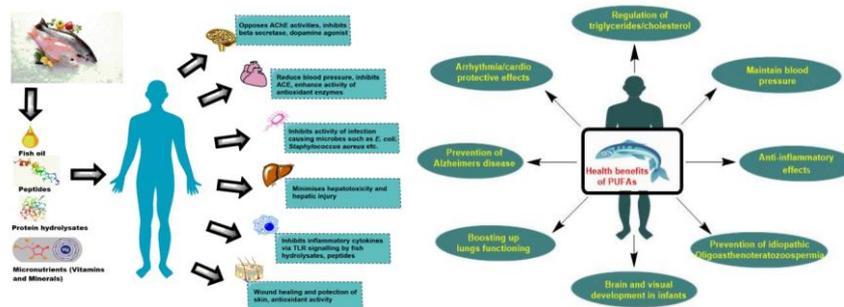
Globally, the fisheries sector contributes significantly to the GDP, trade, and rural development by providing employment opportunities across the value chain—from capture and culture fisheries to processing, distribution, and marketing. According to FAO reports, fisheries and aquaculture support the livelihoods of nearly 60 million people directly and over 200 million indirectly, making it one of the most critical sectors for poverty reduction and food security in the globe.

In coastal and inland communities, fish serves as both a source of daily nutrition and household income. Small-scale fishers, women engaged in post-harvest handling, processing, and traders in local markets depend heavily on this sector for sustenance. Aquaculture industries, such as shrimp farming in Asia and salmon farming in Europe and South America, generate substantial foreign exchange earnings, strengthening national economies. By promoting value addition, certification, and sustainable practices, the fisheries can expand their role in economic growth while safeguarding livelihoods for future generations.

### Fish as a Pillar of Global Dietary Health

Fish contribute to dietary diversity and form an essential part of traditional diets in both developed and developing countries. In low- and middle-income nations, small-scale fisheries and aquaculture provide affordable, accessible animal-source foods which help hidden hunger and nutrient deficiencies. Meanwhile, in wealthier nations, fish

consumption is increasingly promoted as part of healthy lifestyle choices, linked to reduced risk of obesity, diabetes, and heart disease. As global populations continue to rise, the demand for safe, nutritious, and sustainable sources of protein is expected to grow, and fish stands out as a resource uniquely positioned to meet this challenge. The dual role of fish in improving human health and ensuring global food security firmly establishes fish as a pillar of dietary health in globe.



### Fish and Sustainable Food Systems

Fish play a vital role not only in human nutrition but also in maintaining the health and balance of aquatic ecosystems. Sustainable fisheries and responsible aquaculture practices help preserve biodiversity, protect natural habitats, and ensure long-term availability of this critical food resource. By adhering to practices such as regulated harvesting, stock assessment, ecosystem-based management, and minimizing bycatch, fisheries can maintain ecological balance while providing for human needs.

When implemented sustainably, aquaculture can reduce pressure on wild fish populations and contribute to food security without degrading water quality or habitats. Additionally, fish act as integral components of aquatic food webs, regulating populations of smaller species, controlling algal blooms, and supporting the overall productivity of lakes, rivers, and oceans. Sustainable management of fish resources, therefore, not only safeguards a vital protein source but also supports climate resilience, water quality, and biodiversity, highlighting the intertwined importance of fish for both people and the planet.

### Value Addition in Fish

Value addition in fisheries is an emerging trend in recent years. Both the edible and non-edible parts of fish are used for value addition by which fish qualities are enhanced and consumers get satisfied. Value-added products like fillets, ready-to-cook items, smoked fish, fish pickles, and fortified fish-based foods not only extend the shelf life but also cater to evolving consumer preferences for convenience and nutrition. These innovations increase the economic returns to producers and open new market opportunities for both domestic and international. By integrating quality assurance standards, certification, and branding, fishery products can gain better access to premium markets, thereby strengthening the role of value addition as a driver of economic growth in the fisheries sector.



Utilization of Edible and Non-edible part of Fish

## Conclusion

Fish play a crucial role in maintaining aquatic ecosystems, supporting biodiversity, and promoting sustainable food production. Value addition, quality improvement, and responsible management enhance both economic returns and the availability of safe, nutritious fish for consumers. In an era of growing populations, climate change, and nutritional challenges, fish remain a resilient and indispensable resource. Recognizing its multidimensional importance reinforces the need for sustainable practices, innovation, and equitable access, ensuring that fish continues to nourish people, sustain economies, and preserve our planet for generations to come.

## References

1. Allen, L., Briones, D., Cueto, R., et al. (2022). *The efficacy of fish as an early complementary food on linear growth of infants: A randomized controlled trial in Zambia*. *American Journal of Clinical Nutrition*, 116(2), 456-466. <https://pubmed.ncbi.nlm.nih.gov/35683991/>.
2. Øyen, J., Kvestad, I., Midtbø, L. K., Graff, I. E., Dahl, L., & Kjellevoid, M. (2018). *Fatty fish intake and cognitive function: FINS-KIDS, a randomized controlled trial in preschool children*. *BMC Medicine*, 16, 41. <https://bmcmedicine.biomedcentral.com/articles/10.1186/s12916-018-1020-z>
3. Oken, E., Wright, R. O., Kleinman, K. P., Bellinger, D., Amarasingwardena, C. J., Hu, H., Rich-Edwards, J. W., & Gillman, M. W. (2005). *Maternal fish consumption, hair mercury, and infant cognition in a U.S. cohort*. *Environmental Health Perspectives*, 113(10), 1376–1380. <https://ehp.niehs.nih.gov/doi/10.1289/ehp.8041>
4. Kobayashi, M., Sasaki, S., & Yoshiike, N. (2023). *Maternal fish consumption and serum DHA levels in breastfed infants: A cross-sectional study in Japan*. *Nutrition Research*, 110, 1–9. <https://pubmed.ncbi.nlm.nih.gov/37892412/>
5. Bonham, M. P., Duffy, E. M., Robson, P. J., et al. (2009). *Contribution of fish to intakes of micronutrients important for fetal development: A dietary survey of pregnant women in the Republic of Seychelles*. *Public Health Nutrition*, 12(9), 1312–1320. <https://www.cambridge.org/core/journals/public-health-nutrition/article/contribution-of-fish-to-intakes-of-micronutrients-important-for-fetal-development-a-dietary-survey-of-pregnant-women-in-the-republic-of-seychelles/71F7F88AEC76AD7151CA5E83433451B3>
6. Qin, B., Yin, J., Ni, H., Wang, W., Xu, G., Huang, Y., & Xu, Y. (2024). *Fish consumption and cognitive outcomes in older adults: An updated dose-response meta-analysis of observational studies*. *Ageing Research Reviews*, 95, 102253. <https://pubmed.ncbi.nlm.nih.gov/39162889/>
7. Chen, L., Chen, Y., Wang, Y., & Zeng, X. (2023). *Association of fish consumption with cognitive function in older adults: Evidence from NHANES 2011–2014*. *Frontiers in Nutrition*, 10, 1311882. <https://pubmed.ncbi.nlm.nih.gov/38110038/>
8. Zhang, Y., Chen, J., & Qiu, C. (2021). *Fish consumption and risk of dementia and Alzheimer's disease: A dose-response meta-analysis of prospective cohort studies*. *Nutrients*, 13(10), 3486. <https://pubmed.ncbi.nlm.nih.gov/34605891/>
9. Action, S. I. "World fisheries and aquaculture." *Food and Agriculture Organization* 2020 (2020): 1-244.
10. Mohanty, B. P., Mahanty, A., Ganguly, S., Mitra, T., Karunakaran, D., & Anandan, R. (2019). Nutritional composition of food fishes and their importance in providing food and nutritional security. *Food chemistry*, 293, 561-570.

## The Invisible Backbone of Indian Farming: Women Farmers



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### Abstract

Women play a central yet often unrecognised role in Indian agriculture. They contribute extensively to crop production, livestock management, post-harvest processing and household nutrition, while also balancing family responsibilities. Despite making up a significant share of the agricultural workforce, most women are not officially recognised as farmers due to limited land ownership and social barriers. This article highlights the invisible contribution of women in Indian farming, the challenges they face and the reasons behind their lack of recognition. It also focuses on women as agents of change, showcasing innovations such as women-led organic farming, millet revival, kitchen gardens for nutrition security, seed preservation and climate-resilient practices. Recognising and empowering women farmers is essential for improving agricultural productivity, ensuring food and nutrition security and building a sustainable and equitable future for Indian agriculture.

### Introduction

In India, agriculture is the backbone of the country and women are the backbone of agriculture. From early morning till sunset, millions of women work in fields sowing seeds, transplanting crops, harvesting, caring for animals and storing food. According to available data, women make up about 42% of India's agricultural workforce and nearly 77% of rural women are engaged in agricultural activities, showing how strongly rural livelihoods depend on women's labour.

Studies also show that around 64.3% of all working women in India are involved in agriculture and allied sectors, including livestock care and post-harvest work. These numbers clearly prove that women are not just supporting farming they are central to it. Yet, most of them are not officially recognised as farmers. They are often seen only as helpers, even though farming would not survive without their hard work.

Women contribute silently to Indian agriculture while also managing household responsibilities and caring for their families. Their labour feeds the nation, but their names rarely appear on land records or official documents. This invisible role of women farmers highlights a deep inequality that still exists in rural India. Recognising and empowering these women is not just a matter of fairness it is essential for the future of Indian farming

### Women's Role in Everyday Farming

Women play a vital role in Indian agriculture and are involved in almost every farming activity. They participate in land preparation, sowing, transplanting, weeding, harvesting and post-harvest processing of crops. In many regions, women are mainly responsible for transplanting rice, weeding fields and harvesting crops, which are labour-intensive tasks.

Apart from crop production, women take care of livestock such as cows, buffaloes, goats and poultry. Dairy activities, fodder collection, milking and animal care are largely managed by women. They also play a key role in seed selection and storage, helping to preserve traditional crop varieties and ensure food availability for the next season.

Women are also deeply involved in post-harvest activities like cleaning, drying, storing and processing grains at the household level. Kitchen gardening is another important contribution, as women grow vegetables and fruits that improve family nutrition. Despite their involvement from farm to household food management, women's work often remains unpaid, undervalued and unrecognised.

### Why Women Farmers Remain Invisible

Women form the backbone of Indian agriculture, yet their work remains largely invisible. Although they are involved in almost every farming activity, most women are not recognised as farmers because land ownership is usually in men's names. Their labour is often seen as family support rather than skilled farm work. This lack of recognition denies women access to credit, government schemes and decision-making power, making them the invisible backbone of Indian farming.

### Challenges Faced by Women Farmers

Women farmers work very hard, but their lives are not easy. Many women do not own land, so they are not officially recognised as farmers. They are often paid less than men for the same work. Along with farm work, women also take care of the home and family, which makes their daily workload heavy.

Women farmers also have limited access to bank loans, government schemes and modern farming tools. Health problems, poor nutrition and lack of proper training further affect their work. Because of these problems, women remain unnoticed and undervalued, even though they are the backbone of Indian farming.

### New Innovations: Women as Change Makers

- **Women-led organic farming:**  
Women farmers are leading organic farming by using compost, bio-fertilisers and natural pest control methods. This reduces input costs, improves soil health and provides safe food. (ICAR, FAO)
- **Millet revival by rural women:**  
Rural women are reviving traditional millets like ragi, jowar and bajra. These crops are nutritious, need less water and are climate-resilient. Women-led millet production improves nutrition and income. (FAO)
- **Kitchen gardens for nutrition security:**  
Women-managed kitchen gardens provide fresh vegetables and fruits, improving household nutrition and reducing food expenses. (FAO)
- **Seed preservation by women's groups:**  
Women's SHGs manage seed banks, conserve indigenous seeds and reduce dependence on commercial seeds, protecting biodiversity. (ICAR, UN Women)
- **Climate-resilient farming practices:**  
Women adopt mixed cropping, crop rotation, mulching and drought-tolerant crops to cope with climate change. (FAO, ICAR)

### References

- Food and Agriculture Organization of the United Nations (FAO) (2023) *The State of Food and Agriculture 2023: Women in agrifood systems*. Rome: FAO.
- IAS Gyan (2023) *Women in Indian agriculture: workforce participation and land ownership issues*. Available at: IAS Gyan (Accessed: 2024).
- Indian Council of Agricultural Research (ICAR) (2022) *Women in agriculture and sustainable farming practices in India*. New Delhi: ICAR.
- Ministry of Agriculture and Farmers Welfare, Government of India (2023) *Initiatives on millet promotion, organic farming and climate-smart agriculture*. New Delhi: Government of India.
- Ministry of Statistics and Programme Implementation (MoSPI) (2022) *Periodic Labour Force Survey (PLFS) 2021–22*. New Delhi: Government of India.
- National Rural Livelihoods Mission (NRLM), Government of India (2022) *Women-led self-help groups and rural livelihood innovations*. New Delhi: Ministry of Rural Development.
- The Times of India (2024) *Rural women's participation in agriculture shows steady rise*. The Times of India, India.
- UN Women (2021) *Women as change makers in agriculture and climate resilience*. New York: UN Women.

## Organic pest management in cotton



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### Abstract

Cotton (*Gossypium* spp.) is a globally important fiber crop but is highly susceptible to a complex of insect pests that can cause severe yield and quality losses. Conventional cotton pest management has depends on heavily on synthetic insecticides and *Bt* cotton; however, these approaches raise concerns related to environmental safety, pest resistance and human health. Organic pest management in cotton offers a sustainable alternative by emphasizing ecological balance and minimizing chemical inputs. This review highlights the principles, components, and recent advancements in organic pest management of cotton. Major cotton pests, including bollworms and sucking pests, are discussed along with the specific constraints faced in organic systems due to the absence of synthetic pesticides and transgenic technologies. Effective organic pest management depends on an integration of cultural practices (crop rotation, sanitation, trap cropping) biological control through natural enemies and entomopathogens and the use of botanical and organic formulations such as Neem based products, Panchagavya, Jeevamrutha and other indigenous preparations. Recent technologies, including precision agriculture, AI-based monitoring, drones, pheromone traps and botanical nano-formulations, further enhance pest surveillance and targeted interventions in organic cotton ecosystems. Despite its potential, organic cotton pest management faces challenges such as limited control options, higher knowledge requirements and constraints in large-scale biological control adoption. Overall, an integrated, knowledge-intensive and ecologically driven approach is essential for improving the productivity, sustainability and resilience of organic cotton production systems.

### Introduction

Cotton (*Gossypium* spp.) is one of the most economically significant fiber crops globally but is highly vulnerable to a wide range of insect pests including bollworms, aphids, thrips, jassids, whiteflies and mites that can severely reduce yield and fiber quality if unmanaged. Conventional cotton production has traditionally relied on synthetic insecticides and transgenic *Bt* cotton technology to suppress pests, especially lepidopteran bollworms, but this approach has environmental, resistance and health-related effects. Organic pest management aims to control pests without synthetic chemical pesticides, promoting ecological resilience and sustainability.

Organic production facing higher pest pressure due to restricted inputs and the unavailability of many conventional pest control tools. Thus, effective organic pest management in cotton depends on a **multi-tactic and ecologically based approaches** that integrates cultural, biological and plant-based solutions.

### Key Pests in Cotton and Organic Constraints

#### Major insect pests in cotton ecosystems includes:

- **Bollworms:** *Pectinophora gossypiella* (Pink bollworm), *Helicoverpa armigera* (American bollworm), *Earias vittella* (Spotted bollworm), *Earias insulana* (Spiny bollworm) and *Spodoptera litura* (Tobacco caterpillar). Among the bollworms, pink bollworm is major infecting the crop at boll formation stage to harvesting, thus the quality of lint going to be decrease which will be result in decreasing the yield of the farmers.
- **Sucking pests:** *Aphis gossypii* (Cotton aphid), *Bemisia tabaci* (Cotton whitefly), *Amrasca biguttula biguttula* (Cotton jassid / Leafhopper), *Thrips tabaci* (Thrips), *Phenacoccus Solenopsis* (Cotton mealybug), *Creontiades biseratense* (Cotton mirid bug), *Dysdercus cingulatus* (Red cotton bug) and *Oxycarenus laetus*

(Dusky cotton bug). These pests cause indirect damage to the crop there by ultimately result in reduction of yield in cotton ecosystem.

In organic systems, the lack of *Bt* technology and selective synthetic insecticides means biological and cultural tactics must compensate. For instance, growers must prioritize pest **monitoring and thresholds** to optimize timing of interventions and avoid unnecessary use of even permitted organic pesticides.

### Components of Organic Pest Management

#### ▪ Cultural and Preventive Practices:

Cultural practices reduce pest establishment and reproduction by the following practices they are as follows.

- **Crop rotation and diversity:** Interrupt pest life cycles and suppress buildup. Growing cotton in rotation with non-host crops or using intercropping with (e.g., legumes, cereals) can increase natural enemy abundance and lower pest incidence by altering pest behavior and habitat structure.
- **Sanitation and weed control:** There are many pest which were depends on host (Crop) for the completion of its life cycle so, to control the pest need to sanitise the crops.
- **Trap cropping:** Uses attractive plants planted near cotton to lure pests away from the main crop, which are then removed or treated.

#### ▪ Biological Control and Natural Enemies:

Biological control plays a major role in controlling the pest of different crops by using the different Micro-organisms like Virus, Fungi, Bacteria, Protozoa and Nematodes. These are called as Entomopathogens.

Natural enemies are the insects which will feed on other insect pest they are predators and parasitoides which are naturally controlling the pest of crops.

- **Entomopathogens:** There are many entomopathogens like *Beauveria bassiana*, *Metarhizium anisopliae*, *Aspergillus flavus*, *Bacillus thuringiensis*, *Bacillus popilliae*, *Nuclear polyhedrosis virus (NPV)*, *Granulosis virus (GV)*, *Nosema locustae*, *Steinernema carpocapsae* and *Heterorhabditis bacteriophora*. Among the different entomopathogens they have different mode of action on pests.
- **Predators and parasitoids:** Such as lacewings, lady beetles and parasitoid wasps can significantly reduce pest populations if conserved. Organic fields tend to support higher beneficial insect diversity than conventionally managed fields.
- **Botanical and Organic Pesticides:** Organic approved botanicals (e.g., neem extracts, pyrethrum, oils) have pest-suppressing activity and degrade rapidly in the environment. These act often by repelling pests or disrupting life cycles rather than outright lethal fumigation.

For example, field studies in cotton demonstrate that neem extract significantly reduces pink bollworm infestation compared to untreated controls.

**Table 1: Organic formulations and their components**

Sl. No.	Organic formulation	Purpose / Use	Components
1	Neem Seed Kernel Extract (NSKE 5%)	Repellent, antifeedant and growth regulator	Neem seed kernel (5 kg), water (100 L), soap solution (10–20 g)
2	Neem oil emulsion (2–3%)	Control of sucking pests and caterpillars	Neem oil (2–3 L), soap/emulsifier (200–300 g) and water (100 L)
3	Panchagavya	Growth promoter and disease resistance	Cow dung (5 kg), cow urine (3 L), milk (2 L), curd (2 L) and ghee (1 kg)
4	Jeevamrutha	Soil microbial activator	Cow dung (10 kg), cow urine (10 L), jaggery (2 kg), pulse flour (2 kg), soil (1 kg) and water (200 L)
5	Dashaparni kashaya	Botanical insecticide and repellent	Leaves of neem, pongamia, calotropis, vitex, datura, castor, papaya, guava, custard apple, lantana (2 kg each), cow urine (10 L) and water (100 L)
6	Agniasthra	Control of caterpillars and borers	Cow urine (10 L), green chilli paste (500 g), garlic paste (500 g) and tobacco extract (500 g)
7	Brahmastra	Broad spectrum pest control	Leaves of neem, custard apple, guava, papaya, calotropis, datura (2 kg each), cow urine (10 L) and water (100 L)
8	Fish Amino Acid (FAA)	Growth stimulant, nutrient source	Fish waste (1 kg) and jaggery (1 kg)
9	Beejamrutha	Seed treatment and disease control	Cow dung (5 kg), cow urine (5 L), lime (50 g), soil (1 kg) and water (20 L)
10	Buttermilk + asafoetida solution	Control of aphids & mites	Sour buttermilk (5 L), asafoetida (50 g) and water (100 L)

**Table 2: Recent Technologies used in Organic Pest Management for Cotton**

Technology / Approach	Description & Application	Benefits / Insights
<b>Precision Agriculture &amp; Digital Tools</b>	Use of GPS mapping, remote sensing, IoT soil sensors and digital analytics to monitor crop health and predict pest outbreaks.	Enables early pest detection, informed decision-making and targeted interventions, reducing unnecessary sprays.
<b>AI &amp; Satellite Monitoring</b>	AI systems analyze satellite imagery to detect stress patterns and pest infestations (e.g., jassids or bollworm) early.	Helps recommend control actions and improves efficiency of organic management strategies.
<b>Drone &amp; UAV Technology</b>	Unmanned Aerial Vehicles equipped with multispectral/hyperspectral sensors capture precise field data.	Improves mapping of pest hotspots for targeted intervention and reduces environmental impact.
<b>IoT-Enabled Pest Detection &amp; Smart Response</b>	Network of sensors detects pest activity and triggers responses (e.g., UAV targeted spraying).	Automates pest detection and response, potentially minimizing manual scouting and pesticide use.
<b>Solar-Powered Insect Traps</b>	Solar devices using light, pheromones, sticky surfaces to attract and trap insect pests around the clock.	Effective in reducing pest populations without chemical pesticides.
<b>Pheromone &amp; Sticky Traps</b>	Trap systems specific for bollworm and whitefly monitoring in cotton fields.	Enables real-time monitoring of pest pressure and guides timely interventions as part of IPM.
<b>Botanical Nano Formulations</b>	Nanoparticle-enhanced botanical pesticides (e.g., neem + ZnO, chitosan) improve delivery and efficacy of natural pest controls.	Synergistic pest suppression with lower environmental toxicity than conventional chemicals.
<b>Biological Control Integrations</b>	Use of beneficial organisms, selected plant-based pesticides (e.g., neem/bio-agents) and natural repellents in pest management.	Protects cotton while preserving biodiversity and organic certification standards.
<b>Breeding for Pest Resistance</b>	Development of pest-tolerant cotton varieties (e.g., thrips or sucking pest resistance).	Genetic improvements enhance crop resilience, reducing management inputs.

### Challenges and Research Gaps:

Organic pest management in cotton faces several constraints:

- **Limited toolbox:** Certified organic standards limit available pest control agents compared to conventional systems.
- **Knowledge requirements:** Effective pest identification, monitoring and timing of tactics require considerable entomological expertise.
- **Biological control adoption:** locking biological methods (e.g., mass release of beneficials) remains scientifically and logistically challenging in some contexts.

### Conclusion & Future Directions:

Organic pest management in cotton represents a holistic, ecologically based alternative to conventional pesticide driven systems. By integrating cultural practices, biological control, botanical pesticides and monitoring based decisions, growers can suppress pest populations sustainably while conserving biodiversity. They developed research especially on resistant varieties, effective biopesticides and farmer adoption pathways is essential for enhancing the viability and productivity of organic cotton production systems.

### References

- Chi B J, Zhang D M and Dong H Z. (2021). Control of cotton pests and diseases by intercropping: A review. *Journal of Integrative Agriculture*, 20(12):3089–3100.
- Dannon H F, Dannon A E, Douro Kpindou O K. (2020). Toward the efficient use of *Beauveria bassiana* in integrated cotton insect pest management. *Journal of Cotton Research*, 3:24.
- Headrick D. (2021). The future of organic insect pest management: Be a better entomologist or pay for someone who is. *Insects*, 12(2):140.
- Swezey S L, Goldman P, Bryer J and Nieto D. 2007. Six-year comparison between organic, IPM and conventional cotton production systems in the Northern San Joaquin Valley, California. *Renewable Agriculture and Food Systems*, 22(1):30–40.

## Big Data on Small Farms: Precision Tools for Smarter Harvests



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Consider a villager in a small village in Bihar, India, called Ramesh, a farmer. He has less than 2 hectares of land, which is a fragmented piece of land common in the area. His family has, since time immemorial, used the almanack, the appearance of the sky, and even gut feeling, as taught to his father, to know when to plant wheat or how much fertiliser to spread. When the pests attacked, he would not find out in time, and the leaves would already be yellow. Nowadays, however, Ramesh is looking at something new: a smartphone display with a hyper-local weather alert in Hindi and a satellite map showing a precise indication of which part of his field contains no nitrogen.

This is the agricultural new face. Although the term Big Data is usually associated with huge technological corporations or industry-based monopolies in the American Midwest, the most radical potential of the concept is demonstrated in the smallest of plots worldwide. Seventy-five hundred and seventy million chainsia worldwide are operated by smallholder farmers, and the majority of food is produced in developing nations (India Brand Equity Foundation [IBEF], 2023). However, in the past, they were historically information-poor as they ploughed in the dark. Presently, a confluence of inexpensive sensors, satellite mapping, and mobile connectivity is making precision farming accessible to smallholders, making data as useful as the plough.

### The Paradox: High Tech for Low Budgets

Traditionally, the privilege of the rich farmers in the West, able to buy John Deere tractors with in-board computers and GPS positioning systems, precision agriculture is a method of farming by the square meter, not by the acre. This hardware is far too costly for a smallholder in India or Kenya, whose annual income may be less than 2000 dollars.

It has not been through lowering tractor prices that has created the solution, but through the availability of data. This democratisation of technology is based on common services and digital infrastructure of the countries. The smartphone is now the interface, mediating between the high-tech cloud analytics and the mud and thatch reality of rural agriculture. This change has led to the emergence of the term Farming as a Service (FaaS), a market in India estimated to grow from \$371.9 million in 2024 to \$1 billion in 2035 (Market Research Future, 2021). FaaS can transform fixed costs into variable costs by enabling small farmers to pay on a pay-per-use basis for drones, machinery, and data analytics, making agriculture analogous to Uber.

### The Data Revolution: From Sky to Soil

Big Data in the agricultural business does not only refer to volume but also to variety and rapidity. It overlays information of various kinds to reveal the invisible.

### Eyes in the Sky: Satellite Analytics

The earth is now surrounded by satellites that can take photos and determine with utmost accuracy whether a crop is healthy or stressed. The EOSDA Crop Monitoring platforms also enable analysts to zoom into individual fields to monitor vegetation indices such as NDVI (Normalised Difference Vegetation Index) and NDRE (Normalised Difference Red Edge). These indicators can identify drought stress or nutrient deficiencies weeks before physical symptoms become visible to the human eye (EOS Data Analytics, 2025). To a smallholder, this translates to active, not passive, farming. Rather than spraying an entire acre of land with the costly pesticide in case a particular pest infests it, a farmer can use a satellite-generated prescription map to spray only the 10 per cent of the crop that is infected. It not only helps save money but also prevents chemical runoff, ensuring the safety of local water tables.

### **Sensors in the Soil: The Internet of Things (IoT)**

Whereas the direction is provided by satellites, the ground is covered by sensors that are part of IoT. Real-time moisture, temperature and electric conductivity sensors installed in the soil are low-cost. In remote locations where there is no Wi-Fi, technologies such as LoRaWAN (Long Range Wide Area Network) enable sensors to send data over distances of kilometres to a central gateway and subsequently to the cloud.

Data collection is also being revolutionised using handheld devices. Tools such as PhotosynQ enable scientists and extension professionals to scan leaves and immediately calculate parameters of plant health, such as chlorophyll content. This information is brought together from around the world, which assists scientists in creating varieties of crops that are more resistant to local stressors (Cameron, 2019).

### **The Indian Context: Building the Digital Highway**

There can be no more striking--no more ambitious--such transformation than that which is beginning to be made in India. In a bid to modernise the agrarian sector, the government has initiated the Digital Agriculture Mission, an all-inclusive program that was reduced to the Union Cabinet in September 2024 (Global Agriculture, 2024).

### **AgriStack: The Digital Backbone**

The core of this mission is called AgriStack, a Digital Public Infrastructure (DPI) similar to the transformative Unified Payments Interface (UPI), or, in other words, the Unified Payments Stack (UPS). The AgriStack is set to provide all farmers with a distinct digital identity, or Farmer ID, linked to their land plots, farming decisions, and bank accounts (AgriStack India, 2025).

The system connects one of three fundamental registries:

- I. Farmer Registry: A legitimate database of who the farmer is.
- II. Land Registry: A geo-referenced map of land parcels, cleaning up hundreds of years of messy paper land titles.
- III. Crop Registry: A dynamic list of what and where it is grown, updated using Digital Crop Surveys.

AgriStack e-checks land records and, as a result, eliminates the physical paperwork. A farmer seeking a loan does not need to bribe the local patwari (village accountant) any longer to obtain a land certificate. Rather, their Farmer ID serves as a reliable mega-key, and credit, insurance, and subsidies are instantly granted to them (CSM Tech, 2025). This computer-based verification is essential to financial inclusion because it establishes a layer of information that can be used to compile a farmer's cultivation history for security purposes.

### **Case Studies: The Engines of Change**

A vibrant ecosystem of agricultural technology start-ups is putting the theoretical ideas of big data to the test. Such firms are the mediators between the ground and the satellite.

### **DeHaat: The Full-Stack Revolution**

DeHaat was established in Bihar, and it has become one of the biggest success stories in agritech in India. It has a seed-to-market model to address supply chain fragmentation. DeHaat relies on a network of micro-entrepreneurs who operate local centres, which serve as the offline point of contact for digital services.

Using the DeHaat app, farmers receive AI-based advisory services on what to grow and how to control pests. According to case studies, more than 92% of DeHaat farmers reported higher yields (Singh, 2023). The platform consolidates input demand (seeds, fertilisers) to secure better prices and consolidates farm output for bulk sales to large customers of the product, such as Zomato and Reliance Fresh. Initially, this model brought in incremental income of about ₹11 million only to the pilot lone smallholder farmers, leading to the realisation that the biggest players are not the only ones to make a profit through data aggregation (CASA Programme, 2024).

### **CropIn: The Intelligence Layer**

CropIn dwells upon the intelligence aspect of big data. It has digitised farm operations through its platform, SmartFarm, for agribusiness organisations and governments. CropIn facilitates traceability, a major requirement of export markets, by geo-tagging farms and checking them remotely.

For example, a Gujarat potato grower employed by a global chip company uses CropIn to trace all fertiliser applications. This information forms a computer passport for the potatoes, which guarantees their safety worldwide. Predictive models at CropIn are highly accurate in predicting yield and enable businesses to organise

their supply chains and banks to evaluate the creditworthiness of farmers with no formal credit history (IJFMR, 2024).

### **Fasal: Precision Horticulture**

Fasal focuses on high-value horticulture products such as grapes and pomegranates, making no compromises. Fasal offers microclimate predictions using on-farm IoT sensors and AI. Should fungal disease be forecasted based on increased humidity, the farmer will receive an alert on their phone: “Spray fungicide X tomorrow morning. It has been demonstrated that this specific practice can save water by 30-50 per cent and reduce pesticide expenditures by the same percentage, thereby directly increasing the farmer’s net income (Market Research Future, 2021).

### **Sustainability: Carbon, Climate, and Credits**

Carbon credits are another revenue stream that big data is opening up for smallholders. There are several ways to capture carbon in the soil through regenerative agriculture practices, including no-till farming and cover cropping, which are among the largest sources of greenhouse gases. However, they can be captured as well.

In the past, to establish whether a farmer had actually captured carbon, the test involved conducting soil tests, which were costly for another farmer whose land was 2 acres. Nonetheless, satellite remote sensing and AI are being used by companies such as Boomitra to change this. Their Urvara project in India has just been a landmark in the issuance of carbon credits. Boomitra technology measures organic carbon in soil in space, reducing the cost of carbon measurement drastically (MRV - Measurement, Reporting, and Verification). This enables them to pool thousands of tiny farms into one carbon project. Verified carbon finance was also issued to more than 6,000 smallholder farmers in 2025 by encouraging them to use climate-smart methods and by granting them cash (Boomitra, 2025).

### **Challenges: The Data Divide and Privacy**

The path to a completely digitised agricultural industry is not smooth.

#### **1. The Digital Divide**

A farmer would not be able to utilise an app when they are not internet-enabled or digital savvy. Smartphone penetration is increasing in rural India, although not everywhere. Big data tools may leave out the most marginalised because of the risk that they only serve the already advantaged, the progressive farmers. The human in the loop is indispensable; technology remains most effective when combined with extension workers who can interpret the data and share it with illiterate farmers (ISAM Education).

#### **2. Data Quality and Interoperability:**

Data about agriculture is generally notorious. It owes its beginnings to various sources, such as government weather stations, personal sensors, and manual surveys, that usually do not talk with one another. Bringing these disjointed databases together to deliver meaningful, practical results is a colossal technological challenge. The performance of AgriStack lies in its interoperability, i.e., the degree to which these diverse data streams are standardised.

#### **3. Privacy and Data Sovereignty:**

The most important issue is probably data ownership. Privacy activists have expressed concerns about the possibility of abuse. When a private insurance company actually knows that a farmer’s crop has failed, will they act to reject the claim? It is feared that the commodification of farm data may lead to a form of digital feudalism, in which farmers are treated as data Points to big companies. Legal experts have argued that the absence of a well-developed data protection law specific to the agricultural sector may lead to programs such as AgriStack violating informational privacy. The pool of grainy information about land properties and credit details could erode farmers’ bargaining power if it is shared with commercial parties without specific permission (Oxford Human Rights Hub).

The Digital Personal Data Protection (DPDP) Act, 2023, in India, aims to address situations in which farmers are introduced to Consent Managers, which require giving consent before their data is explicitly shared. But the effectiveness of this mechanism in a low-digital-literacy population is yet to be determined.

### The Future: A Collaborative Ecosystem

Smallholder farming will not become robots, but the farmers will have the power of a digital assistant on their side. With the decrease in the cost of AI models and the increase in the quality of satellite data, the resolution of the global agricultural map is shifting toward the blind spots.

It is heading towards a hyper-local intelligence age. In the near future, a farmer will not only be able to know the weather forecast for their district, but also the level of soil moisture on their piece. They will not only be selling to the local mandi (market), but their produce will also be quality-checked using a smartphone camera and auctioned to buyers all over the country.

This is the difference between taking a gamble and business decision for a smallholder. Big Data is rendering the small farm visible, viable, and valuable. It is changing agriculture from a subsistence to a data-driven business, where the smallest piece of land will have a smarter, more sustainable crop.

### References

- AgriStack India. (2025, April 20). *How AgriStack India is transforming Indian agriculture*. <https://agristack.co.in/how-agristack-india-is-transforming-indian-agriculture/>
- Boomitra. (2025, May 18). *First issuance of URVARA credits*. <https://boomitra.com/landmark-urvara-issuance-india/>
- Cameron, L. (2019, September 29). *Deploying precision agriculture in developing countries provides opportunities, challenges*. Michigan State University. <https://www.canr.msu.edu/news/deploying-precision-agriculture-in-developing-countries-provides-opportunities-challenges>
- CASA Programme. (2024, November). *Inclusive business case study: DeHaat*. <https://casaprogramme.com/wp-content/uploads/2024/11/CASA-Technical-Assistance-Facility-Inclusive-Business-Case-Study-DeHaat.pdf>
- CSM Tech. (2025, May 1). *How AgriStack is empowering India's agricultural ecosystem*. <https://www.csm.tech/blog-details/how-agristack-is-empowering-indias-agricultural-ecosystem>
- EOS Data Analytics. (2025, September 18). *Big data in agriculture: Analytics for smart farming decisions*. EOS.com. <https://eos.com/blog/big-data-in-agriculture/>
- Global Agriculture. (2024, September 5). *Pillars of India's digital agriculture: Empowering farmers with technology*. <https://www.global-agriculture.com/india-region/pillars-of-indias-digital-agriculture-empowering-farmers-with-technology/>
- India Brand Equity Foundation. (2023, October 8). *AgriTech ecosystem in India*. <https://www.ibef.org/blogs/agritech-ecosystem-in-india>
- International Journal of Farmers' Market Research. (2024, January). *A case study of smart agriculture practices in rural India*. IJFMR. <https://www.ijfmr.com/papers/2024/1/38502.pdf>
- ISAM Education. (n.d.). *The three challenges of big data in agriculture: Data collection and integration*. International School of Agri Management. <https://isam.education/en/challenges-of-big-data-in-agriculture-data-collection-and-integration/>
- Market Research Future. (2021, June 21). *India farming as a service market size, share, trends 2032*. <https://www.marketresearchfuture.com/reports/india-farming-as-a-service-market-60396>
- Oxford Human Rights Hub. (n.d.). *The digitisation of agriculture in India: How AgriStack infringes informational privacy*. <https://ohrh.law.ox.ac.uk/the-digitisation-of-agriculture-in-india-how-agristack-infringes-informational-privacy/>
- Singh, S. (2023, February). *A case study of agri-franchising in Bihar*. Indian Institute of Management Ahmedabad. <https://www.iima.ac.in/sites/default/files/2023-02/10-Sukhpal%20Singh-01.pdf>

## Waste to Feed: Black Soldier Fly Larvae as a Circular and Sustainable Protein Source



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### Introduction

The rising global demand for sustainable and efficient protein sources in animal feed has prompted the investigation of alternative protein meals beyond conventional fish meal (FM) and soybean meal (SBM). Black Soldier Fly Larvae (BSFL) meal has attracted considerable interest as a possible alternative due to its nutritional value and ecological advantages. *Hermetia illucens*, known as the black soldier fly, offers an environmentally sustainable and nutritionally adequate alternative for animal feed.

BSFL is a superior protein source, with 31–59% protein and 15–49% fat, contingent upon diet and developmental stage. Its amino acid profile is analogous to that of fish meal, rendering it a feasible substitute in livestock and aquaculture nutrition. In addition to their nutritional benefits, BSFL provide sustainability advantages by being cultivated on organic waste, hence facilitating nutrient recycling and minimizing waste. Moreover, their production necessitates considerably less land, water, and energy compared to traditional feed ingredients, thus reducing environmental effect (Veldkamp et al., 2012).

The regulatory approval of BSFL as a feed component, especially in aquaculture and pet food in the European Union, has facilitated its wider use in chicken, swine, and pet diets. In aquaculture, BSFL has shown suitability for the dietary requirements of carnivorous and omnivorous fish species, including tilapia, salmon, and European sea bass, all of which necessitate high-protein diets. Studies indicate that substituting fish meal with BSFL in aquaculture diets does not adversely affect growth performance or feed efficiency (Biasato et al., 2019). In the nutrition of poultry, livestock, and pets, BSFL has been associated with enhanced growth rates, nutrient digestibility, and gastrointestinal health, establishing it as a viable alternative protein source.

### Advantages of insect-based feed sources in terms of nutrition and sustainability

Exceeding one million documented bug species globally, insects have historically been a part of both animal and human diets owing to their substantial nutritional content. In recent decades, entomophagy, or the ingestion of insects, has garnered notice as an alternative nutritional resource, especially for animal feed. Numerous insect species, such as grasshoppers, termites, caterpillars, houseflies, weevils, and beetles, have been recognized as abundant sources of protein. Insect larvae possess 21–65% crude protein, closely mirroring the protein composition of meat and fish (Van Huis et al., 2015).

### Primary insect protein sources

1. **Black Soldier Fly Larvae (*Hermetia illucens*):** Indigenous to tropical and subtropical areas, BSFL have disseminated worldwide owing to their elevated protein (35–57% DM) and fat (42–49%) content, rendering them a sustainable substitute for traditional protein sources. They can be cultivated on organic waste, advancing circular economy concepts while providing an amino acid profile akin to fish meal. In contrast to soybean meal, BSFL meal is devoid of anti-nutritional elements such as tannins and phytates, hence improving its digestibility (Liu et al., 2017).
2. **Housefly Maggot Meal (*Musca domestica*):** Housefly larvae flourish on organic refuse, offering 40–63% protein and 10–20% fat (dry matter). Their protein quality is analogous to that of fish and meat proteins, featuring favorable fatty acid content (Biasato et al., 2019).
3. **Mealworm (*Tenebrio molitor*):** Mealworms comprise 44–70% protein and 23–47% fat (dry matter), providing important amino acids and B vitamins. Their elevated fat content renders them a significant energy source in animal nutrition (Biasato et al., 2019).

4. **Locusts, Grasshoppers, and Crickets (Orthoptera):** These insects contain 29–70% protein and 4–22% fat (dry matter), in addition to vital minerals such as iron and zinc. They can substitute up to 25% of soymeal or fishmeal in animal feed (Makkar et al., 2014).
5. **Silkworm Pupae Meal (*Bombyx mori*):** SWPM, a by-product of silk manufacture, has 50–80% protein (defatted) and is abundant in important fatty acids and amino acids such as lysine and methionine. Studies demonstrate that SWPM may completely substitute fish meal in layer diets and replace up to 50% in grill meals (Higa et al., 2021).

#### **Advantages of BSFL compared to other insect larvae?**

Black Soldier Fly Larvae (BSFL) are distinguished as a favored source of insect protein owing to their elevated protein content (35-57%) and fat levels (42-49%), contingent upon their diet. Their amino acid composition, which includes lysine, is analogous to that of fish and animal proteins (Mohan et al., 2022). Furthermore, BSFL are abundant in vital minerals including calcium, phosphorus, and iron. In contrast to plant-based feeds like as soybean meal, BSFL are devoid of anti-nutritional elements including tannins and phytates, which may impede digestion and growth. They effectively transform organic waste into nutrient-dense biomass, rendering them environmentally sustainable and economically viable for feed production. Their adaptability, prolific egg production, and safety for human interaction further augment their feasibility as a sustainable protein substitute.

#### **Nutritional profile of BSFL**

BSFL are acknowledged for their superior protein, vital fatty acids, and vitamin composition. Their nutrient composition fluctuates according to developmental stage and food, although it stays exceptionally appropriate for animal feed.

##### **1. Crude protein and amino acid composition**

Black Soldier Fly Larvae (BSFL) provide a competitive edge, exhibiting crude protein (CP) concentrations that peak at 46.2% during early pupal stages and attain 57.6% in post-mortem adults. Defatted BSFL meal increases protein concentration, with partially defatted meal at 55.3% CP and highly defatted meal at 65.5% CP, comparable to fish and meat meals. Their amino acid composition features elevated concentrations of lysine, methionine, and threonine, exceeding those seen in maize gluten meal. Non-essential amino acids, including alanine, proline, and tyrosine, are also plentiful. With a protein recovery rate of 98%, BSFL offer a highly digestible protein source that can effectively substitute soybean meal in animal diets.

##### **2. Crude fat and fatty acid composition**

BSFL exhibit a significant fat content, reaching a maximum of 28.4% by the fourteenth day of development. Their lipid profile comprises important fatty acids such as linoleic (C18:2) and  $\alpha$ -linolenic acid (C18:3), crucial for the growth and wellbeing of poultry and animals. The ratio of linoleic to  $\alpha$ -linolenic acid varies from 6.1:1 to 11.1:1, according with dietary guidelines. BSFL are abundant in dodecanoic acid (C12:0), comprising up to 50.7% of their total fatty acids, in addition to significant quantities of oleic acid (C18:1). Although polyunsaturated fatty acids (PUFAs), such as omega-3s, are scarce, they can be augmented through targeted dietary interventions. Their lipid content enhances meat quality and diminishes oxidative deterioration in animal products.

##### **3. Micro-nutrients and chitin composition**

BSFL supply vital micronutrients such as iron, calcium, phosphorus, zinc, and vitamin E. Their mineral composition fluctuates with developmental stage, as mature larvae had elevated vitamin E levels (6.68 mg/100g) in contrast to early prepupae (3.26 mg/100g) (Liu et al., 2017). Phosphorus and calcium concentrations are elevated throughout the prepupal stage, rendering them a significant mineral resource. BSFL cultivated on equine excrement exhibit elevated phosphorus concentrations (920 mg/100g DM), alongside supplementary minerals comprising 4.43% calcium, 1.56% potassium, 0.41% magnesium, and 0.3% sodium (Higa et al., 2021). Additional research is required to evaluate the mineral bioavailability from black soldier fly larvae cultivated on enhanced organic waste. Chitin, the second most prevalent polysaccharide in nature, is found in BSFL and possesses considerable biological significance (Lee et al., 2008). It augments immunological responses and demonstrates antibacterial, antifungal, and antiviral characteristics. Chitin, extensively used in food, pharmaceuticals, and agriculture, enhances poultry growth performance by bolstering immunity, antioxidant capacity, and intestinal development, rendering it a feasible substitute for antibiotics in feed.

## **Black Soldier Fly Larvae in the nutrition of livestock, poultry, pig, pets, and aquaculture**

The adaptability of BSFL as a protein source has been extensively researched in multiple animal industries, including aquaculture, poultry, livestock, swine, and pet nutrition.

- 1. Aquaculture:** BSFL has become significant in aqua feeds owing to its superior digestibility and alignment with the nutritional requirements of carnivorous and omnivorous fish species. Research demonstrates that substituting a fraction of fish meal with BSFL in aquaculture diets yields equivalent or enhanced growth rates and feed conversion efficiency (Biasato et al., 2019). Moreover, BSFL provides advantageous bioactive substances, including antimicrobial peptides and lauric acid, which can improve fish health and bolster disease resistance.
- 2. Poultry:** In poultry diets, BSFL is an exceptional protein substitute characterized by enhanced digestibility and elevated fat content. Studies indicate that the inclusion of BSFL in chicken feed enhances feed efficiency, growth rates, and immunological responses. Bioactive lipids, including lauric acid, have antibacterial characteristics that enhance intestinal health and overall avian performance (Lee et al., 2008).
- 3. Livestock and Pig:** In the nutrition of pigs and ruminants, BSFL offers a sustainable protein supply that improves feed efficiency and growth performance. The superior protein and fat composition enhances nutrition absorption and overall animal well-being. Moreover, BSFL supplementation has been associated with improved gut microbiota composition, facilitating greater digestion and immunity (Veldkamp et al., 2012).
- 4. Pet Nutrition:** The incorporation of BSFL in pet food is increasing in popularity owing to its hypoallergenic characteristics and superior digestion. It supplies vital amino acids, omega fatty acids, and bioactive peptides that promote skin health, coat quality, and gut microbiota equilibrium in dogs and cats. Research demonstrates that BSFL meal can substitute conventional protein sources in pet diets without compromising palatability and nutritional sufficiency (Shumo et al., 2019).

### **Challenges and prospective outlooks**

#### **1. Regulatory considerations**

Notwithstanding its advantages, the incorporation of BSFL in animal feed requires regulatory authorization in many nations. Although it has received approval for usage in swine and pet feed in many places, additional research and regulatory alignment are required to enhance its global acceptance (Mohan et al., 2022).

#### **2. Cost and scalability**

The extensive production of BSFL meal necessitates effective agricultural and processing methods to maintain cost competitiveness with traditional protein sources. Improvements in automation, feed substrate optimization, and processing techniques are anticipated to reduce production costs in the future (Shumo et al., 2019).

#### **3. Consumer perception**

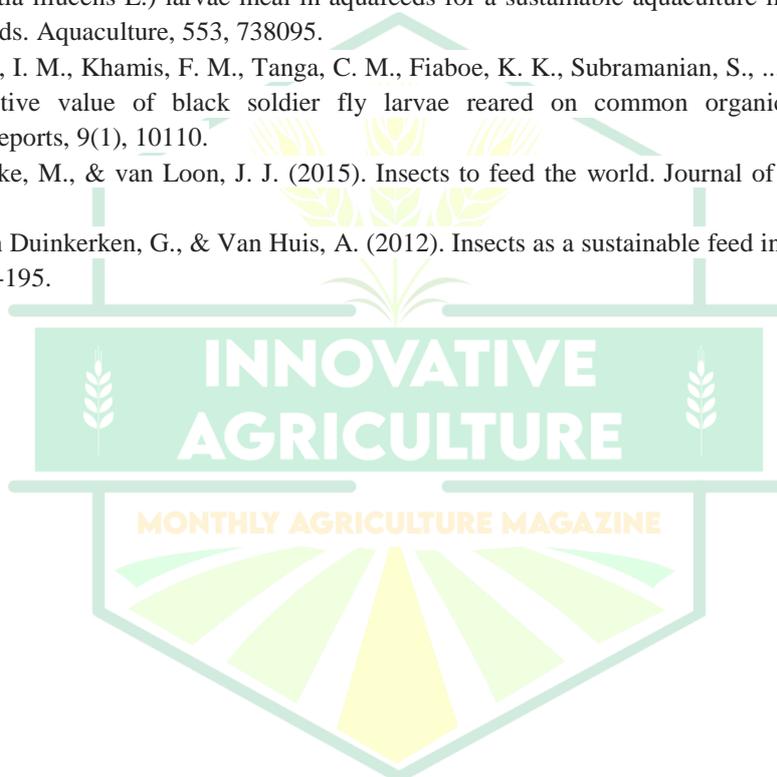
Despite the increasing acceptability of BSFL-based feed, certain consumers continue to exhibit reluctance towards insect-derived goods. Educational and awareness initiatives emphasizing the nutritional and ecological advantages of BSFL can enhance adoption rates among pet owners and farmers (Van Huis et al., 2015).

### **Conclusion**

BSFL serve as a sustainable, nutritious, and eco-friendly alternative protein source for swine and pet feed. Their elevated protein content, functional attributes and little ecological impact render them a compelling choice for the future of animal nutrition. Progress in research, regulatory structures, and production technologies will be essential for expanding BSFL-based feed solutions and promoting their general acceptance in international markets. The incorporation of BSFL into the diets of livestock, poultry, and aquaculture represents a significant advancement in sustainable animal nutrition. With the advancement of scientific knowledge and commercial utilization, BSFL possess the capacity to substantially enhance a more sustainable and efficient global food system.

## References

- Biasato, I., Renna, M., Gai, F., Dabbou, S., Meneguz, M., Perona, G., ... & Gasco, L. (2019). Partially defatted black soldier fly larva meal inclusion in piglet diets: effects on the growth performance, nutrient digestibility, blood profile, gut morphology and histological features. *Journal of animal science and biotechnology*, 10(1), 12.
- Higa, J. E., Ruby, M. B., & Rozin, P. (2021). Americans' acceptance of black soldier fly larvae as food for themselves, their dogs, and farmed animals. *Food Quality and Preference*, 90, 104119.
- Lee, C. G., Da Silva, C. A., Lee, J. Y., Hartl, D., & Elias, J. A. (2008). Chitin regulation of immune responses: an old molecule with new roles. *Current opinion in immunology*, 20(6), 684-689.
- Liu, X., Chen, X., Wang, H., Yang, Q., ur Rehman, K., Li, W., ... & Zheng, L. (2017). Dynamic changes of nutrient composition throughout the entire life cycle of black soldier fly. *PloS one*, 12(8), e0182601.
- Makkar, H. P., Tran, G., Heuzé, V., & Ankers, P. (2014). State-of-the-art on use of insects as animal feed. *Animal feed science and technology*, 197, 1-33.
- Mohan, K., Rajan, D. K., Muralisankar, T., Ganesan, A. R., Sathishkumar, P., & Revathi, N. (2022). Use of black soldier fly (*Hermetia illucens* L.) larvae meal in aquafeeds for a sustainable aquaculture industry: A review of past and future needs. *Aquaculture*, 553, 738095.
- Shumo, M., Osuga, I. M., Khamis, F. M., Tanga, C. M., Fiaboe, K. K., Subramanian, S., ... & Borgemeister, C. (2019). The nutritive value of black soldier fly larvae reared on common organic waste streams in Kenya. *Scientific reports*, 9(1), 10110.
- Van Huis, A., Dicke, M., & van Loon, J. J. (2015). Insects to feed the world. *Journal of Insects as Food and Feed*, 1(1), 3-6.
- Veldkamp, T., Van Duinkerken, G., & Van Huis, A. (2012). Insects as a sustainable feed ingredient in pig. *food chemistry*, 50, 192-195.



## Molecular Tools in Modern Aquaculture: A Fish Biology Perspective



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### Abstract:

Modern aquaculture is increasingly dependent on advanced biological approaches to overcome challenges related to fish health, productivity, and sustainability. Molecular tools have emerged as powerful techniques for understanding fish biology at the genetic and cellular levels, enabling precise interventions in breeding, disease management, and conservation. Techniques such as molecular markers, polymerase chain reaction, DNA barcoding, and genomic analysis provide valuable insights into genetic diversity, stock improvement, pathogen detection, and reproductive regulation in fishes. These approaches support the development of robust aquaculture systems by improving growth performance, enhancing disease resistance, and maintaining biodiversity. This article highlights the significance of molecular tools in modern aquaculture from a fish biology perspective and emphasizes their role in promoting sustainable and scientifically driven fisheries development.

**Keywords:** Aquaculture; Fish Biology; Molecular Tools; Genetic Diversity; Disease Diagnostics; DNA Barcoding; Genomics; Sustainable Fisheries

### Introduction

Aquaculture has emerged as one of the fastest-growing sectors of global food production and plays a vital role in ensuring food and nutritional security for a rapidly increasing population. Fish and other aquatic organisms are valued sources of high-quality protein, essential fatty acids, vitamins, and minerals. With capture fisheries reaching their maximum sustainable limits, aquaculture has become the primary means of meeting the rising demand for animal protein, particularly in developing countries where fish contributes significantly to livelihoods and economic growth.

Despite its rapid expansion, the aquaculture sector faces several biological and environmental challenges that restrict sustainable production. Disease outbreaks remain one of the most serious constraints, often leading to massive economic losses and threatening farm viability. In addition, poor-quality seed, inbreeding depression, environmental stress due to fluctuating water quality, climate change, and the gradual erosion of genetic diversity further compromise productivity and resilience in cultured fish populations. Traditional management practices alone are often insufficient to address these complex challenges.

In this context, molecular biology has brought a paradigm shift to modern aquaculture by enabling a deeper understanding of fish biology at genetic, molecular, and cellular levels. Molecular tools provide precise, rapid, and reliable methods to analyze genetic variation, identify pathogens, and understand physiological responses to stress and disease. These techniques allow scientists and aquaculture practitioners to make informed decisions regarding broodstock selection, breeding strategies, health management, and conservation of valuable fish genetic resources.

The integration of molecular approaches into aquaculture has transformed conventional practices into more scientific, targeted, and sustainable systems. By bridging fundamental fish biology with applied aquaculture, molecular tools offer promising solutions to improve productivity while ensuring environmental sustainability and long-term genetic health of cultured fish populations. This article explores the role of molecular tools in modern aquaculture from a fish biology perspective and highlights their potential in shaping the future of sustainable fisheries and aquaculture development.

### Understanding Genetic Diversity and Stock Improvement

Genetic diversity forms the foundation of healthy and productive aquaculture systems. In fish populations, genetic variability ensures resilience against diseases, environmental stresses, and inbreeding depression. Loss of genetic

diversity can lead to reduced growth, poor survival, susceptibility to pathogens, and a decline in overall stock quality. Therefore, monitoring and managing genetic diversity is a critical step in modern aquaculture.

Molecular tools have revolutionized the assessment of genetic diversity in fish. Techniques such as **Random Amplified Polymorphic DNA (RAPD)**, **microsatellite markers**, and **mitochondrial DNA analysis** allow researchers to examine genetic differences at the molecular level. RAPD markers are widely used for quickly screening genetic variation without prior knowledge of the genome. Microsatellites, with their high polymorphism and co-dominant inheritance, provide precise information on allelic variation within and between populations. Mitochondrial DNA markers, being maternally inherited and highly conserved, help trace lineage, population structure, and evolutionary relationships.

These molecular analyses serve multiple purposes in aquaculture. First, they help **identify genetically superior broodstock**, which exhibit desirable traits such as faster growth, better feed conversion, and enhanced stress tolerance. Second, they **prevent inbreeding**, which is common in closed or intensive aquaculture systems. Inbreeding can result in reduced fertility, slower growth, and increased vulnerability to diseases. By selecting broodstock based on genetic profiles, aquaculture practitioners can maintain robust, diverse, and healthy populations.

Moreover, these tools support **selective breeding programs**, enabling the systematic improvement of fish stocks over generations. Breeders can prioritize specific traits, such as disease resistance, thermal tolerance, or feed efficiency, while maintaining overall genetic diversity. This approach not only enhances productivity but also contributes to the sustainability of aquaculture systems by producing resilient fish that can adapt to environmental changes.

In addition, understanding genetic diversity is crucial for **conservation and management of indigenous and endangered fish species**. By analyzing genetic structure, researchers can identify unique populations, design breeding programs to preserve rare alleles, and prevent genetic homogenization caused by indiscriminate crossbreeding.

Although, molecular tools provide a **powerful, precise, and efficient means** to assess genetic diversity, identify superior stocks, and implement scientifically guided breeding strategies. Integrating these techniques into aquaculture practices ensures healthier, more productive, and sustainable fish populations, ultimately supporting the growth of modern aquaculture worldwide.

#### **Molecular Diagnostics for Fish Health Management**

Disease outbreaks are one of the most critical challenges in aquaculture, often causing massive economic losses and threatening the sustainability of fish farming operations. Pathogens—including bacteria, viruses, fungi, and parasites—can spread rapidly in intensive culture systems, and conventional diagnostic methods such as visual inspection, culture-based techniques, or histopathology are often **time-consuming, labor-intensive, and less sensitive**, especially during the early stages of infection.

To address these limitations, **molecular diagnostic tools** have become an indispensable part of modern aquaculture. Techniques like **Polymerase Chain Reaction (PCR)**, **real-time PCR (qPCR)**, **Loop-mediated Isothermal Amplification (LAMP)**, and **DNA sequencing** allow for **rapid, highly sensitive, and specific detection** of pathogens at the genetic level. These methods can detect minute amounts of pathogen DNA or RNA, often before clinical signs appear in the host, enabling **early intervention and disease management**.

For example, PCR can amplify pathogen-specific DNA sequences, allowing precise identification of bacterial strains such as *Aeromonas* or *Vibrio* species. Real-time PCR further improves detection by quantifying pathogen load, helping farmers understand the severity of infection and monitor treatment efficacy. DNA sequencing provides detailed information on pathogen identity and genetic variations, which is crucial for tracking outbreaks and preventing recurrence.

The benefits of molecular diagnostics extend beyond early detection. By enabling accurate and timely identification of pathogens, these tools **reduce the unnecessary use of antibiotics and chemical treatments**, promoting environmentally friendly aquaculture practices. Minimizing chemical intervention not only protects the aquatic ecosystem but also reduces the risk of antibiotic resistance in pathogens, ensuring safer fish for human consumption.

Additionally, molecular diagnostics support **disease surveillance programs**, which are essential for maintaining biosecurity in hatcheries and grow-out systems. Regular monitoring using molecular tools allows farm managers to detect emerging pathogens, implement quarantine measures, and adjust husbandry practices before large-scale outbreaks occur.

In review, molecular diagnostics have transformed fish health management by providing **fast, precise, and reliable detection** of pathogens. Their integration into aquaculture systems enhances productivity, reduces economic losses, and promotes sustainable and responsible fish farming. By combining molecular approaches with traditional husbandry practices, aquaculture can achieve both **high efficiency and ecological safety**, securing the future of modern fish production.

### **Role of Molecular Tools in Fish Reproduction**

Reproductive efficiency is a cornerstone of successful aquaculture, directly influencing seed production, stock sustainability, and overall productivity. Traditional methods of studying fish reproduction often rely on observation of gonadal development, spawning behavior, and hormone assays. While useful, these approaches can be **time-consuming and limited in precision**, particularly for early detection of sex or maturation stages. Molecular biology has revolutionized this field by providing tools that enable a **deeper and more precise understanding of reproductive physiology in fishes**.

**Gene expression studies** are one of the key molecular approaches applied in aquaculture. By analyzing the transcription levels of specific genes, researchers can identify the hormones and regulatory pathways that control gonadal development, maturation, and spawning. For instance, genes related to gonadotropins, aromatase, and steroid hormone receptors can indicate the onset of sexual maturity or reproductive readiness. Such insights are particularly valuable for **induced breeding programs**, where precise timing and selection of broodstock are critical for successful spawning.

Molecular tools also enable **early sex determination**, which is highly beneficial in species where one sex exhibits superior growth or market value. Using **molecular sex markers**, scientists can identify the sex of fish at larval or juvenile stages, long before sexual characteristics become visible. This allows aquaculture practitioners to **selectively culture the desired sex**, enhancing growth performance, feed efficiency, and overall production yields.

Additionally, molecular approaches aid in **broodstock management and conservation**. By assessing genetic variation and reproductive gene expression in breeding populations, farmers and researchers can avoid inbreeding, maintain healthy broodstock, and optimize breeding cycles. These techniques also contribute to the development of **species-specific breeding protocols**, improving reproductive success in both freshwater and marine aquaculture systems.

In conclusion, molecular tools have significantly advanced our understanding of fish reproduction, providing **precise, rapid, and actionable insights** that support efficient breeding and stock management. By integrating gene expression studies and molecular sex identification into aquaculture practices, fish farmers can improve hatchery efficiency, maintain genetic health, and enhance the sustainability of cultured populations.

### **Applications in Conservation and Biodiversity Management**

Aquatic biodiversity is facing increasing threats worldwide due to overfishing, habitat degradation, pollution, and climate change. Many indigenous and economically important fish species are now at risk, and the loss of genetic diversity can have severe consequences for ecosystem stability and aquaculture productivity. In this context, **molecular tools have emerged as powerful instruments for conservation biology and sustainable fisheries management**.

One of the most widely used molecular techniques in conservation is **DNA barcoding**. By analyzing a short, standardized region of the mitochondrial genome, scientists can accurately identify fish species, even at early life stages or when morphological features are ambiguous. This capability is especially valuable for distinguishing **closely related species**, detecting **cryptic species**, and resolving taxonomic ambiguities that often hinder effective management strategies.

Molecular tools also facilitate the study of **population structure and genetic diversity**, which are critical for designing conservation plans. By examining genetic variation within and between populations, researchers can

identify **genetically distinct stocks**, monitor changes in population health, and prioritize populations that require urgent protection. Such information is essential for establishing **broodstock programs, restocking initiatives, and habitat restoration efforts**, ensuring the long-term survival of threatened species.

In addition, molecular techniques play a crucial role in **monitoring illegal and unregulated trade** of fish species. DNA-based species identification helps regulatory authorities detect mislabeling, prevent the exploitation of endangered species, and enforce compliance with conservation laws.

Beyond individual species, molecular approaches also support **ecosystem-level conservation** by tracking the genetic diversity of multiple species within aquatic habitats. This holistic view enables scientists to understand the resilience of ecosystems and the potential impacts of environmental changes on biodiversity.

In summary, molecular tools such as DNA barcoding, microsatellite analysis, and mitochondrial DNA sequencing are invaluable for **conservation planning, sustainable management, and biodiversity monitoring** in fisheries. By providing precise and actionable insights, these techniques empower aquaculture practitioners, researchers, and policymakers to protect aquatic resources, maintain genetic diversity, and ensure the sustainable use of fish populations for future generations.

### Emerging Trends: Genomics and Gene Editing

Recent advancements in **genomics and transcriptomics** are transforming aquaculture by enabling a deeper understanding of fish biology at the molecular level. **Whole-genome sequencing** allows researchers to explore the complete genetic blueprint of a species, providing insights into genes responsible for critical traits such as growth rate, immune response, stress tolerance, and reproductive efficiency. By mapping these genes and understanding their interactions, scientists can develop strategies to optimize fish performance and productivity in aquaculture systems.

In addition to genome analysis, **transcriptomic studies**—which examine RNA expression patterns—reveal how genes are activated or suppressed in response to environmental stress, pathogens, or dietary interventions. This information helps identify **molecular pathways that regulate immunity, metabolism, and adaptation**, enabling targeted improvements in fish health and culture practices.

One of the most promising innovations in modern aquaculture is **gene-editing technology**, particularly **CRISPR-Cas systems**. This precise and efficient method allows scientists to modify specific genes to enhance desirable traits, such as disease resistance, faster growth, or tolerance to environmental stressors. Although gene editing in aquaculture is still under ethical, regulatory, and biosafety scrutiny, its potential to revolutionize fish breeding is immense. By directly manipulating genetic pathways, researchers can accelerate selective breeding programs and develop superior fish strains without relying solely on traditional methods.

From a **fish biology perspective**, genomics and gene editing not only improve production traits but also provide fundamental insights into physiological and molecular mechanisms. Understanding how genes control immune responses, hormonal regulation, or metabolic pathways allows researchers to design **precision-based aquaculture strategies**, which can enhance both productivity and sustainability.

In summary, the integration of genomics and gene-editing tools in aquaculture represents a **cutting-edge approach** for improving fish health, growth, and adaptability. These technologies promise to transform modern aquaculture from conventional practices into **science-driven, efficient, and sustainable systems**, while simultaneously advancing our understanding of the molecular biology of fishes.

### Challenges and Future Prospects

While molecular tools have revolutionized aquaculture, their widespread application faces several challenges. One of the primary obstacles is **high cost**. Advanced techniques such as whole-genome sequencing, transcriptomics, and gene editing require sophisticated laboratory equipment, reagents, and computational resources, which may be prohibitive for small- and medium-scale aquaculture operations.

Another challenge is the **requirement for technical expertise**. Molecular diagnostics, bioinformatics analysis, and gene-editing procedures demand skilled personnel with specialized training. Without proper capacity-building and training programs, the effective implementation of these tools at the field level remains limited.

**Regulatory and ethical concerns** also play a significant role, particularly in the context of genetically modified

or gene-edited fish. Approval processes, biosafety regulations, and public perception can slow down the adoption of advanced molecular approaches in commercial aquaculture. Additionally, translating laboratory research into practical, cost-effective applications in farms requires careful planning and validation.

Despite these challenges, the **future prospects of molecular aquaculture are highly promising**. As awareness increases and infrastructure for research and training improves, more aquaculture practitioners will be able to adopt molecular tools for breeding, disease management, and conservation. Interdisciplinary collaboration between molecular biologists, fish physiologists, aquaculture specialists, and policymakers will be essential to develop scalable solutions.

Looking ahead, integrating molecular techniques with **precision aquaculture**, smart monitoring systems, and sustainable management practices is expected to create **resilient, high-yielding, and environmentally friendly aquaculture systems**. By overcoming current limitations, molecular approaches can become a cornerstone of modern aquaculture, supporting food security, biodiversity conservation, and the economic growth of the sector.

### Conclusion

Molecular tools have fundamentally transformed modern aquaculture by offering a **comprehensive understanding of fish biology**, from genetic and molecular mechanisms to organismal physiology. Techniques such as molecular markers, DNA barcoding, PCR-based diagnostics, genomics, and gene-editing have opened new avenues for **improving growth, disease resistance, reproductive efficiency, and genetic conservation** in cultured fish populations.

The integration of these molecular approaches with traditional aquaculture practices not only enhances productivity but also supports **sustainable and environmentally responsible fish farming**. By enabling early disease detection, selective breeding, and precise monitoring of biodiversity, molecular tools help maintain **healthy, resilient, and genetically diverse stocks**, which are essential for long-term food security.

Looking forward, advances in genomics, transcriptomics, and gene-editing, coupled with increased accessibility and capacity-building, are expected to make molecular interventions **more practical and widely adopted in aquaculture systems**. These innovations promise to transform conventional fish farming into a **science-driven, high-efficiency, and sustainable sector**, capable of meeting global nutritional demands while conserving aquatic ecosystems.

In summary, the application of molecular biology in aquaculture represents a **powerful convergence of science and practice**, ensuring the health, productivity, and sustainability of aquatic resources for current and future generations.

### References

1. Al-Omairi, M. S. S. (2025). Random Amplified Polymorphic DNA – PCR technique in fish genetic diversity studies. *Indonesian Journal on Health Science and Medicine*. [ijhsm.umsida.ac.id](http://ijhsm.umsida.ac.id)
2. Modeel, S., Joshi, B. D., Yadav, A., Negi, T., & Negi, R. K. (2025). DNA-based identification of fishes: Barcoding methods and efficiency assessment. *Iranian Journal of Ichthyology*. [ijichthyol.org](http://ijichthyol.org)
3. Zhao, S., et al. (2024). Integrated DNA barcoding methods for species identification. *Food Research International*. [ScienceDirect](https://www.sciencedirect.com)
4. Aquatic molecular barcoding improves traceability and conservation of species. *Molecular Barcoding: A Tool to Guarantee Correct Seafood Labelling...* MDPI. (2025). [MDPI](https://www.mdpi.com)
5. Abdelsalam, M., et al. (2022). A review of molecular diagnosis of bacterial fish diseases. *Aquaculture International*. [PubMed](https://pubmed.ncbi.nlm.nih.gov/)
6. Ador, M. A. A., et al. (2022). Potential application of PCR-based molecular methods in fish pathogen identification. *Aquaculture Studies*. [aquast.org](http://aquast.org)
7. Halder, C. (2020). Molecular markers and their application in aquaculture: new opportunities and challenges. *Fauna Journal*. [faunajournal.com](http://faunajournal.com)
8. Microsatellites as molecular markers with applications in aquatic animal populations. *PubMed*. (2023). [PubMed](https://pubmed.ncbi.nlm.nih.gov/)

9. Research advances in genomics and applications for molecular breeding of aquaculture animals. *Aquaculture*. (2020). [ScienceDirect](#)
10. Sukumaran, S. (2023). Genetic and genomic tools in fisheries and aquaculture. *ICAR-CMFRI Workshop Proceedings*. [eprints.cmfri.org.in](#)
11. Maluwa, A. (2022). Genomics, genetics, and breeding in aquaculture. *ScienceDirect*. [ScienceDirect](#)
12. Bayır, A. (2025). CRISPR/Cas-based genetic improvement of aquaculture species. *MDPI Aquaculture*. [MDPI](#)
13. Robinson, N. A. (2024). A guide to assess the use of gene editing in aquaculture. *Wiley Online Library*. [Wiley Online Library](#)
14. Huang, Y. (2025). Fish genomics applied to disease-resistance breeding. *RAQ Journal*. [Wiley Online Library](#)
15. Ramzan, S. (2025). Advances in molecular and genomic tools for sustainable fisheries management. *Haya Saudi Journal of Life Sciences*. [Scholars Middle East Publishers](#)
16. DNA barcoding in ecological and conservation contexts. *Wikipedia: DNA barcoding*. (2025). [Wikipedia](#)
17. Fish DNA barcoding and environmental DNA applications. *Wikipedia: Fish DNA barcoding*. (2025). [Wikipedia](#)
18. Marker-assisted selection in breeding programs. *Wikipedia: Marker-assisted selection*. (2025). [Wikipedia](#)
19. Genome sequencing applications in conservation biology. *Wikipedia: Genome sequencing of endangered species*. (2025). [Wikipedia](#)
20. Genetic and genomic technologies reshape fisheries science. *FAO Fisheries Proceedings*. (2023). [FAOHome](#)
21. RAPD and microsatellite analysis in common carp broodstock. *ScienceDirect*. (2003). [ScienceDirect](#)
22. Silva, A. J., et al. (2020). PCR cloning combined with DNA barcoding identification of fish species. *Frontiers in Ecology and Evolution*. [Frontiers](#)



## Feeding India in a Warming World: Climate Risks and Food Futures



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The fragile mantle of topsoil and the once-predictable cadence of the seasons have long functioned as the unseen engines of human civilization. In India, this truth transcends science and enters the realm of culture and consciousness. For millennia, the *Ritu Chakra* - the traditional cycle of six seasons shaped agricultural practices, food habits, festivals, and rural economies across the subcontinent. Climate, in this sense, was not merely observed; it was lived. Today, however, these foundational systems are under unprecedented strain. Rising global temperatures are eroding the very distinction between episodic *weather woes*—manifested as erratic storms, heat waves, and droughts—and the deeper *climate crisis*, characterized by the long-term destabilization of Earth's natural rhythms. What once appeared as isolated anomalies is now converging into a single, pervasive, and existential threat.

This convergence casts a long and ominous shadow over India's food security. The challenge before us cannot be met through incremental interventions better seeds, enhanced irrigation, or higher subsidies alone. Instead, it calls for a fundamental reorientation of how we generate knowledge, educate practitioners, and cultivate the land. Indian agriculture is entering a transformative phase: a shift from the traditional paradigm of *managing production* to a far more complex and urgent mandate—*managing uncertainty*. In this new reality, resilience, foresight, and climate intelligence will define the sustainability of our food systems.

### **1. The Double Threat: Volatility and Crisis in the Indian Heartland**

Global warming is no longer a distant projection discussed in international summits; it is a lived reality for the Indian farmer. We are witnessing a transition from the predictable agricultural cycles that fueled the Green Revolution to a state of permanent volatility.

#### **1.1. Immediate Weather Woes**

These are the acute shocks to the system. In recent years, India has seen a rise in "flash droughts"—rapid-onset moisture stress that can parch the Marathwada region in weeks—followed by extreme "cloudburst" events. In the wheat belts of Punjab and Haryana, unseasonal hailstorms and heatwaves in March (the terminal heat stage) have begun to flatten standing crops, leading to significant shriveling of grains. This volatility turns farming into a high-stakes gamble, where a year's worth of investment can be liquidated by forty-eight hours of erratic weather.

#### **1.2. The Structural Climate Crisis**

Beyond the storms lies the slow-onset disaster. In the Sundarbans and coastal Odisha, rising sea levels are pushing saltwater deep into the hinterlands. This soil salinization renders traditional paddy varieties useless, forcing a migration of people and a loss of ancestral knowledge. Simultaneously, the warming climate is altering the biological geography of India. The 2020 locust attacks across Rajasthan and Gujarat, driven by unusual cyclonic patterns in the Arabian Peninsula, served as a grim reminder that a warming world creates new corridors for biological threats.

Most critically, the "Third Pole"—the Himalayan glaciers—is receding. As these glaciers melt, the perennial rivers of the Indo-Gangetic plain face a future of "peak water" (flooding) followed by long-term scarcity. This threatens the very breadbasket that ensures India's National Food Security Act remains functional.

## 2. Reorienting Education: From "Factory Farming" to "Ecosystem Management"

To meet these challenges, the Indian educational system must undergo a paradigm shift. For decades, agricultural universities have taught a "linear" model: add nitrogen, add water, get yield. This model is failing in a non-linear climate. We must move toward "climate-smart" literacy.

### 2.1. A Need-Based, Tech-Forward Curriculum

Modern agriculture education must integrate Data Science, Meteorology, and Regenerative Ecology. A student graduating from an agricultural university in Bihar or Karnataka should be as fluent in interpreting satellite-based soil moisture data and weather telemetry as they are in understanding soil pH. We must introduce "Climate-Resilient Agriculture" (CRA) as a core discipline, where students learn to manage carbon cycles and biodiversity as primary farm outputs alongside grain.

### 2.2. The Role of Top-Class Professional Teachers

We must elevate the status of agricultural educators. To produce top-tier graduates, we need teachers who are not just lecturers but practitioners. This involves investing in the recruitment of world-class faculty and ensuring they have access to continuous training. When research on CRISPR-edited drought-tolerant crops or advanced hydroponics is developed, it shouldn't stay trapped in academic journals. Top-class teachers act as the conduit, ensuring that cutting-edge science reaches the student and, eventually, the farmer's soil.

### 2.3. The Digital Revolution: AI, IoT, and Precision Farming

The integration of Artificial Intelligence (AI), the Internet of Things (IoT) and precision farming represents a technological leapfrogging for Indian agriculture.

- **AI Analytics:** AI can process vast amounts of historical weather data and satellite imagery to provide hyper-local "micro-weather" forecasts. In a country where the monsoon can vary from one village to the next, AI-driven precision can tell a farmer exactly when to sow to avoid a dry spell.
- **IoT in the Field:** Low-cost sensors can now monitor soil moisture, nitrate levels, and ambient temperature in real-time. For a small farmer, this means moving from "scheduled" irrigation to "need-based" irrigation, saving precious groundwater.
- **Precision Farming:** A strategic shift from input-intensive agriculture to data-driven efficiency. By integrating satellite imagery, sensors, AI-based advisories, and site-specific management, it enables optimal use of water, nutrients, and energy while minimizing environmental stress. For policymakers, precision agriculture offers a scalable pathway to enhance productivity, reduce risk, and improve farm incomes—especially when embedded within extension systems and supported by targeted incentives.

## 3. Bridging the Gap: Research, Extension, and Citizen Science

The "lab-to-land" pipeline in India is currently too slow. While India has one of the world's largest National Agricultural Research Systems (NARS), there is a disconnect between high-level innovation and the 85% of farmers who are small and marginal.

### 3.1. Focus on Small and Marginal Farmers

Research must pivot to prioritize low-cost, high-impact innovations. This includes the development of indigenous, climate-resilient seeds (like deep-water rice or drought-hardy millets) that require fewer chemical inputs.

### 3.2. Integration of Citizen Science

We must stop viewing farmers as mere "end-users" and start viewing them as "co-researchers." Citizen Science involves farmers collecting data on local pest outbreaks, soil health, and rainfall patterns, and feeding this into a national database. This "bottom-up" data collection allows scientists to see real-time trends that a satellite might miss.

### 3.3. Revitalizing Extension Personnel

Extension workers are the "first responders" of the climate crisis. The current ratio of extension workers to farmers in India is woefully inadequate. These workers require intensive, ongoing training and must be equipped with digital tools to provide site-specific advice. They are the bridge that translates "big data" into "local action."

### 3.4. Incentivizing Sustainability and On-Farm Training

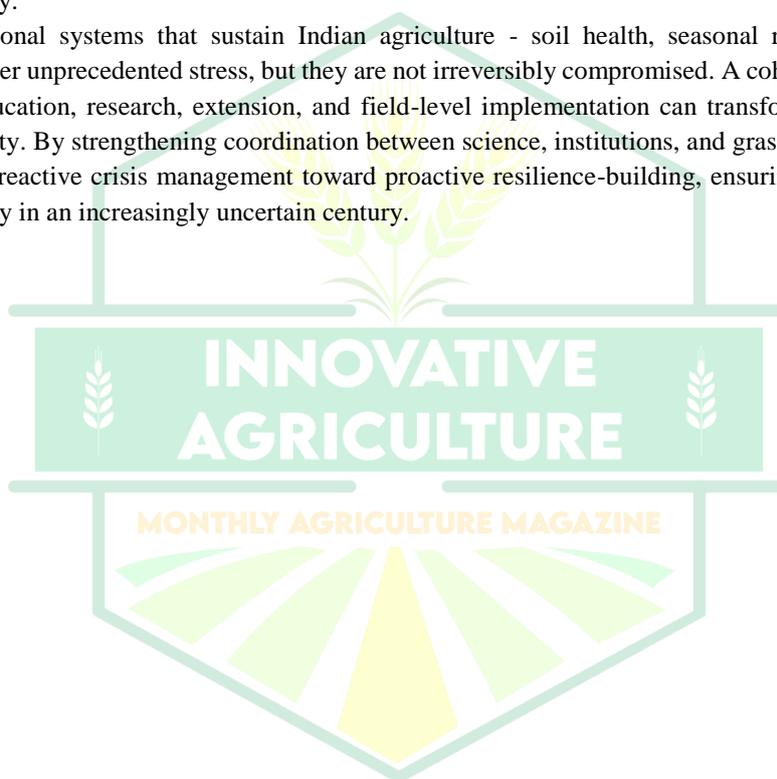
Knowledge alone cannot drive change if the economics don't add up. We must make sustainability the most profitable choice for the Indian farmer.

- **On-Farm Training:** Moving education out of the lecture hall and onto the field is essential. When farmers see a successful demonstration of "Natural Farming" or "LBNF" (Low Budget Natural Farming) in their own climate zone, the fear of risk diminishes.
- **Economic Incentives:** Governments must provide tangible rewards for sustainable practices. This includes Green Credits for carbon sequestration, subsidized insurance for those who adopt crop diversification, and premium price support for climate-resilient crops like millets.

#### 4. **Cultivating Tomorrow: Towards an Agricultural Renaissance**

The future of India's food security will hinge on the effectiveness of public policy in anticipating and responding to a rapidly changing climate. While rainfall and extreme events remain beyond direct control, the capacity to reduce vulnerability through preparedness, planning, and institutional resilience lies squarely within the domain of governance. Strategic investments in climate-responsive education, the systematic integration of artificial intelligence and Internet of Things technologies into agricultural decision-making, and the direct delivery of risk-mitigation tools supported by appropriate incentives to small and marginal farmers must form the cornerstone of national food policy.

The foundational systems that sustain Indian agriculture - soil health, seasonal rhythms, and farmer livelihoods are under unprecedented stress, but they are not irreversibly compromised. A coherent realignment of policies across education, research, extension, and field-level implementation can transform climate risk into managed uncertainty. By strengthening coordination between science, institutions, and grassroots practice, India can move beyond reactive crisis management toward proactive resilience-building, ensuring food security and agricultural stability in an increasingly uncertain century.



## From Farms to the World: High-Value Agri-Export



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### Introduction

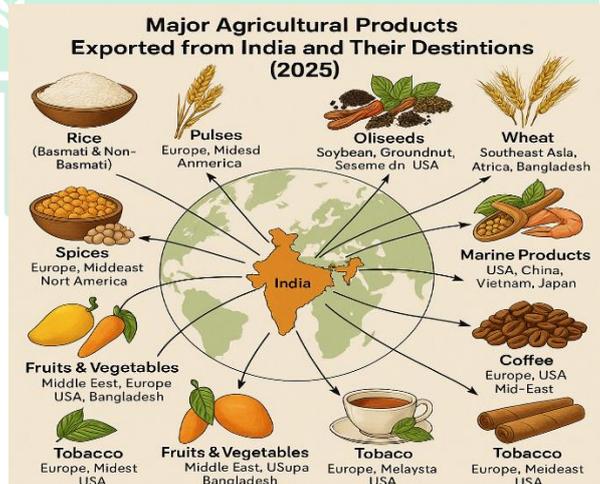
India is not solely a land of ancient cultures and rich diversity; it is also on the verge of becoming a food superpower. With its fertile regions extending from Punjab to Andhra Pradesh, varied agro-climatic conditions, and a populace deeply engaged in agriculture, India stands at the center of global food production. However, to emerge as a genuine global supplier of high-quality food products, India needs to pursue a strategic, contemporary, and quality-focused approach.

Agricultural exports represent more than just the movement of goods; they encompass the livelihoods of Indian farmers, the nation's reputation, and innovative developments that reach dining tables across the world. Recently, India's agricultural export statistics have indicated consistent growth, showcasing an array of products including rice, spices, fruits, processed foods, organic items, and an expanding variety of offerings.

### The Advantages That Distinguish India

#### 1. Richness and Variety

The agricultural landscape of India is remarkable. From Basmati rice that captivates customers in the Middle East and Europe to spices that enrich cuisines globally, Indian agricultural products have a ready market around the world. India is already among the leading exporters of rice and spices, with trading practices that date back centuries.



#### 2. Proactive Government Policies

Initiatives such as the Agricultural Export Policy (2018) promote diversification that goes beyond conventional bulk exports to encompass high-value and processed foods, organic goods, and niche products. These policies aim to not only boost export quantities but also elevate farmers' incomes and improve their access to markets.

#### 3. Developing Value Chains and Processing

Shifting focus from merely exporting raw commodities, India is venturing into the realm of value-added food products—such as ready-to-eat meals, processed fruits, juices, and ethnic snacks. Processing enhances shelf life, increases nutritional value, and enables Indian brands to command higher prices in international markets.

## Quality: The Key to Global Markets

Exporting food to demanding markets — such as the European Union, USA, Japan, or Australia — necessitates adherence to strict quality standards. Here, quality encompasses more than just freshness: it includes safety, traceability, certification, and sustainability.

### 1. Adhering to Global Standards

International customers expect products that meet rigorous food safety and agricultural regulations. India has enhanced its testing, certification, and traceability systems to guarantee that exports align with worldwide expectations. Certifications such as Global GAP and organic qualifications are increasingly prevalent among exporters.

### 2. Food Testing and Laboratory Networks

To ensure quality, India is establishing food testing laboratories capable of analysing pesticide residues, heavy metals, nutritional information, and more. This infrastructure is crucial for Indian exporters seeking to gain access to premium markets characterized by consumers with high quality expectations.

### 3. Transparency and Traceability

Consumers across the globe are keen to understand the origins of their food. Digital traceability solutions — incorporating blockchain and IoT — help document each step from production to consumption. This level of transparency fosters trust, enhances brand reputation, and often enables Indian products to penetrate markets that previously appeared out of reach.

### Overcoming Challenges on the Path Forward

While the potential is significant, so too are the obstacles:

#### 1. Issues in Logistics and Cold Chain

The export of food—particularly perishable items such as fruits and vegetables—relies on quick, effective transportation and cold chain systems. Enhancing this area is crucial to minimize waste, uphold quality, and keep items fresh during shipping.

#### 2. Diversification of Markets

A large portion of Indian exports is directed towards a limited number of destinations. Investigating growing markets in Africa, Southeast Asia, and Latin America can help mitigate the impacts of global trade fluctuations and expand demand.

#### 3. Inclusion of Small Farmers

The majority of farmers in India manage small-scale farms. To compete on a global level, these farmers require assistance—ranging from access to quality supplies to education on international standards and improved collective efforts through cooperatives or Farmer Producer Organizations (FPOs).

### Strategic Pathways for a Global Presence

To establish India as a credible and esteemed global provider of high-quality food, various strategic pathways must be enhanced:

#### 1. Focus on Technological Investment

Utilizing advanced farming techniques, digital platforms, blockchain for traceability, and modern processing technology will increase productivity and in still confidence in Indian goods among international buyers.

#### 2. Enhance Brand India

The concept of “Brand India” for food exports involves delivering consistent quality, recognized certifications, and narratives that link consumers to Indian farms. Geographic Indication (GI) tags for items such as Basmati rice and Alphonso mangoes help to elevate them as premium brands on the global market.

#### 3. Establish Strong Trade Agreements

Free Trade Agreements (FTAs), such as the India–EFTA agreement, enhance market access by lowering tariffs and making Indian food products more competitive



EFTA Agreement

internationally. These agreements facilitate Indian exporters' entry into affluent markets while fostering lasting trade partnerships.

#### **India's Global Food Vision: A Win-Win Future**

Ultimately, the goal of transforming India into a global supplier of quality food rests on fulfilling international demand and enhancing the livelihoods of its farming communities. It signifies converting agricultural land into hubs of prosperity, linking rural areas to global food markets, and turning India's agricultural richness into globally trusted, quality-assured food items.

This endeavor—rooted in quality, sustainability, innovation, and cooperative trade—will not only bolster India's international status but also guarantee food security, economic stability, and rural development for future generations.

#### **References**

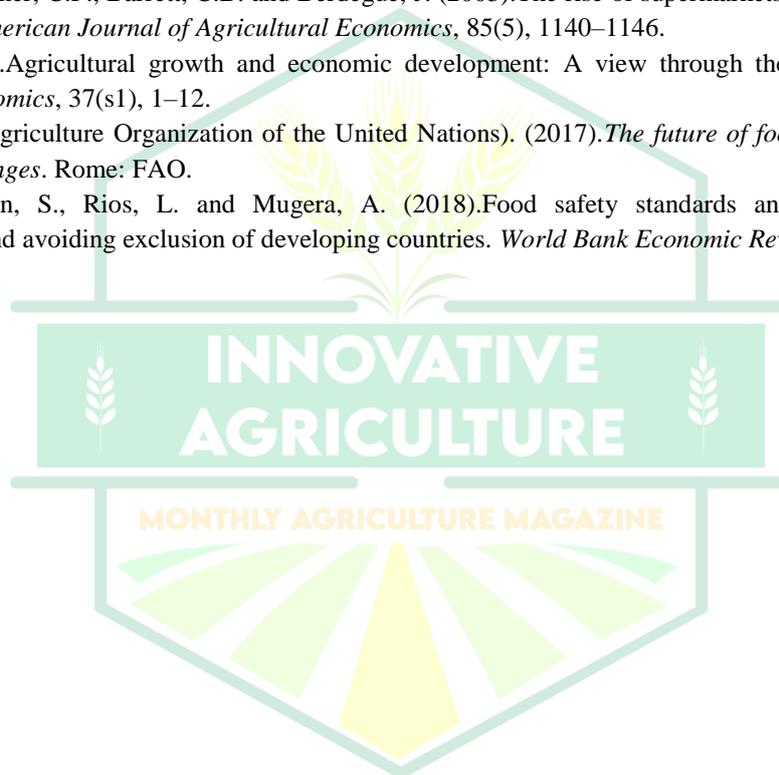
Anderson, K., Rauser, G. and Swinnen, J. (2013). Political economy of public policies: Insights from distortions to agricultural and food markets. *Journal of Economic Literature*, 51(2), 423–477.

Reardon, T., Timmer, C.P., Barrett, C.B. and Berdegue, J. (2003). The rise of supermarkets in Africa, Asia, and Latin America. *American Journal of Agricultural Economics*, 85(5), 1140–1146.

Pingali, P. (2007). Agricultural growth and economic development: A view through the globalization lens. *Agricultural Economics*, 37(s1), 1–12.

FAO (Food and Agriculture Organization of the United Nations). (2017). *The future of food and agriculture – Trends and challenges*. Rome: FAO.

Jaffee, S., Henson, S., Rios, L. and Mugera, A. (2018). Food safety standards and trade: Enhancing competitiveness and avoiding exclusion of developing countries. *World Bank Economic Review*, 32(1), 1–20.



## Aquaculture-Ecosystem interactions and environmental impacts under climate change



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### Abstract:

Aquaculture currently stands as the world's most rapidly expanding food production industry; however, its continued success is increasingly jeopardized by the immediate and projected impacts of climate change. This review examines how shifting climatic conditions threaten the long-term sustainability of aquatic farming systems. Key environmental stressors analyzed include rising global temperatures, sea-level rise, and fluctuating sea surface salinity. Additionally, the paper addresses the disruptive effects of altered rainfall patterns, the increased frequency of severe climatic events, and the surge in biological risks such as harmful algal blooms and disease outbreaks. The uncertainty surrounding the supply of external inputs is also highlighted as a critical vulnerability. While climate change may offer isolated benefits in specific contexts, the review concludes that negative consequences predominantly overshadow any positive outcomes. Consequently, the sector's survival hinges on a dual approach: implementing immediate adaptation strategies to manage current risks while pursuing long-term mitigation measures. The effectiveness of these interventions will largely depend on the specific adaptive capacities of producers across different global regions, highlighting the need to address gaps in current knowledge to ensure future viability.

**Keywords:** Aquaculture, Climate Change, Sustainability, Adaptation Strategies, Mitigation, Environmental Stressors.

### Introduction:

The aquaculture industry is a necessary food production solution because it maintains economic strength while meeting the nutritional needs for seafood. The aquaculture sector is an essential food production alternative. Climate change negatively impacts the environmental requirements for aquaculture operations, posing a growing challenge to the seafood-producing sector. The effects of climate change, such as rising temperatures, ocean acidification, and extreme weather that compromise ecosystem stability, put operational strain on aquaculture systems. Aquaculture and the environment have a variety of intricate two-way interactions. Traditional aquaculture is mostly environmentally compatible because it primarily employs locally accessible and on-farm wastes and by-products, such as crop residues and animal or human manures, for natural food or nutritional inputs in open water culture-based fisheries and mollusk and seaweed farming systems. Traditional aquaculture is often environmentally friendly. Prior to the relatively recent and growing usage of pelleted feed in contemporary aquaculture, waste, by-products, and natural food were the only sources of nutritional inputs for the majority of farmed aquatic organisms, raising serious environmental concerns. Environmental elements of aquaculture intensification are evaluated, along with their relationship to ecosystems and agro-ecosystems in interior terrestrial and aquatic, coastal/offshore, land- and water-scapes. Pollution from home, industrial, and agricultural sources is rapidly having a negative effect on aquaculture.

Variations in the statistical distribution of weather over long periods of time, usually decades to millions of years, are referred to as climate change. These changes may be restricted to a certain area or occur globally, and they could be seen in the average weather or only in the distribution of weather occurrences around an average. Due to their use of fossil fuels (coal, oil, and gas) for energy and their deforestation and forest degradation, which

release greenhouse gases (GHGs) into the atmosphere, humans have been identified as the primary cause of climate change. These human activities have been connected to the growing build-up of greenhouse gases (GHGs) in the atmosphere throughout time, including carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxides (N<sub>2</sub>O), and fluorinated gases. The consequences of climate change have already been documented on several important global economic sectors and services. Most current research on aquaculture shows that while certain climate changes, including rising temperatures, altered precipitation patterns, and a rise in the frequency of some severe events, are already apparent on water resources, others are still developing. Effects of climate change recently Due to the industry's substantial contribution to global food security, nutrition, and livelihoods, research on aquaculture sustainability has attracted a lot of attention. However, most of these studies have tended to focus on the detrimental consequences of climate change that are anticipated to affect aquaculture, paying far less attention to the beneficial aspects that are crucial for adaptation methods. A more thorough examination of the advantages and disadvantages of climate change will increase producers' readiness and reduce the risks to their output.

### THE IMPACT OF CLIMATE CHANGE ON AQUACULTURE:

Aquaculture productivity is anticipated to be impacted by climate change in both direct and indirect ways. The physical and physiological characteristics of finfish and shellfish stocks in production systems are among the direct effects, whereas the primary and secondary productivity, ecosystem structure, input supplies, product prices, fishmeal and fish oil costs, and other goods and services required by fishermen and aquaculture producers are examples of indirect effects. Activities related to aquaculture, including feed production, transportation, and power input, are thought to be the primary ways that the industry contributes to greenhouse gas emissions. Despite being large when compared to their food producing sectors, this sector's contribution is very tiny.

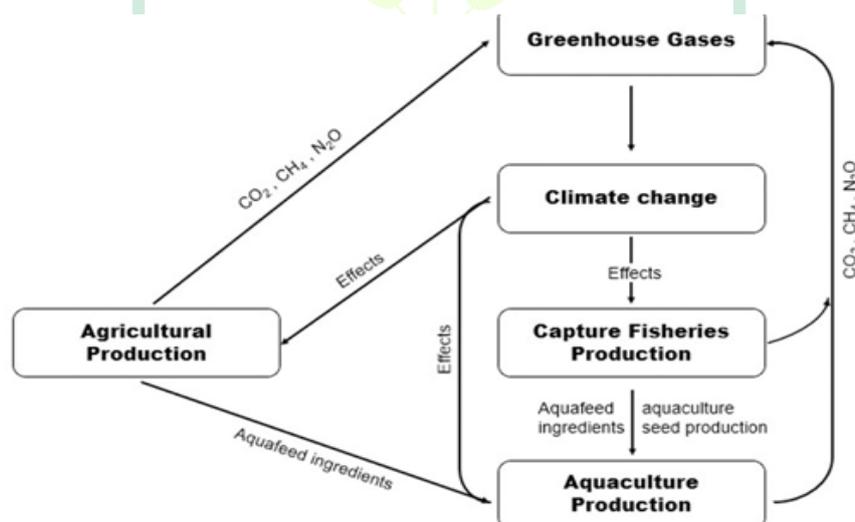


Fig 1: Direct and indirect pathways through the climate change, Maulu *et al.*,2021

Aquaculture must thus last for many generations in order to be sustainable. Three sustainability indicators may be used to evaluate the sustainability of aquaculture systems:

- Environmental
- economic and
- Social Indices

The effective use of natural resources, pollution control, and biodiversity preservation are examples of environmental sustainability indicators. The efficient use of financial resources, economic viability, resilience, the ability to bear unfavourable external expenditures, and the creation of cash for reinvestment are the main components of economic sustainability. Social sustainability, on the other hand, emphasizes aquaculture's ability to assist communities in ways including food security, employment, equitable distribution of opportunities and revenue, and inclusion of disadvantaged groups. The information that follows is a summary of the anticipated aspects of climate change that pose a danger to the aquaculture industry's sustainability and productivity.

### 1) Increasing temperatures:

Positive effects:

- Longer growth seasons for species found in warmer water
- More advancements in the potential for genetic breeding

Negative effects:

- Poor development and survival of cold-water species
- Degradation of water quality
- Weakened immune systems of cold-water species
- Weakened capacity of the ocean to absorb carbon
- Thermal stratification and
- Increased virulence of warmer water diseases.

### 2) Ocean acidification:

Positive effects:

- Increased production feasibility in hatcheries
- Identification of more marine species for culture

Negative effects:

- Reduced species growth performance and survival
- Poor coral skeleton development for shell-forming species
- Increased water acidity levels
- Increased production costs in marine areas

### 3) Diseases and harmful algal blooms:

Positive effects:

- Potential elimination of cold-water pathogens
- Potential identification and development of new species

Negative effects:

- Reduced survival and poor species development
- Deteriorating water quality
- Higher production expenses as a result of disease outbreaks
- And an increase in exotic disease outbreaks

### 4. Modifications to precipitation and rainfall patterns

Positive effects:

- Expanding areas in some locations that are suited for aquaculture production
- Droughts may encourage advancements in wastewater treatment

Negative effects:

- Flooding may increase the loss of organisms in low-lying places.
- Droughts may raise production expenses.
- Flooding may impair water quality and contaminate the environment
- Production facilities may be destroyed

### 5) Rising sea levels

Positive effects:

- Destroying several coastal habitats
- In certain areas, saltwater may seep into freshwater systems and cultural facilities.

Negative impact:

- Phonological changes, species richness, abundance, and distribution may all be impacted.

### 6) Uncertainty is supplied by external input:

Positive effects:

- Higher production expenses as a result of potential increases in the price of inputs like fish feed and seed.

Negative effects:

- Potential discovery of sustainable and alternative input sources, including protein sources to replace traditional sources

### 7. Salinity of the sea surface:

Positive effects:

- Potential rise in the production of tolerant species

Negative effects:

- A decrease in the ocean's ability to store heat
- A decrease in the movement of carbon and nutrients
- and an increase in species mortality.

### 8. Climate-related incidents:

Positive effects:

- Better nutrient and water column mixing
- Potentially reducing growing temperature pressures by lowering the temperature

Negative effects:

- Production system destruction
- Higher management expenses
- A rise in the loss of cultural species.

### MITIGATION AND ADAPTATION:

Health, food security, livelihood, water supply, human security, and economic growth are all under danger from climate change under the projected 1.5°C global warming, with an additional rise anticipated at 2°C. Communities and the industry will need to take use of new possibilities that arise from altered resources in order to manage these risks and adapt to the changing environment. In order to create resilience and deal with climate change as effectively and economically as possible, mitigation and adaptation may assist prepare farming communities, ecosystems, and populations in general. The goal of mitigation is to slow down or stop the rate of climate change. This mostly entails lowering GHG emissions, with a particular emphasis on CO<sub>2</sub> emissions, which make up over 60% of increases caused by human activity. By modifying their production methods to reduce greenhouse gas emissions, aquaculture farmers and other stakeholders may significantly contribute to reducing the consequences of climate change. In particular, this involves minimizing air and water pollution through the use of eco-friendly technologies and practices including solar energy, appropriate feeding methods, and sustainable wastewater treatment. Aquaculture's primary source of greenhouse gas emissions is thought to be feed production. On the other hand, mitigation is a long-term solution to climate change, and its advantages could not materialize for some time. Furthermore, since the majority of greenhouse gases build up over time and mix internationally, effective mitigation necessitates global cooperation. A. For better and more successful outcomes, it is advised that adaptation techniques be used in tandem with mitigation. Because it provides producers with alternatives from which to draw their livelihoods and build adequate resistance against the consequences of climate change, livelihood diversification may be one of the keys to successful adaptation. It entails integrating or separating aquaculture production systems with other industries, such agriculture. It is very beneficial to diversify sources of income, particularly in areas or nations where it is anticipated that fish productivity would decrease and agricultural production will rise. Moving to aquaculture species, methods, or regions that are more robust or less susceptible to a changing environment and resources may also be advantageous for aquaculture producers. In order to ensure a sustained supply of fish from capture fisheries, aquaculture producers may also adapt to climate change by encouraging changes in fishermen's behavior, governance, and the use of efficient management plans and tactics. For instance, implementing modifications to the way the tradable quota allotted to individual fishermen is managed. In addition, modelling aquaculture projects must take climatic variability and change into account in order to lessen the effects of climate change on livelihoods dependent on fishing. A. Since aquaculture is a relatively young field, more research is required to fully understand its advantages and how it affects farmers' financial circumstances, particularly in the most disadvantaged regions.

### Conclusion:

The aquaculture industry is increasingly under threat from human-caused climate change consequences, which are both a current and future reality, even though it is seen to be the only way to fulfill the ongoing growth in demand for aquatic goods worldwide. Both good and negative effects on aquaculture are anticipated, while the negative ones are predicted to outnumber the favourable ones. A. Furthermore, even while climate change poses a concern to the world's food supply, the hazards it poses to aquaculture are anticipated to vary depending on the country's economy, geographic or climatic zones, water environment, production processes, production size, and cultivated species of aquaculture producers. Aquaculture producers must respond to the available alternatives in the near term and mitigate the consequences by making the required long-term changes to their production processes in order to create resilience and maintain output in a changing environment.

### References:

- Barange, M. (2019). Avoiding misinterpretation of climate change projections of fish catches, food for thought. *ICES J. Mar. Sci.* 76, 1390–1392. doi: 10.1093/icesjms/fsz06
- Cochrane, K., De Young, C., Soto, D. T., and Bahri, D. T. (2009). *Climate Change Implications for Fisheries and Aquaculture: Overview of Current Scientific Knowledge*. FAO Fisheries and Aquaculture Technical Paper No. 530. Rome: FAO
- De Silva, S. S., and Soto, D. (2009). “Climate change and aquaculture: potential impacts, adaptation and mitigation,” in *Climate Change Implications for Fisheries and Aquaculture: Overview of Current Scientific Knowledge*. FAO Fisheries and Aquaculture Technical Paper. No. 530, eds K. Cochrane, C. De Young, D. Soto, and T. Bahri (Rome: FAO), 151–212.
- Ellis, R. P., Urbina, M. A., and Wilson, R. W. (2017). Lessons from two high CO<sub>2</sub> worlds—future oceans and intensive aquaculture. *Glob. Change Biol.* 23, 2141–2148. doi: 10.1111/gcb.13515
- Fleming, A., Hobday, A. J., Farmery, A., van Putten, E. I., Pecl, G. T., Green, B. S., et al. (2014). Climate change risks and adaptation options across Australian seafood supply chains—a preliminary assessment. *Clim. Risk Manage.* 1, 39–50. doi: 10.1016/j.crm.2013.12.003
- Gao, Y., Yu, G., Yang, T., Jia, Y., He, N., and Zhuang, J. (2016). New insight into global blue carbon estimation under human activity in land sea interaction area: a case study of China. *Earth Sci. Rev.* 159, 36–46. doi: 10.1016/j.earscirev.2016.05.003
- Hamdan, R., Othman, A., and Kari, F. (2015). Climate change effects on aquaculture production performance in Malaysia: an environmental performance analysis. *Int. J. Bus. Soc.* 16, 364–385. doi: 10.33736/ijbs.573.2015
- Hégaret, H., Brokordt, K. B., Gaymer, C. F., Lohrmann, K. B., García, C., and Varela, D. (2012). Effects of the toxic dinoflagellate *Alexandrium catenella* on histopathological and escape responses of the Northern scallop *Argopecten purpuratus*. *Harmful Algae* 18, 74–83. doi: 10.1016/j.hal.2012.04.006
- Kettle, N. P., Dow, K., Tuler, S., Webler, T., Whitehead, J., and Miller, K. M. (2014). Integrating scientific and local knowledge to inform risk-based management approaches for climate adaptation. *Clim. Risk Manage.* 17–31. doi: 10.1016/j.crm.2014.07.001
- Lim-Camacho, L., Hobday, A. J., Bustamante, R. H., Farmery, A., Fleming, A., Frusher, S., et al. (2014). Facing the wave of change: stakeholder perspectives on climate adaptation for Australian seafood supply chains. *Reg. Environ. Change* 15, 595–606. doi: 10.1007/s10113-014-0670-4
- Makondo, C. C., and Thomas, D. S. G. (2018). Climate change adaptation: linking indigenous knowledge with western science for effective adaptation. *Environ. Sci. Policy* 88, 83–91. doi: 10.1016/j.envsci.2018.06.014
- Maulu, S., Hasimuna, O. J., Haambiya, L. H., Monde, C., Musuka, C. G., Makorwa, T. H., ... & Nsekanabo, J. D. (2021). Climate change effects on aquaculture production: sustainability implications, mitigation, and adaptations. *Frontiers in Sustainable Food Systems*, 5, 609097.
- Morris, J. P., Backeljau, T., and Chapelle, G. (2019). Shells from aquaculture: a valuable biomaterial, not a nuisance waste product. *Rev. Aquac.* 11, 42–57. doi: 10.1111/raq.12225

- Palmer, T., and Stevens, B. (2019). The scientific challenge of understanding and estimating climate change. *Proc. Natl. Acad. Sci. U.S.A.* 116, 24390–24395. doi: 10.1073/pnas.1906691116
- Riphah, S. U. (2015). Global warming: causes, effects, and solutions. *Durreesamin J.* 1, 1–7
- Saba, V. S., Griffies, S. M., Anderson, W. G., Winton, M., Alexander, M. A., Delworth, T. L., et al. (2016). Enhanced warming of the Northwest Atlantic Ocean under climate change. *J. Geophys. Res. Oceans* 121, 118–132. doi:10.1002/2015JC011346
- Tisdell, C. A., and Leung, P. S. (1999). Overview of environmental and sustainability issues in aquaculture. *Aquac. Econ. Manage.* 3, 1–5. doi: 10.1080/13657309909380228
- Valenti, W. C., Kimpara, J. M., Preto, B. L., and Moraes-Valenti, P. (2018). Indicators of sustainability to assess aquaculture systems. *Ecol. Indic.* 88, 402–413. doi: 10.1016/j.ecolind.2017.12.068
- Zhang, P. F., Zhao, T., Zhou, L., Han, G. D., Shen, Y. W., and Ke, C. H. (2019). Thermal tolerance traits of the undulated surf clam *Paphia undulata* based on heart rate and physiological energetics. *Aquaculture* 498, 343–350. doi: 10.1016/j.aquaculture.2018.08.037
- Zolnikov, T. R. (Ed.). (2019). *Global Adaptation and Resilience to Climate Change*. Palgrave Studies in Climate Resilient Societies. (Bern) doi: 10.1007/978-3-030-01213-7



## Green Manure Incorporation in Organic Farming: A Sustainable Approach to Soil Health



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### Introduction

Organic farming emphasizes the use of natural processes and materials to cultivate healthy crops while maintaining ecological balance. One of the key practices in organic farming is the incorporation of green manure, which plays a vital role in enhancing soil fertility, structure, and microbial activity.

### What is Green Manure?

Green manure involves growing specific plants primarily to be incorporated into the soil to improve its fertility. These plants, often legumes, are grown during off-season periods or between crop cycles and then tilled into the soil. Common green manure crops include clover, vetch, sunn hemp, and mustard.



### Benefits of Green Manure in Organic Farming

**Enhances Soil Fertility:** Green manure adds organic matter and nutrients like nitrogen, phosphorus, and potassium to the soil, reducing the need for external fertilizers.

**Improves Soil Structure:** It helps in increasing soil porosity, aeration, and water retention.

**Suppresses Weeds:** Green manure crops can outcompete weeds, reducing their growth.

**Increases Microbial Activity:** Incorporating green manure stimulates beneficial microbial populations, essential for nutrient cycling.

**Reduces Soil Erosion:** The plant cover protects the soil from erosion caused by wind and water.

### Incorporation Process

**Selection of Crop:** Choose appropriate green manure crops based on the soil type, climate, and crop rotation plan.

**Cultivation:** Sow the green manure seeds during the off-season or as a cover crop.

**Growth Period:** Allow the crop to grow to the desired stage, usually before flowering.

**Incorporation:** Cut and incorporate the crop into the soil using plowing or tilling. This should be done when the plant is lush but before seed formation.

**Decomposition:** The incorporated organic matter decomposes, releasing nutrients that become available for the next crop.

**Challenges and Considerations**

- Proper timing is essential to maximize benefits.
- Some green manure crops may compete with main crops if not managed correctly.
- Cost and labor involved in cultivation and incorporation.

**Conclusion**

Green manure incorporation is a sustainable and eco-friendly practice that significantly benefits organic farmers. It helps in building healthy soils, reducing dependence on chemical inputs, and promoting biodiversity. When integrated effectively into crop management systems, green manure can be a cornerstone of successful organic farming.



## Carrot Erwinia Rot Disease: Causes, Symptoms, and Management Strategies



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Carrots are a popular root vegetable enjoyed worldwide. However, their cultivation can be threatened by various diseases, one of which is *Erwinia* Rot, caused by the bacterial pathogen *Erwinia carotovora*. This disease can cause significant crop losses if not managed properly.

### What is Carrot Erwinia Rot Disease?

*Erwinia* Rot is a bacterial disease that affects carrots, leading to soft, watery, and decayed roots. It usually occurs in warm and humid conditions, creating an ideal environment for bacterial proliferation. The disease often starts at the wound sites during harvesting or planting and rapidly spreads, causing the roots to rot and become unfit for consumption.

### Symptoms of Erwinia Rot in Carrots

- ❖ Soft, watery rot: Infected roots become soft and mushy.
- ❖ Darkened tissue: The affected areas darken as decay progresses.
- ❖ Unpleasant smell: A foul odor often accompanies the rot.
- ❖ Lesions and wounds: Initial infection sites are usually at wounds or damaged tissues.
- ❖ Rapid decay: The disease spreads quickly in conducive conditions.



### Causes and Spread

The disease is primarily caused by *Erwinia carotovora*, which survives in soil, plant debris, and infected plant material. It spreads through:

#### Infected planting material

- ❖ Wounds during harvesting or handling
- ❖ Contaminated tools and equipment
- ❖ Poor sanitation and drainage

#### Management Strategies

##### Effective management of Carrot Erwinia Rot involves integrated approaches:

Use of Disease-Free Seeds and Planting Material

Select healthy, certified seeds to prevent initial infection.

#### Proper Crop Rotation

Avoid planting carrots in the same location consecutively; rotate with non-host crops to reduce bacterial inoculum.

#### Field Sanitation

- ❖ Clear crop debris and weeds that harbor bacteria.
- ❖ Disinfect tools and equipment regularly.

- ❖ Optimal Water Management
- ❖ Avoid overwatering and ensure good drainage to reduce humidity around the roots.

#### **Timely Harvesting**

- ❖ Harvest carrots at maturity and handle them carefully to minimize wounds.
- ❖ Avoid injuring roots during harvesting and transportation.

#### **Use of Biological and Chemical Controls**

Application of approved bactericides may help, but prevention through cultural practices is more effective. Biological control agents such as certain beneficial bacteria may suppress pathogen activity.

#### **Post-Harvest Handling**

- ❖ Cool carrots promptly after harvest.
- ❖ Store in well-ventilated, dry conditions to inhibit bacterial growth.

#### **Conclusion**

Carrot Erwinia Rot is a challenging disease but can be managed effectively through good agricultural practices, sanitation, and proper handling. Awareness and early intervention are crucial to minimize crop losses and ensure healthy, marketable carrots.



## Innovative and Sustainable Disease Management in Onion Cultivation



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### Introduction

Onion (*Allium cepa* L.) is one of the most important vegetable crops cultivated worldwide and holds a prominent position in Indian agriculture due to its high domestic consumption, export potential, and role in farmer livelihoods. The major onion producing states are Maharashtra, Tamil Nadu, Andhra Pradesh, Bihar and Punjab. As we know, the onion is the most profitable and highly cultivated spice-vegetable crops, full yield potential of these crops is not realized due to number of constraints. Among the various constraints, vulnerability of the crop to different diseases encountered during the production, storage and marketing are more crucial. Economic losses due to diseases vary significantly across three seasons. Being favorable environmental conditions, *kharif* /rainy crop is more prone to disease attacks resulting in sometimes 50-60% of yield loss as compared to 20-30% yield loss in *rabi* crop. In this training manual chapter, we tried to incorporate the desired information for important fungal diseases and their management.

The crop is attacked by many fungal, bacterial pathogens, viruses and nematodes. The prevalence of pathogens depends on seasons, variety and region. Many fungal pathogens have been reported causing foliar and bulb diseases of onion. Soil-borne fungal diseases such as Purple blotch (*Alternaria porri*), Damping off (*Pythium* spp., *Rhizoctonia solani*), Anthracnose/-twister (*Colletotrichum gloeosporioides*; *Gibberilla moniformis*), leaf blight (*Stemphylium vesicarium*), etc. challenge sustainable onion production and storage in a wide range of agro-ecologies. These diseases drastically reduce onion productivity, quality and yield.

Traditionally, onion disease management has relied heavily on chemical fungicides. Although chemicals provide quick and visible control, their indiscriminate use has led to several challenges such as fungicide resistance, residue problems, environmental contamination, soil health degradation, and increased cost of cultivation. In recent years, climate change, erratic rainfall, and intensive cropping systems have further aggravated disease incidence.

To address these challenges, there is a growing need to shift from a chemical-dependent approach to innovative, integrated, and sustainable disease management strategies. This article discusses major onion diseases, their epidemiology, and novel management approaches that combine biological control, host resistance, precision agriculture, and climate-smart practices.

### Major Diseases of Onion

#### 1. Damping-off and Seedling Blight

Caused by *Pythium*, *Rhizoctonia*, and *Fusarium* species, damping-off is a major problem in onion nurseries. Infected seedlings show rotting at the collar region, leading to poor plant stand and uneven crop establishment.

#### 2. Anthracnose-Twister

The causal organism of anthracnose disease is *Colletotrichum gloeosporioides*. The disease is characterized by curling, twisting, and chlorosis of the leaves which spreads lengthwise covering entire leaf blade. The affected leaves shrivel and droop down. There is abnormal elongation of the necks and formation of slender bulbs.

#### 3. Purple Blotch

Purple blotch caused by *Alternaria porri* is one of the most destructive foliar diseases of onion. It appears as small whitish spots that enlarge into purplish-brown lesions surrounded by yellow halos. High humidity and moderate temperatures favour disease development. Purple blotch pathogen may be associated with many other fungal pathogens and promoted by heavy moisture

#### 4. *Stemphylium* leaf Blight

*Stemphylium* blight (*Stemphylium vesicarium*) has emerged as a serious threat in major onion-growing regions. The disease is characterized by small yellowish water-soaked lesions that develop into elongated spots which turn dark olive, brown to black during spore development. Leaves may be completely blighted as the lesions coalesce. *Alternaria porri* in conjunction with *S. vesicarium* is responsible for significant qualitative and quantitative destruction of onion crop

#### 5. Downy Mildew

Downy mildew caused by *Peronospora destructor* occurs under cool and humid conditions and spreads rapidly through air-borne spores. It causes pale green patches followed by violet-grey fungal growth on leaves.

#### 6. Basal Rot

Basal rot caused by *Fusarium oxysporum* f. sp. *cepae* affects onion at both field and storage stages. *Fusarium falciforme* and *F. acutatum* are also found to be associated with this disease. The disease is characterized by yellowing of leaves and stunted growth of plant. At later stage of disease development leaves become dry from tip onwards. Diseased bulbs become discolored and the infected tissue appeared brown in color with watery appearance. The disease leads to bulb rotting from the base, causing severe post-harvest losses.

#### 7. Neck rot

Neck rot of onion caused by *Botrytis allii* is one of the most serious disease that attack onion plants grown for seed or bulb production (Sayed et al., 2014; Sumner et al., 1997). The symptoms appear as water soaked lesions and softening of the scales. Infection become severe when moist conditions prevail before and during harvest. Excessive nitrogen and irrigation increases the disease incidence. The fungus attacks seedling leaves symptomlessly, producing conidiophores after the leaf tissue became necrotic. The infection takes place successively, first invades the tip of leaves and then growing downwards and eventually attacks on the neck of onion bulb.

#### 6. Storage Rots

Black mould (*Aspergillus niger*), bacterial soft rot (*Erwinia/Pectobacterium* spp.), and Fusarium rot are major storage diseases that reduce bulb quality and market value.

#### Innovative Approaches for Onion Disease Management

Conventional disease management in onion largely depends on repeated use of chemical fungicides, but this approach has several serious limitations. Continuous and indiscriminate application of fungicides leads to the development of resistant strains of pathogens, making disease control increasingly difficult over time. Chemical residues often remain on onion bulbs, posing risks to food safety and reducing market acceptability. These chemicals also destroy beneficial soil microorganisms that are essential for soil health and plant growth. In addition, frequent spraying increases the cost of cultivation and exposes farmers and the environment to health hazards. Due to these drawbacks, there is a growing need to shift from chemical-based practices to integrated and innovative disease management approaches that are safer, cost-effective, and sustainable.

#### 1. Integrated Disease Management (IDM): A Holistic Strategy

IDM combines cultural, biological, physical, and chemical methods in a compatible manner to reduce disease pressure while minimizing chemical use. IDM is the backbone of sustainable onion disease management.

Key principles of IDM include:

- Prevention rather than cure
- Use of multiple compatible strategies
- Emphasis on eco-friendly solutions
- Rational use of chemicals only when necessary

#### 2. Bio-control Agents: Harnessing Beneficial Microorganisms

Biological control is one of the most promising innovations in onion disease management.

*Trichoderma* spp.

*Trichoderma* species such as *T. harzianum*, *T. viride*, and *T. asperellum* suppress soil-borne pathogens through:

- Mycoparasitism
- Competition for nutrients

- Production of antifungal metabolites
- Induction of systemic resistance in plants

#### Application methods:

- Seed treatment (10 g/kg seed)
- Nursery bed treatment (5 kg/ha mixed with FYM)
- Soil application at transplanting

#### Bacterial Bio agents

*Bacillus subtilis*, *Pseudomonas fluorescens*, and related PGPR strains inhibit foliar and soil-borne pathogens by producing antibiotics, siderophores, and lytic enzymes.

These microbes also enhance plant growth and stress tolerance, making them ideal components of IPDM programs.

#### 3. Bio-formulations and Consortia-Based Approaches

Recent research emphasizes the use of **microbial consortia** rather than single strains. Combining *Trichoderma*, *Bacillus*, and *Pseudomonas* offers broader disease suppression and improved crop vigor.

Innovative bio-formulations include:

- Talc-based and liquid formulations
- Encapsulated microbial products
- Carrier-based formulations using vermicompost or lignite

Such formulations improve shelf life, field efficacy, and farmer acceptance.

#### 4. Use of Botanical Extracts and Natural Products

Plant-based products such as neem seed kernel extract (NSKE), garlic extract, turmeric extract, and essential oils have shown antifungal activity against *Alternaria*, *Stemphylium*, and *Fusarium* species.

Botanicals are:

- Biodegradable
- Safe to humans and beneficial organisms
- Suitable for organic and residue-free onion production

#### 5. Host Resistance and Tolerant Varieties

Breeding for disease resistance remains a cost-effective and farmer-friendly approach. Although complete resistance is rare in onion, several varieties show tolerance to major diseases.

Use of tolerant varieties:

- Reduces disease severity
- Minimizes chemical sprays
- Stabilizes yield under stress conditions

Future breeding programs are focusing on:

- Marker-assisted selection
- Identification of resistance genes
- Incorporation of quantitative resistance

#### 6. Precision Disease Management and Digital Tools

Innovative disease management now includes precision agriculture tools such as:

- Disease forecasting models based on temperature, humidity, and rainfall
- Risk maps to identify disease-prone regions
- Mobile apps for real-time disease diagnosis and advisories
- Remote sensing and drones to detect early disease symptoms

These tools help farmers apply control measures at the right time, reducing unnecessary sprays.

#### 7. Climate-Smart Cultural Practices

Climate change has altered disease dynamics in onion. Climate-smart practices play a crucial role in disease suppression includes;

- Proper spacing and aeration to reduce humidity

- Drip irrigation to avoid leaf wetness
- Raised beds to improve drainage
- Crop rotation with non-host crops
- Timely planting to escape peak disease periods

### 8. Rational and Reduced Use of Fungicides

Chemical fungicides still have a role in onion disease management but should be used judiciously.

- Rotation of fungicides with different modes of action
- Use of need-based sprays guided by disease thresholds
- Integration with bioagents and botanicals
- Preference for low-dose and eco-friendly fungicides

This approach reduces resistance development and environmental impact.

### 9. Post-Harvest Disease Management Innovations

Post-harvest losses can be minimized through:

- Use healthy and clean seeds for cultivation and follow crop rotation.
- Avoid bruising and injury during harvest, handling, and transport
- Harvest onions promptly and do not delay drying.
- During harvesting the neck length should be 20mm.
- Maintain stable temperatures during transport, as well as when bulbs are going into and coming out of storage.
- Shade curing up to 21 days and avoid high-temperature curing.
- Sorting of bulbs should be done at the field level, which eliminates pathogen inoculum during storage.
- After curing, bulbs can be stored at a low temperature (2-12 °C) and humidity (80%).
- Storage condition should be well ventilated. Avoid high temperature and high relative humidity during storage conditions.
- Biological treatments before harvest help reduce storage rots and extend shelf life.

### Future Perspectives

The future of onion disease management lies in:

- Microbiome-based solutions
- Nano-formulations of bioagents
- AI-driven disease prediction systems
- Climate-resilient varieties
- Farmer-friendly extension models

Adoption of these innovations will not only reduce crop losses but also promote sustainable and profitable onion production.

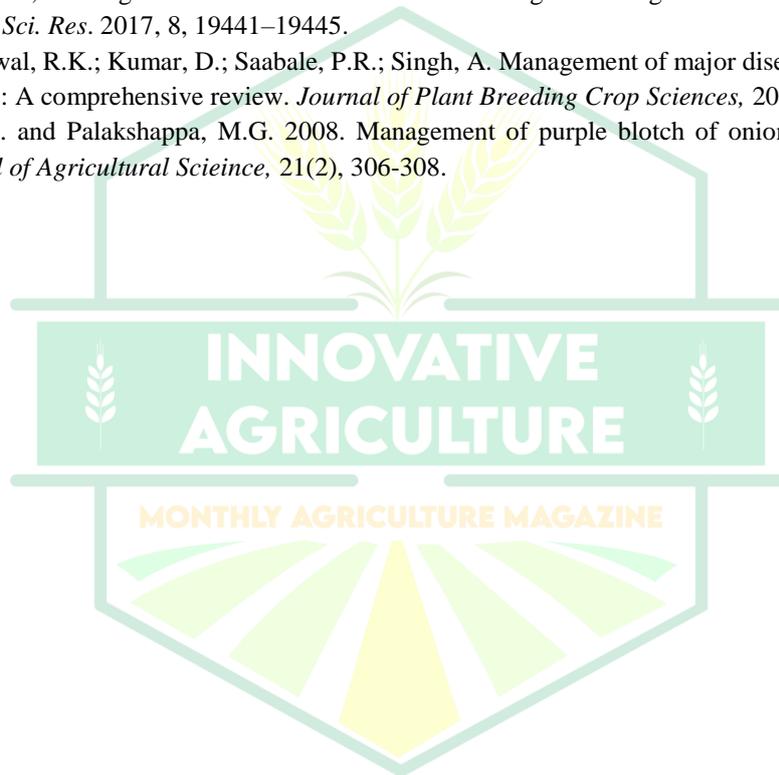
### Conclusion

Onion disease management is undergoing a paradigm shift from chemical-centric approaches to integrated, eco-friendly, and innovative strategies. The use of bio-control agents, bio-formulations, precision tools, tolerant varieties, and climate-smart practices provides a sustainable answer to the increasing disease problems in onion cultivation. By following simple and farmer-friendly practices such as healthy nursery management, use of beneficial microbes, need-based sprays, and proper post-harvest handling, farmers can effectively manage diseases without relying on costly inputs. Adoption of these practices not only reduces disease losses and environmental risks but also improves bulb quality, productivity, and overall farm profitability.

### References:

Chethan, P.; Lohate, S.R.; Hasabnis, S.N.; Bansode, G.M. 2021, In vitro evaluation of fungicides against the pathogens associated with post-harvest bulb rot of onion. *Journal of Pharmacology Innovation*. 10, 2290–2294.  
Dutta, R., Jayalakshmi, K., Radhakrishna, A., Kumar, S., Mahajan, V. 2024, Active Prevalence of *Fusarium falciforme* and *F. acutatum* Causing Basal Rot of Onion in Maharashtra, India. *Journal of Fungi* 10, 413.

- Dutta, Ram, Jayalakshmi K., Sharath M. Nadig, Dalasanuru Chandregowda Manjunathgowda, Vishal S. Gurav, and Major Singh. 2022. "Anthracnose of Onion (*Allium cepa* L.): A Twister Disease" *Pathogens* 11, no. 8: 884. <https://doi.org/10.3390/pathogens11080884>
- Gupta, R.C. and Gupta, R.P. 2013. Effect of integrated disease management packages on diseases incidence and bulb yield of onion (*Allium cepa* L.). *SAARC Journal of Agriculture*, 11(2), 49-59
- Malathi, S. and Mohan, S. 2011. Evaluation of biocontrol agents and organic amendments against onion basal rot caused by *Fusarium oxysporum* f.sp. *cepae*. *Madras Agriculture Journal*, 98(10-12), 382-385. 27.
- Mathur, Kamlesh, Gurjar, R.B.S., Shanna, S.N. and Sharma, K. 2007. Efficacy of fungicides, bioagents and plant extracts against pink root rot disease of onion induced by *Fusarium solani*. *Journal of Mycology and Plant Pathology*, 37(3).
- Manjunathgowda DC, R Selvakumar, S Shilpashree, M Anjanappa, R Dutta, MN Sharath, SR Shalaka, V Mahajan (2022). Purple blotch disease of onion (*Allium cepa*): perspective and prospects. *International Journal of Agriculture Biology*, 27:393–398.
- Meena, L. and Verma, A. Fungal Diseases of Onion and Their Biological Management: A Review. *International Journal of Recent. Sci. Res.* 2017, 8, 19441–19445.
- Mishra, R.K.; Jaiswal, R.K.; Kumar, D.; Saabale, P.R.; Singh, A. Management of major diseases and insect pests of onion and garlic: A comprehensive review. *Journal of Plant Breeding Crop Sciences*, 2014, 6, 160–170
- Pramod Kumar, T. and Palakshappa, M.G. 2008. Management of purple blotch of onion through bioagents. *Karnataka Journal of Agricultural Science*, 21(2), 306-308.



## ECONOMIC IMPACT OF PM KUSUM SCHEME ON THE LIVELIHOOD OF FARMERS IN INDIA (2019 – 2025)



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### Abstract

The Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM), launched in 2019, aims to promote solar energy in agriculture by enabling farmers to install solar pumps, grid-connected renewable power plants, and replace diesel pumps with solar-powered alternatives. This review paper analyzes studies conducted between 2019 and 2024 to assess the economic impact of the PM-KUSUM scheme on farmers' livelihoods in India. The findings reveal that the scheme has significantly reduced irrigation costs, increased farm income through power sales, improved energy security, and generated employment opportunities in rural areas. The overall growth in farmer income attributable to PM-KUSUM is estimated at 7.8% annually, highlighting its role in sustainable and inclusive rural development.

### 1. Introduction

Agriculture remains the backbone of the Indian economy, providing livelihood to more than half of the country's population. However, Indian farmers continue to face multiple challenges such as rising input costs, unreliable electricity supply, increasing fuel prices, and the adverse effects of climate change. Among these challenges, access to affordable and reliable energy for irrigation plays a crucial role in determining agricultural productivity and farm income. A large proportion of Indian farmers depend on diesel-powered pumps or irregular grid electricity for irrigation, which significantly increases the cost of cultivation and reduces profit margins, particularly for small and marginal farmers. To address these issues and promote sustainable agricultural practices, the Government of India launched the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) scheme in 2019. The scheme aims to integrate renewable solar energy with agriculture by encouraging the installation of solar-powered irrigation pumps and grid-connected solar power plants in rural areas. PM-KUSUM was designed not only as an energy reform initiative but also as an income enhancement programme for farmers, with the broader objective of improving rural livelihoods while contributing to India's renewable energy targets.

### 2. Revised literature review (2019- 2024)

Sharma and Joshi (2019) conducted one of the earliest studies on the pm-Kusum scheme in the drought-prone districts of Rajasthan, focusing on farmers who adopted solar-powered irrigation pumps. The study revealed that the replacement of diesel pumps with solar pumps significantly reduced irrigation costs and improved net farm income. The authors emphasized that small and marginal farmers benefited the most due to savings on fuel expenditure and reduced dependence on unreliable electricity supply.

Kumar and Singh (2020) carried out a field study in Haryana to examine the economic benefits of grid-connected solar components under pm-Kusum. Their findings showed that farmers who sold surplus solar power to electricity distribution companies earned an additional annual income ranging between ₹20,000 and ₹30,000. The study highlighted that income from solar power sales provided financial stability during years of low agricultural output.

A national-level assessment by the Indian renewable energy development agency (ireda) in 2020 evaluated the performance of pm-Kusum across several Indian states. The report concluded that the scheme contributed to a reduction in electricity subsidy burden on state governments while ensuring reliable daytime power for irrigation. It also observed that solar pump adoption led to improved irrigation efficiency and lower operational costs for farmers.

Patel et al. (2021) studied the impact of pm-Kusum implementation in Gujarat and reported a positive shift in cropping patterns and cropping intensity among beneficiary farmers. The study found that assured solar-

powered irrigation encouraged diversification towards high-value crops, resulting in improved farm income and better livelihood security.

Niti aayog (2021) conducted a policy evaluation of pm-kusum as part of india's renewable energy and agricultural sustainability framework. the study emphasized that the scheme played a dual role in enhancing farmers' income and promoting environmentally sustainable farming practices. However, it also pointed out challenges such as limited awareness among small farmers and delays in grid connectivity.

Kavitha and Usha Nandhini (2022) conducted a study in Coimbatore district of Tamil Nadu to assess farmers' perception and economic benefits of solar-powered irrigation systems under pm-Kusum. The study revealed that farmers using solar pumps experienced a substantial reduction in irrigation costs and improved reliability of water supply. the authors also noted that non-loanee farmers showed greater awareness and adoption of solar technologies compared to loanee farmers, while high initial investment and procedural delays were identified as major constraints in Tamil Nadu.

Meena and Verma (2022) analyzed the socio-economic impact of pm-Kusum in Madhya Pradesh and reported that the scheme generated rural employment through installation, operation, and maintenance of solar infrastructure. The study concluded that pm-Kusum contributed to livelihood diversification by creating non-farm income opportunities in rural areas.

Rao et al. (2023) examined the livelihood impact of pm-Kusum among small and marginal farmers in Maharashtra. Their findings indicated improved income stability due to reduced irrigation expenditure and assured earnings from surplus solar power generation. The authors emphasized that pm-Kusum enhanced farmers' resilience to climate and market risks.

An evaluation report published by the ministry of new and renewable energy (more) in 2024 assessed the national progress of the pm-Kusum scheme. the report highlighted that farmers' net income increased by nearly 30–50 percent in regions with high adoption of solar pumps, including parts of Tamil Nadu, Gujarat, and Rajasthan. The study concluded that pm-Kusum has strong potential to transform rural livelihoods if supported by improved awareness campaigns, financial assistance, and timely infrastructure development.

### 3. Methodology

The present study is based on secondary data collected from published research articles, government reports, policy documents, and evaluation studies related to the PM-KUSUM scheme during the period 2019 to 2024. Relevant information was gathered from journals, reports of the Ministry of New and Renewable Energy (MNRE), NITI Aayog publications, and Other authenticated sources to assess the economic impact of the scheme on farmers' livelihoods in India.

The analytical tool used in this study is the Compound Annual Growth Rate (CAGR), which was employed to measure the average annual growth in farmers' income resulting from the adoption of PM-KUSUM components over the study period. CAGR helps in understanding the trend and consistency of income growth due to reduced irrigation costs and additional earnings from solar power generation.

#### Formula,

$$CACR (\%) = (Ending Value / Beginning Value) power 1/n-1$$

### 4. Key Findings

The review of studies on the PM-KUSUM scheme indicates a consistent improvement in the economic condition of farmers between 2019 and 2024. The adoption of solar-powered irrigation systems under the scheme resulted in a substantial reduction in irrigation costs, with farmers reporting savings of nearly 50–70 percent compared to diesel and conventional electric pumps. This reduction in recurring expenditure directly contributed to an increase in net farm income.

Farmers participating in grid-connected components of PM-KUSUM benefited from the sale of surplus solar power, which provided an additional annual income ranging from ₹20,000 to ₹35,000. This supplementary income improved livelihood security and reduced farmers' dependence on crop income alone, especially during periods of drought or crop failure. The average annual growth in farmers' income due to PM-KUSUM adoption during 2019–2024 was estimated to be around 7–8 percent.

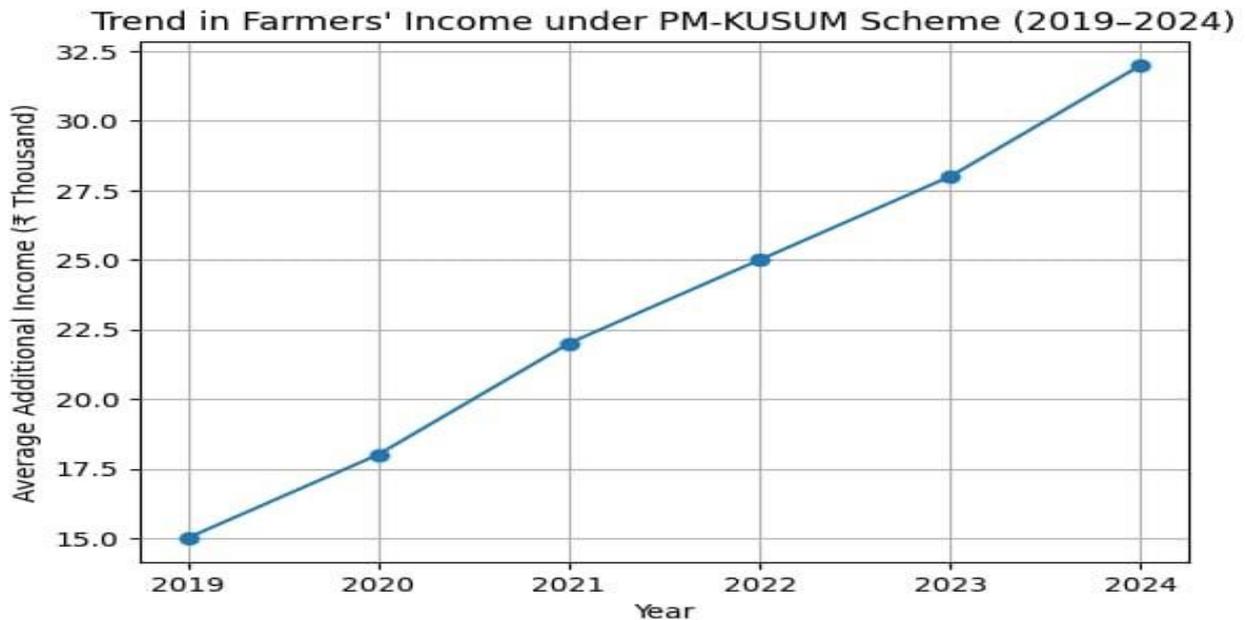


Figure 1 : Trends in Farmer's income under PM-KUSUM scheme (2019- 2024)

The scheme showed better economic outcomes in western and southern states such as Gujarat, Rajasthan, Maharashtra, and Tamil Nadu, where awareness levels, institutional support, and infrastructure availability were relatively higher. Education level and access to technical guidance played a significant role in influencing adoption and income benefits. However, small, marginal, and tenant farmers experienced relatively lower participation due to limited awareness and high initial investment requirements.

Overall, the findings highlight that PM-KUSUM has positively impacted farmers' livelihoods by reducing production costs, enhancing income stability, and promoting sustainable energy use in agriculture. Strengthening awareness campaigns and improving access to financial and technical support can further enhance the scheme's economic benefits across all regions.

### 5. Result and discussion

The economic condition of farmers adopting the PM-KUSUM scheme has shown a steady improvement from 2019 to 2024. In 2019, the average additional income gained by farmers through reduced irrigation costs and solar power usage was estimated at ₹15,000 per year. This increased to ₹18,000 in 2020 and ₹22,000 in 2021. With improved implementation and wider adoption of solar pumps and grid-connected systems, the additional income further increased to ₹25,000 in 2022 and ₹28,000 in 2023, finally reaching ₹32,000 per farmer per year in 2024. Using the CAGR formula:

$$\text{CAGR} = 7.8\% \text{ per year}$$

This indicates that farmers' income under the PM-KUSUM scheme increased at an average annual growth rate of 7.8 percent during the period 2019–2024.

This consistent increase in income can be attributed to multiple factors such as reduced expenditure on diesel and electricity for irrigation, assured availability of daytime power, and additional earnings from the sale of surplus solar power to the electricity grid. States such as Gujarat, Rajasthan, Maharashtra, and Tamil Nadu recorded better economic outcomes due to higher adoption rates, stronger institutional support, and better infrastructure facilities. Education level, awareness about renewable energy benefits, and access to technical assistance played a crucial role in enhancing farmers' participation. However, challenges such as high initial investment costs, limited awareness among small and tenant farmers, and delays in grid connectivity continue to affect the full realization of economic benefits under the PM-KUSUM scheme.

## 6. Conclusion

The PM-KUSUM scheme has emerged as an important initiative for improving the economic condition and livelihood security of farmers in India. The analysis of studies conducted between 2019 and 2024 indicates that the scheme has contributed significantly to reducing irrigation costs, increasing farm income, and ensuring reliable access to energy for agricultural operations. The steady rise in farmers' income over the years reflects the positive impact of solar-powered irrigation systems and the opportunity to earn additional income through the sale of surplus solar power.

The consistent improvement in income levels can be attributed to factors such as increased adoption of renewable energy technologies, government financial support, improved awareness, and better institutional and infrastructural facilities in several states. Southern and western states such as Tamil Nadu, Gujarat, Maharashtra, and Rajasthan showed better economic outcomes compared to other regions due to higher adoption rates and effective implementation mechanisms. Education, access to technical guidance, and timely grid connectivity played a crucial role in enhancing the benefits of the scheme.

Despite the positive outcomes, challenges such as high initial investment, limited awareness among small and tenant farmers, and procedural delays continue to affect the scheme's reach and effectiveness. Addressing these issues through strengthened extension services, improved financing options, and simplified implementation procedures can further enhance the economic impact of PM-KUSUM. Overall, the scheme holds strong potential to promote sustainable agriculture, enhance farmers' livelihoods, and support India's transition towards renewable energy-driven rural development.

## 7. Reference

1. Sharma, R., & Joshi, P. K. (2019). Economic impact of solar-powered irrigation pumps under the PM-KUSUM scheme in drought-prone regions of Rajasthan. *Indian Journal of Agricultural Economics*, 74(4), 512–526.
2. Kumar, A., & Singh, R. (2020). Grid-connected solar power generation and farm income stability under PM-KUSUM: Evidence from Haryana. *Energy Policy*, 142, 111512. <https://doi.org/10.1016/j.enpol.2020.111512>
3. Indian Renewable Energy Development Agency. (2020). Assessment of PM-KUSUM scheme: Performance, outcomes, and policy implications. IREDA, Ministry of New and Renewable Energy, Government of India.
4. Patel, K. J., Mehta, D. R., & Shah, S. P. (2021). Impact of solar irrigation under PM-KUSUM on cropping patterns and farm income in Gujarat. *Agricultural Economics Research Review*, 34(2), 245–257.
5. NITI Aayog. (2021). Evaluation of PM-KUSUM scheme under India's renewable energy and agricultural sustainability framework. Government of India. <https://www.niti.gov.in>
6. Kavitha, V., & Ushanandhini, M. (2022). Farmers' perception and economic benefits of solar-powered irrigation systems under PM-KUSUM in Tamil Nadu. *Journal of Extension Education*, 34(1), 6835–6842.
7. Meena, S. L., & Verma, H. C. (2022). Socio-economic impact of PM-KUSUM scheme on rural livelihoods in Madhya Pradesh. *Indian Journal of Rural Development*, 41(3), 289–302.
8. Rao, P. S., Kulkarni, R. R., & Deshmukh, A. S. (2023). Livelihood resilience of small and marginal farmers under the PM-KUSUM scheme in Maharashtra. *Journal of Rural Studies*, 98, 102–111. <https://doi.org/10.1016/j.jrurstud.2023.102111>
9. Ministry of New and Renewable Energy. (2024). Evaluation report on PM-KUSUM scheme: National progress and farmer income impacts. Government of India. <https://mnre.gov.in>
10. Council on Energy, Environment and Water. (2022). Solarising agriculture in India: Economic and livelihood impacts of PM-KUSUM. CEEW. <https://www.ceew.in>

## Targeted Potassium Nutrition by Foliar Application: A Key to Alleviate Moisture Stress in Maize



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### ABSTRACT

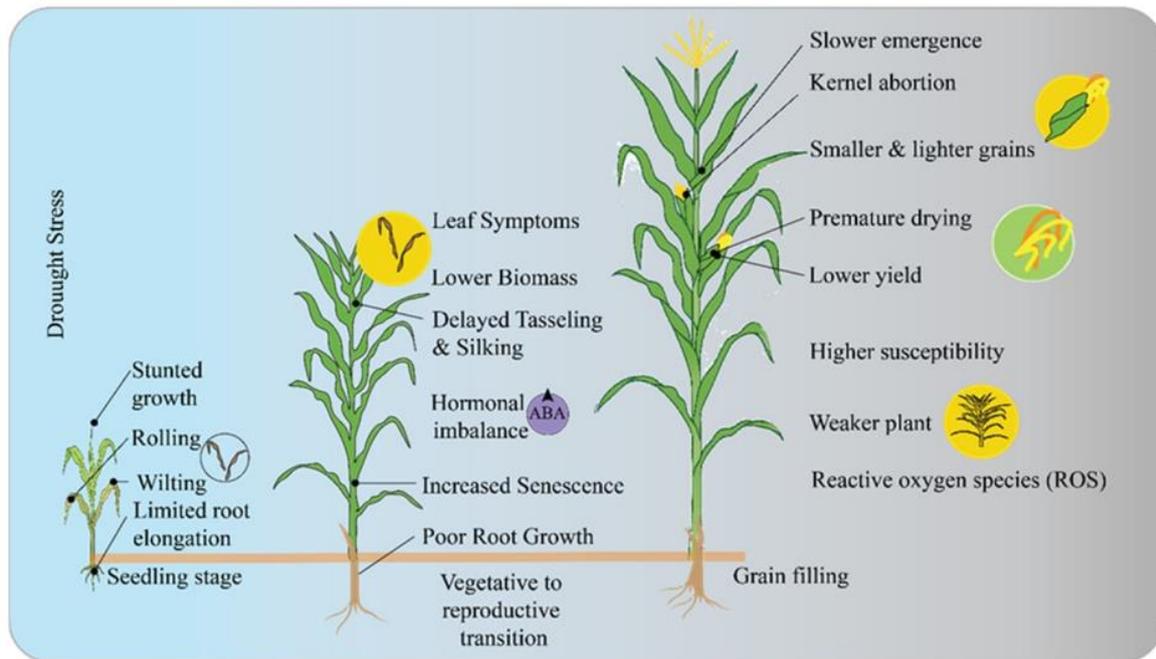
Moisture stress is a significant abiotic factor restricting maize (*Zea mays* L.) production, especially in rainfed and water-scarce agroecosystems. Potassium (K) is essential for plant water relations, osmotic adjustment, stomatal control, and enzyme activation, therefore enhancing stress tolerance. Soil-applied K often demonstrates restricted availability under drought circumstances owing to diminished mass flow and root activity. In this context, targeted foliar K feeding serves as an effective method to swiftly rectify K deficit and improve drought resistance in maize. The foliar delivery of K facilitates direct nutrient absorption *via* leaf tissues, guaranteeing prompt availability during essential growth phases under moisture stress. Foliar K supplementation often results in improved leaf hydration status, increased relative water content, greater photosynthetic efficiency, and superior stomatal conductance. Moreover, K-induced activation of antioxidant defense mechanisms alleviates oxidative damage caused by drought stress. These physiological and biochemical modifications combined result in enhanced biomass buildup, grain filling, and yield stability under conditions of restricted water supply. Targeted foliar K feeding is a viable and resource-efficient agronomic strategy to mitigate moisture stress in maize. Incorporating foliar K treatment into drought management measures may markedly improve fertilizer usage efficiency, maintain crop output, and promote climate-resilient maize production systems.

**Keywords:** Moisture stress, maize, potassium, ROS, drought

### 1. Introduction

Maize (*Zea mays* L.) is the third most important cereal crop in India after rice and wheat in terms of area and production (Sanodiya et al., 2023). This cereal crop can be cultivated for diverse purposes, seasons, and environments, and it is rich in protein (10.3%), fat (4.5%), fiber, antioxidants, vitamins (A, B, and C), and various minerals (magnesium, phosphorus, zinc, iron, and potassium). Maize serves primarily as animal feed and is also processed into various products such as cornmeal, grits, starch, flour, tortillas, snacks, breakfast cereals and chapatis, a type of flatbread made from maize flour in certain northern Indian regions. The United States of America (USA) is the leading producer of maize, contributing approximately 35% of the world's total maize production. It is renowned as the "Mother grain of Americans" and is the driving force behind the US economy (Garcia-Lara et al., 2019). Maize is the world's most widely cultivated plant, occupying 197 million hectares of land. The United States Department of Agriculture reported that over 1150 million tons of maize were produced worldwide in the 2022-23 market year. In India, maize is grown on 9.09 million hectares and yields approximately 23.29 million tons with a productivity of 2563 kg ha<sup>-1</sup> (Sowjanya et al., 2024). Maize is an efficient water consumer and a medium-maturity grain crop requiring 600 to 800 mm of water for optimal production. The overall water consumption efficiency of maize is 8 kg Ha<sup>-1</sup> mm<sup>-1</sup>. The distribution of rainfall has become more unpredictable and unequal owing to climate change, and under drought conditions, moisture stress poses a significant environmental restriction that affects the physiological and morphological phases of maize. The most vulnerable stages of maize to drought stress are the vegetative, silking and ear growth, which could result in yield decreases of up to 50%, 25% and 21%, respectively (Sah et al., 2020). This moisture stress causes a number of stress indicators at various stages of growth, such as leaf rolling and restricted root growth during the seedling stage. It also reduces element accessibility, lowers the crop canopy's active photosynthetic leaf area, respiration,

delayed silk emergence, kernel abortion, and ultimately reduces seed yield during the grain filling stage (Figure 1). To lessen the negative impacts of water deficiency conditions, maize needs to be well managed for nutrients such as nitrogen (N), phosphorous (P), and potassium (K), as well as secondary and micronutrients. Due to its faster absorption and assimilation in leaf surfaces, K foliar nutrition must be provided to the crop to increase maize's resistance to drought. Targeted foliar K treatment increases the absorption of many elements, including iron, phosphorus, zinc, and nitrogen, thereby satisfying the plant's nutritional needs (Dezfouli et al., 2024). Additionally, K serves as a cofactor for numerous major enzymes, supporting a variety of physiological and metabolic processes. It boosts the amount of chlorophyll in the leaves, the intensity of photosynthesis and the biomass of the plant, all of which improve the production of maize seed and ultimately boost farmer's income.



**Figure 1. Detrimental effects of drought on maize at different stages**

## 2. Potassium nutrition for maize growth and development under water scarcity

Potassium (K) is a central regulator of plant water relations and plays a pivotal role in maize tolerance to water scarcity. K is also called “Quality element” as it enhances the quality of various crops and vegetables. K shows luxury consumption as well. Due to moisture stress, plants cannot extract water from root zone and also K from soil. That's why  $K_2SO_4$  solution spray is found effective (Wasaya et al., 2021). Water stress inhibits plant development by interfering with a variety of biochemical and physiological responses, including Osmo protectant and ROS activity, photosynthesis, chlorophyll synthesis, and gas exchange parameters (Zia et al., 2021). The dry climate negatively impacts plant growth and production, disrupting metabolic pathways in many ways. Under deficiency of potassium,  $CO_2$  fixation during photosynthesis decreased and interfere with translocation and consumption of photo-assimilates followed by chlorophyll (Trankner et al., 2018). Additionally, K application can ameliorate the negative effects of drought stress by improving salicylic acid concentration while decreasing jasmonic acid and ABA concentrations involved in stomatal closure (Sulaman et al., 2025). By this way, maize growth and developmental process is drastically reduced.

## 3. Potassium foliar nutrition: new avenue to reclaim drought stress in maize

Maize is called as the “Backbone of America” as originated from south America (Mexico). Maize is that type of crop which is highly affected by water stress as well as water logging at a time. potassium application as in spray form plays significant role in osmoregulation, co-transport of sugars, regulation of membrane potential and plant growth. It offers regulatory roles in several biochemical processes under drought stress such as carbohydrate metabolism, protein synthesis and enzyme activation. Furthermore, under drought stress, K regulates stomatal opening and assists plant to acclimate (Aksu and Altay, 2020). Under abiotic stress such as drought, plants

undergo oxidative stress due to unaccounted production of ROS. Under such conditions, K application has been reported to reduce endogenous ROS levels and alleviate oxidative stress in plants (Figure 2). As salinity is a major problem and to remove this stress potassium application maintain osmotic balance (Kumar et al., 2020). A concentration of 2% K<sub>2</sub>SO<sub>4</sub> spray improved proline which act as drought indicator and chlorophyll contents, which in turn enhanced photosynthetic activity and maintained higher relative water content under severe drought conditions in maize (Wasaya et al., 2021). The exogenous application of K not only improved root dry matter in maize but also improved shoot dry matter under drought conditions, which might be attributed to enhanced cell membrane permeability under drought stress, indicating its effectiveness as a drought mitigation agent (Figure 2). Moreover, application of K might have good effect on increasing number of leaves on a plant under drought stress. potassium has good ability to enable plants to approach longer root length under conditions of drought stress.



Figure 2: Various activities of potassium in plants

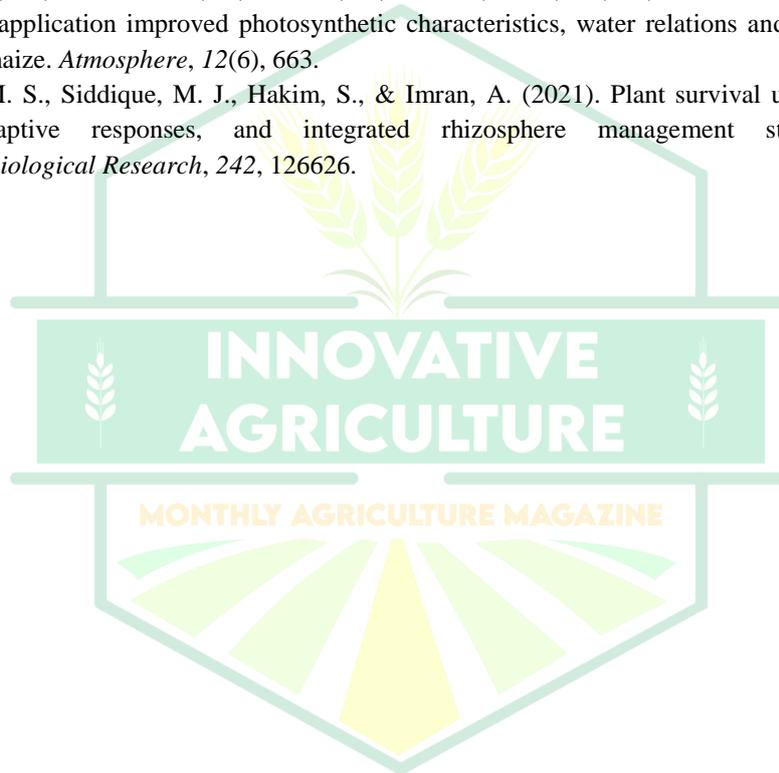
#### 4. Conclusion

Targeted foliar application of K greatly increases maize's resistance to moisture stress by enhancing physiological and biochemical stability. Under stress, potassium supplementation boosted growth, chlorophyll retention, and photosynthetic efficiency by controlling stomatal conductance, maintaining a greater relative water content, and improving osmotic adjustment. Drought-induced oxidative damage was further reduced by increased antioxidant activity and root viability. Better tassel emergence, pollen viability, and kernel set are all indicators of improved reproductive performance, which eventually results in increased grain output in moisture-deficit conditions. In rainfed and drought-prone agro-ecosystems, timely and controlled foliar K nutrition appears as a quick, efficient, and crop-responsive way to improve maize production stability, resource-use efficiency, and drought resilience. Further, we have to be focused on dose optimization, stage-specific foliar scheduling, and integration with other inputs that reduce stress, like nano-nutrient formulations and biofertilizers in the modern mechanisation era.

#### References

- Aksu G, Altay H (2020) The effects of potassium applications on drought stress in sugar beet. *Sugar Tech* 22:1092-102
- García-Lara, S., Chuck-Hernandez, C. & Serna-Saldivar, S. O. (2019). Development and Structure of the Corn Kernel. In: Serna-Saldivar, S.O. (Ed.), *Corn* (Third Edition). AACC International Press, Oxford, pp. 147–163.
- Kouchak Dezfouli, M., Shokuhfar, A., Lak, S., Alavi Fazel, M. and Mojaddam, M. 2024. Effect of foliar application of potassium and zinc elements on maize yield and grain nutrient content under water-deficit conditions. *Communications in Soil Science and Plant Analysis* 55(1): 1-20.

- Kumar P, Kumar T, Singh S, Tuteja N, Prasad R, Singh J (2020) Potassium: A key modulator for cell homeostasis. *J Biotechnol* 324:198–210.
- Sah, R. P., Chakraborty, M., Prasad, K., Pandit, M., Tudu, V. K., Chakravarty, M. K., & Moharana, D. (2020). Impact of water deficit stress in maize: Phenology and yield components. *Scientific reports*, 10(1), 2944.
- Sanodiya, P., Tiwari, P. and Gupta, C. (2023). Maize (*Zea mays* L.)-The future potential cereal crop of an indispensable significance in agro-forestry system. *Maize Journal*, 12(2), 61-71.
- Sowjanya, M. U., Trimurtulu, N., Gopal, A. V., Rao, G. R., Ramana, J. V. and Sreelatha, T. 2024. Influence of endophytic bacterial consortium on maize rhizospheric soil nutrient status under moisture stress conditions. *The Journal of Research ANGRAU* 52(1): 09-20.
- Sulaman, S., Nadeem, M., Shabaan, M. *et al.* Exogenous Application of Nitrogen (N) and Potassium (K) Improves Drought Tolerance in Plants: A Review. *J Soil Sci Plant Nutr* 25, 4850–4865 (2025).
- Tränkner M, Tavakol E, Jáklí B (2018) Functioning of potassium and magnesium in photosynthesis, photosynthate translocation and photoprotection. *Physiol Planta* 163:414–431.
- Wasaya, A., Affan, M., Ahmad Yasir, T., Mubeen, K., Rehman, H. U., Ali, M., & EL Sabagh, A. (2021). Foliar potassium sulfate application improved photosynthetic characteristics, water relations and seedling growth of drought-stressed maize. *Atmosphere*, 12(6), 663.
- Zia, R., Nawaz, M. S., Siddique, M. J., Hakim, S., & Imran, A. (2021). Plant survival under drought stress: Implications, adaptive responses, and integrated rhizosphere management strategy for stress mitigation. *Microbiological Research*, 242, 126626.



## THE SECRET BEHIND INSECT SURVIVAL – INSECT NUTRITION



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### INTRODUCTION

Insects dominate the living world in terms of diversity, abundance and ecological significance. From pollinating crops and decomposing organic matter to acting as pests and vectors of disease, insect influence almost every aspect of human life and natural ecosystems. Key reasons for behind their survival were the ability of insects to exploit a wide range of food resources effectively. Nutrition is the chemicals required by an organism for their growth, tissue maintenance, reproduction and energy. Like all other organisms, most insects have similar nutritional requirements such as proteins, carbohydrates, lipids, vitamins, minerals, trace elements and water. These chemical compounds can either be synthesized by the insects themselves or provided by beneficial symbionts or acquired in food. Achieving optimal nutrition involves interaction between feeding behavior and nutritional processing of food by the insect body. Insects should eat correct amounts of suitable foods, but they should avoid intake of excesses toxins and nutrients. Understanding the insect nutrition helps for pest management, conservation and environmental sustainability.

### INSECT NUTRITION

Insect nutrition refers to the subject concerned with the conversion of food material into insect performance which is measured by their growth, development, survival, reproduction and other vital functions. It also refers to the acquisition, digestion, absorption and utilization of nutrients required for normal physiological functioning.

Insect diet and the fraction of nutrients acquired in food can vary among species and developmental stages of the same species, resulting from adaptations to particular environments in which access to nutrients is restricted by the types and diversity of foods available. Insects have to obtain specific essential food substances or nutrients, which are needed as nutritional requirements for body material and energy to do all the things attributed to life.

Insects need the same basic nutritional components that higher animals need. Immature insects often have different nutritional requirements from adults. Nutrient balance can affect rate of food consumption and efficient utilization; parasites with respect to host food; rate of growth and development as such, and with respect to temperature; and food selection in an insect.

### NUTRITIONAL REQUIREMENT AND FEEDING DIVERSITY OF INSECTS

Insects require carbohydrates as an energy source for complete development and metabolic activity; proteins and amino acids for growth, tissue formation, enzyme production and reproduction; lipids for energy storage, hormone synthesis and cell structure; vitamins and minerals for vital physiological processes. Insects are unable to synthesize sterols, but they require sterols in diet for normal growth and reproduction.



Figure 1: Major Nutritional Sources of Insects

Predatory insects often require higher amino acid as compared to carbohydrates as they show the protein content of animal tissues as they feed on another insects. Phloem feeders or storage grain beetles requires higher amount of carbohydrates. Phytophagous insects require equal quantity of proteins, amino acids and carbohydrates. Insects are able to get their nutrients from a wide range of different food sources for various reasons. Termites and many beetles feed on wood and rely on symbiotic microorganism for supplement diet, while cockroaches and crickets feed on dead plant

materials. Sap feeders feed on plant phloem (e.g., aphids) and plant xylem (e.g., spittlebugs and cicadas) or in the case of the sucking lice and some flies (e.g., mosquitoes) vertebrate blood. Ants and beetles obtain their nutrient from the symbiotic fungi actively present within them. Other polyphagous feeders switch their host plants depending on nutritional suitability. Detritivores feed on decaying organic matter. Parasitic insects derive nutrition from host organism.

#### NEED FOR INSECT NUTRITION

- For meeting energetic needs associated with general maintenance.
- For fueling growth and development.
- For metabolic activities.
- For improved reproductive capacity.
- For molting and metamorphosis.
- For studying the biochemistry, behaviour and other biological process.
- For testing various internal components for physiological and anatomical effects.
- For artificial mass production of insects for various purposes.
- For rearing predators and parasitoids and for pest management.
- For understanding feeding strategies.
- For understanding nutritional ecology.
- To study the evolution of insects.
- To analyze the nutritional physiology and biochemistry.
- To study insect biology.

#### APPROACHES OF INSECT NUTRITIONAL REQUIREMENT

There are three main approaches to understanding insect nutritional requirement

1. Deletion method
2. Substitutional method
3. Radio-labelled precursor

The most common approach is the deletion method that measures the effect of removing one specific component from a chemically defined artificial diet and then measuring whether the insect can develop on the modified diet under sterile conditions. After identification of the essential nutrients by deletion method, the substitution method is used to test whether analogues of these nutrients also support development. Last radiolabeled precursors were fed to insects to determine which nutrients insects are able to produce endogenously.

#### NUTRITION AND REPRODUCTION

Reproductive success in insects is closely linked to nutrition. Adult female insects require protein to mature their ovaries and egg production. It is crucial for successfully secrete juvenile hormone (JH) that is required for ovary and egg development. Adult male insect doesn't require protein to mature their sperm. Carbohydrates are important fuel in mating and flight activities. Intake of protein determines the number and viability of eggs laid.

#### IMPORTANCE OF NUTRITION IN PEST MANAGEMENT

Balanced plant nutrition is a powerful preventive strategy in pest management. By manipulating nutritional resources pest populations can be regulated without heavy reliance on chemicals.

- Balanced fertilizer application to avoid pest-favoring conditions.
- Use of trap crops with higher nutritional attractiveness.
- Deployment of antifeedants that interfere with nutrient intake.
- Targeting insect digestive enzymes and nutrient metabolism.
- Increasing natural enemies by ensuring flower rich diversity.
- Habitat management to provide nutritional support for beneficial insects.
- RNA interference and metabolic inhibitors targeting nutrient assimilation pathways.

#### CONCLUSION

Insects have evolved specific adaptations that allow them to overcome the nutritional hurdles that prevent other animals from using certain foods as a source of nutrients. Insects also have different ways to solve the problem

of balancing nutrient intake in a nutritionally variable world. Future studies employing multidisciplinary approaches will continue to unravel the mysteries of insect nutrition and its consequences and significance to insect biology. Artificial insect diet was developed to study the overall nutritional requirements of the insects and used to laboratory rearing on prepared food. Those diets are useful in the mass production of natural enemies such as predators and parasitoids which plays a major role in Integrated Pest Management programs and other sterile insects programs. Understanding and manipulating nutritional factors provide effective, eco-friendly and sustainable pest management approaches.

#### REFERENCES

- 1) Chapman, R.F. (1998). *The Insects: Structure and Function*. 4th edition. Cambridge University Press, UK. Pp 770.
- 2) Dadd, R. H. (1973). Insect nutrition: Current developments and metabolic implications. *Annual Review of Entomology*. 18, 381-420.
- 3) Hanife, G. E. N. C. (2006). General principles of insect nutritional ecology. *Trakya University Journal of Science*. 7(1), 53-57.
- 4) Nation, J.L. (2001). *Insect physiology and biochemistry*. Boca Raton, CRC Press. Pp 485.



## Field Practices Determining Export-Quality Grapes and Market Acceptance



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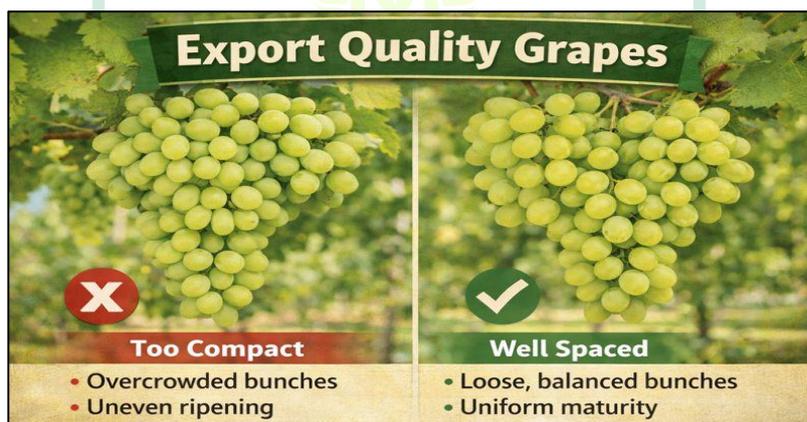
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### Introduction

India has recently become an exporter of table grapes to several international markets in the European Union, United Kingdom, Middle East and Southeast Asia due to its ability to produce high-quality grapes, beneficial weather conditions, knowledgeable growers and advancements in production techniques (Chadha 2013). However, simply growing large volumes of grapes does not ensure success when exporting them. The export success of Indian grapes will be determined by the ability of a vineyard to consistently produce grapes that meet strict quality, safety, and uniformity criteria as required by importing countries (Chadha 2013).

Many times, the rejection or devaluing of grapes after export does not happen as a result of one major cause, but rather as the result of many minor errors connected with vineyard practices, harvest operations and post-harvest activities. Growers seeking to export grapes must identify and take action to mitigate these factors at the vineyard level to improve their chances of successfully exporting their table grape production.



### Export market expectations and quality benchmarks

Export buyers evaluate grapes on multiple parameters simultaneously. Visual appearance is the first filter. Bunches must be uniform in size and shape, berries should be evenly sized, free from blemishes, and exhibit good color development. Texture and firmness are equally important, as grapes must withstand long distance transport without deterioration (Winkler *et al.*, 1974).

The monitoring of a variety of Chemical parameters such as total Soluble Solids, Acidity balance etc. are continuously monitored. In addition to evaluating the quality of grapes, the compliance with Food Security's regulations is critical. For example, Countries importing grapes (e.g., compliance with the US EPA, Environmental Canada, the Canadian Food Inspection Agency, etc.) have extremely low Maximum Residue Limits (MRLs) for pesticides, and as such Continue to test shipments upon arrival (FAO, 2011). The export of Grapes requires traceability of spray records and the full implementation of Good Agricultural Practices (GAPs).

### Variety selection and its influence on export suitability

The nation's top grape export varieties are seedless type varieties; for example: the Thompson Seedless and its Clones such as Tas A Ganesh, Sonaka, Manik Chaman, and others. The Sharad Seedless, Flame Seedless, Crimson Seedless, Fantasy Seedless, and Red Globe are also considered leading International grape export

varieties, although Red Globes typically require careful berry thinning and gentle handling due to their large berry size (Chadha, 2013).

Each grape export variety will demonstrate a range of factors in addition to the actual quality of the grapes; for example: each grape variety has a variable bunch compactness, berry set rate, and ripening behaviours. An understanding of each grape variety's specific characteristics will allow growers to implement best management practices specific to those varieties rather than universally implement a set of management practices across all vineyards (Jackson, 2014).

#### **Bunch architecture as the foundation of export quality**

A critical aspect of exporting grapes via bunch architecture is that export markets prefer bunches that are loosely to moderately compact, with adequate gaps between the berries. When grape bunches are tightly grouped together, the growth of the berries may be limited because of a lack of air circulation and greater susceptibility to fungal diseases like powdery mildew and bunch rot. In India, under high fertility and assured irrigation, grapevines can produce excess berries. To prevent grape bunches from becoming too compact, growers use a variety of methods, including flower thinning at bloom, berry thinning at the pea stage, and shoulder trimming. These methods improve the uniformity of berry size, enhance the attractiveness of the bunch to potential customers, and reduce the likelihood of post-harvest decay during transportation. (Pearson and Goheen, 1988).

#### **Crop load regulation and vine balance**

Grapes of export quality are best produced from a balanced vine; an excessively loaded vine will produce berries that are small due to a diversion of carbohydrates from each individual berry, and may also delay maturity and create uneven accumulation of sugars (Winkler *et al.*, 1974). The methods used to regulate the crop load of grapes are through bunch thinning and berry thinning. Growers commonly reduce the crop load of seedless varieties by 25 to 40 percent to produce export-quality fruit (Maharashtra State Grape Growers Association, 2019). Balanced grapevines have a better relationship between their vegetative growth and fruit development, resulting in larger berry size and higher total soluble solids (TSS), as well as a more uniform maturity of the berries.

#### **Use of growth regulators, benefits and caution for export markets**

Table grapes have long been improved using plant growth regulators (like Gibberellic Acid, or GA3) to increase berry size and create a looser cluster structure, especially in the case of seedless grapes. The effective use of GA3 in conjunction with removal of excess clusters can lead to less compacted clusters, and larger, firmer berries (Alshallash *et al.*, 2023).

While GA3 may provide some benefit, it should not be used as a shortcut for effective crop load management. The over-application or wrong timing of GA3 can result in increased variability between berries (texture), poor fruit quality, and/or difficulty in achieving uniform ripening. Studies assessing the impact of GA3 on thinning and sizing previously proven that the impact of GA3 on berry size and tightness within clusters relies heavily on timing and quantity. Therefore, to obtain the greatest benefit from GA3, it must always be applied in conjunction with other practices for the regulation of both the canopy and crop load (van der Vyver, 2016).

New studies continue to investigate the effects of pre-harvest treatments containing GA3 and their effects on berry firmness and quality through various physiological mechanisms. These studies have found that a well-designed, evidence-based program of growth regulators for export markets is required (Hu *et al.*, 2025).

#### **Nutrient management for export quality**

Fertility-related nutrients play an important role in determining whether grapes can be shipped for export. When vines receive too much nitrogen, they will produce an abundance of excessive vegetative growth and shading of the grapes. Excessive vegetative growth will negatively affect grape color development and take longer for them to ripen or mature (Chadha, 2013).

Exporting vineyards typically have balanced fertilization programs, where the basis of their fertilizer regime is based on soil and petiole tests. To limit the chance of producing physiological abnormalities in grapes, wineries or growers should refrain from applying any further nitrogen fertilizers during the period leading up to harvest and that there is always a healthy supply of potassium, calcium to the vines. By managing these nutrients properly, there will be fewer chances of developing abnormal grapes because there will be consistency in how grapes develop through their growing season.

### **Canopy management and microclimate control**

The way a vineyard's canopy is built has a direct impact on how well its fruiting zones get sunlight, how many disease problems are created and how efficiently sprays are applied. When there is a dense canopy on a vineyard, an excessive amount of humidity is trapped in it and sunlight cannot penetrate to allow the grapes to fully ripen. Having excess moisture trapped in the canopy also creates the ideal conditions for powdery mildew and bunch rot to occur (Pearson and Goheen, 1988).

Techniques and practices that encourage shoot positioning, removes excess laterals and removes selective leaves in and around the fruiting zone can all help to produce a more open canopy. Exposing the grapes to more sunlight increases the grape's ability to develop its red color and helps to ensure that green varieties develop uniformly during the ripening period (Jackson, 2014). A more open canopy will also reduce the need to spray with so many chemical products and can help provide better compliance with pesticide residue regulations.

### **Managing weather risks in export oriented vineyards**

Export acceptance for table grapes from India can be influenced by unpredictable short term weather events that fall close to the harvest. Unpredictable scenarios may include unexpected rainfall after a prolonged dry spell or sharp fluctuations in vine moisture content that contribute to berry turgor increases and subsequently, berry cracking and splitting, which create the potential for berry decay during storage/transportation (Chang *et al.*, 2021; La Spada *et al.*, 2024). An effective means of managing potential high moisture transport problems associated with drought cycles before harvest is through the irrigation management approach of avoiding severe moisture fluctuations as grapes enter veraison (ripening) and during the harvesting period.

More recently, a variety of studies have been conducted regarding the impact that deficit irrigation may have on the production and overall quality of exportable table grapes during long-term, cold storage. Recent research has shown that the method by which growers make decisions regarding irrigation will influence the ultimate quality and performance of table grapes after they have been harvested (Conesa *et al.*, 2015).

Growers also observe that the amount and location of rainfall play a critical role in disease management. The amount and type of rainfall, combined with humidity and temperature levels, all contribute to the overall risk of powdery mildew diseases developing, as demonstrated in classic research that quantified the effects of humidity and temperature levels on pathogen growth in the field (Delp, 1954). As growers move towards green disease management methods (i.e., cultivars with naturally resistant traits), they are increasingly utilizing weather forecasts and predictive models to eliminate unnecessary spray applications of fungicide; thereby, ensuring both compliance with environmental residue standards and control of diseases (Maddalena *et al.*, 2023).

In addition, growers have identified heat stress events as being significant risks to the quality and quantity of exportable table grapes. Heat events can negatively affect the quality of table grapes and the ability to sell them because grapes that have been damaged by sunburn resulting from excessive berry exposure to sunlight will have a brown or black appearance (sunburn browning or necrosis) and therefore are less visually appealing to consumers when they arrive in the market. Canopy decisions therefore need to balance ventilation with protection from extreme heat, especially during hot spells (Gambetta *et al.*, 2021).

### **Disease management with residue awareness**

Export Vineyard disease management takes a preventive approach rather than curative growth that attacks the vine. Powdery mildew is the most significant disease economically in Export Grapes, producing losses of around \$30 million in India (Pearson and Goheen, 1988).

Integrated Disease Management is promoted through a combination of Canopy Management at the Vine Level; Weather Predictive Tests; and the Use of Judicious Fungicide Materials. Compliance with Export Schedule Sprays demands careful rotation of material (molecules), attention to accurate and correct dosage; and strict adherence to Pre-Harvest Interval (PHI). Ensuring that late spray applications are not used unnecessarily is vitally important to achieve and maintain compliance with Residue Analysis (APEDA, 2022).

### **Residue management and traceability systems**

Incompatibility with Residues is the primary reason countries reject export shipments. Countries importing products impose strict Maximum Residue Limits (MRLs) on Organic Products; therefore, Australia does not

export barbecue-type meats because of these restrictions. No less than 30+ days is expected between application and harvest before sending out a shipment (FAO, 2011).

To manage residues, grapes must be treated with approved Export Molecules, and each application must conform to the Sponsor's Export Spray Schedules. Accurate records must be maintained, including Sprays, Batch Identifications, and Harvesting. All Export Programs require registration and compliance through legally recognized Certification Systems that coordinate with APEDA (APEDA, 2022).

#### **Pre-harvest quality checks, avoiding last minute rejections**

Export quality control must begin before harvest, not at the pack house. A key practical step is structured field sampling, where growers check TSS, berry size, firmness, and color uniformity across representative vineyard blocks. Peer reviewed work on maturity assessment across table grape cultivars and environments highlights that maturity indices can vary across locations and conditions, which is exactly why block wise sampling is essential rather than relying on a single vineyard average (Hamie *et al.*, 2023).

In addition to conventional methods, studies have evaluated contactless or rapid approaches for measuring internal maturity parameters in table grapes, showing the direction in which quality checking is moving, especially for large export oriented operations that need fast decisions (Daniels *et al.*, 2019).

A practical way to present this in the article is to recommend a simple pre harvest protocol.

- Select multiple representative vines per block (not only border vines).
- Sample bunches from different canopy positions.
- Record TSS, berry size, and visual uniformity.
- Decide harvest in lots, not as one single date for the whole vineyard.

This reduces mixed maturity within export cartons, improves consistency at destination, and lowers rejection risk.

#### **Harvest maturity and timing decisions**

The time at which grapes are harvested has a direct impact on export quality. Prematurely harvested fruit will have no sweetness or flavour, while overripe containers may exhibit berry drop, shrivelling, and shortened shelf life (Winkler *et al.*, 1974).

Harvest maturity is defined using TSS levels, berry hardness, and consistent colour development. Vines intended for export frequently undergo harvesting multiple times throughout the growing season to ensure that all containers are harvested at the same ripeness level. Harvesting during the cool hours of day also reduces field heat and helps preserve fruit freshness.

#### **Vineyard Handling Practices**

Post-harvest losses of grapes can often be prevalent following the mechanical damage associated with grape harvesting, as well as by the impact of the field handling of grape containers. By having too many berries in crates being carried, rough handling of the containers in crates, and/or exposing berries to sunlight, berries can be subjected to either cracking from the pressure created by the excess fruit weight and/or dehydrating (FAO, 2011).

Utilising clean, shallow harvest crates in combination with trained/polished labour to transport grapes to shaded areas inside vineyards allows the prevention of quality degradation of grapes. Cleaning creamy washroom surfaces reduces diseases from being spread to vineyards.

#### **Post-Harvest Handling and Cold Chain Integrity**

When exporting, grapes must be in full cold chain management. By pre-cooling rapidly with refrigerants, the grape's internal field temperatures can be decreased, while the grape's respiration rate will be slowed. Without doubt, hygienic conditions must be maintained for grading and packing grapes (FAO, 2011).

Any interruptions in the cold chain will ultimately lead to brown stems, loss of moisture, and ultimately the premature breaking down of fruits. It is imperative to maintain the temperature ranges recommended from the pack house to the final shipment in order to achieve successful export consignments.

#### **Common export rejection reasons and practical solutions**

- a. Compact bunches and small berries  
Cause: Excessive crop load and inadequate thinning.  
Solution: Timely flower and berry thinning, regulated bunch number per vine.
- b. Uneven ripening and color variation

- Cause: Canopy imbalance, irregular irrigation, excess nitrogen.  
Solution: Balanced nutrition, canopy management, uniform water supply.
- c. High pesticide residues  
Cause: Excessive sprays and violation of pre harvest intervals.  
Solution: Export compliant spray programs and strict PHI adherence.
- d. Berry cracking and shrivelling  
Cause: Moisture stress and sudden irrigation changes.  
Solution: Uniform irrigation scheduling and timely harvest.
- e. Stem browning and reduced shelf life  
Cause: Field heat and cold chain breaks.  
Solution: Early morning harvest, rapid pre cooling, continuous temperature control.
- f. Mechanical damage  
Cause: Rough handling and improper containers.  
Solution: Gentle handling, proper crates, trained workers.

### Conclusion

Grapes for export quality will require a precision-oriented system, not just yield-driven methods. The accepted market will depend upon the grower's ability to manage; bunch architecture, crop load nutrition; canopy structure; residue compliance; handling practices; etc. Disciplined management of these area, will help an Indian grape grower significantly reduce their risk of rejection from the global market and will allow sustainable participation within these markets.

### References

- Agricultural and Processed Food Products Export Development Authority. (2022). *Package of practices for export of table grapes from India*. APEDA.
- Alshallash, K. S., Almuwayhi, M. A., et al. (2023). GA3 and hand thinning improve physical, chemical, and sensory quality of table grapes. *Horticulturae*, 9(2), 160. <https://doi.org/10.3390/horticulturae9020160>
- Chadha, K. L. (2013). *Handbook of horticulture*. Indian Council of Agricultural Research.
- Chang, B. M., Keller, M., et al. (2021). Cuticle and skin cell walls have common and unique roles in grape berry splitting. *Plants*, 10(8), 1604. <https://doi.org/10.3390/plants10081604>
- Conesa, M. R., de la Rosa, J. M., Domingo, R., & Pérez Pastor, A. (2015). Long term impact of deficit irrigation on the physical quality of table grapes at harvest and after cold storage. *Postharvest Biology and Technology*, 102, 1–10. <https://doi.org/10.1016/j.postharvbio.2014.11.006>
- Daniels, A. J., Poblete Echeverría, C., et al. (2019). Measuring internal maturity parameters contactless on table grapes. *Frontiers in Plant Science*, 10, 1517. <https://doi.org/10.3389/fpls.2019.01517>
- Delp, C. J. (1954). Effect of temperature and humidity on the grape powdery mildew fungus. *Phytopathology*, 44(11), 615–626.
- Food and Agriculture Organization of the United Nations. (2011). *Guide to good hygiene practices for fresh fruits and vegetables*. FAO.
- Gambetta, J. M., Herrera, J. C., et al. (2021). Sunburn in grapes, a review. *Frontiers in Plant Science*, 12, 638933. <https://doi.org/10.3389/fpls.2021.638933>
- Hamie, N., Al Shoffe, Y., et al. (2023). Maturity assessment of different table grape cultivars grown under contrasting conditions. *Horticulturae*, 9(5), 559. <https://doi.org/10.3390/horticulturae9050559>
- Hu, L., et al. (2025). Pre harvest treatment with gibberellin (GA3) and related compounds, effects on grape firmness and quality with mechanistic insights. *Journal of Agriculture and Food Research*, 15, 100900.
- Jackson, R. S. (2014). *Wine science, principles and applications* (4th ed.). Academic Press.
- La Spada, P., et al. (2024). Factors influencing fruit cracking, an environmental and agronomic perspective. *Frontiers in Plant Science*, 15, 1298764.
- Maharashtra State Grape Growers Association. (2019). *Field guidelines for quality table grape production*. MSGGA.
- Pearson, R. C., & Goheen, A. C. (1988). *Compendium of grape diseases*. APS Press.
- van der Vyver, L. (2016). *The influence of gibberellic acid (GA3) for berry thinning and berry sizing on table grape production and quality* (Master's thesis). Stellenbosch University.
- Winkler, A. J., Cook, J. A., Kliewer, W. M., & Lider, L. A. (1974). *General viticulture*. University of California Press.

## Fertilizer Broadcaster: A Tool to Reduce Drudgery and Improve Fertilizer Use Efficiency



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In the fast-moving and ever-changing modern agricultural era, mechanization has gone from being an extraordinary improvement to a necessity and it is among the many new implements that have been moulded and fashioned into use, that the fertilizer broadcaster has come into its own as one of the most simple and practical and efficient labour-saving devices for farmers. This simple but valuable machine saves the back-breaking labour involved in the manual broadcast of fertilizers and permits of uniformly distributing which leads to an increase in fertilizer efficiency in the use of fertilizers and also the production of crops. Fertilizer management is an important factor in increasing the productivity of agriculture. In many localities farmers still rely too much upon the traditional method of hand broadcasting and the like which are laborious, slow, and inefficient ways to apply fertilizer, as irregularities of fertilizer application led to a too poor fertilizer efficiency, waste of fertilizer and much of the pollution through leaching and irrigational run-off. Hand application of fertilizers is also injurious to the physical condition of the operator in that it necessitates loading in excess of the proper weight and walking long distances. Because of the increasing cost of labour and scarcity of labour during the busy agricultural seasons, farmers frequently fall behind in their applications of fertilizer which fact in turn is reflected in poor crop performance. The fertilizer broadcaster provides a solution of these conditions. Not only does it take away much of the manual labour involved in the application of fertilizer, but in a very large way it automates the distribution of the fertilizer over the field, thus saving time and labour, but securing at the same time the fact that at all times and parts of the field the same uniform amount of material is applied which permits of greater fertilizer use efficiency, lower costs and a better crop production due to the uniformity, assuredness and result of the application of fertilizer.

### About Fertilizer Broadcaster

1. Fertilizer broadcaster is an implement used to uniformly spread granular fertilizers across field. It consists mainly of a hopper, metering mechanism, agitator, spreading disc or impeller and a control lever for flow rate.
2. As the implement starts operating, fertilizer from the hopper flows to the rotating disc through a calibrated opening. Then Fertilizer was thrown out due to the centrifugal force of the disc. This creates uniform spread pattern over the field surface.
3. Fertilizer broadcasters are available in various types, depending on the power source and farm size. These can be manually operated (shoulder mounted), battery operated (shoulder mounted) or tractor operated for larger farms.
4. Broadcasters are available in various types, depending on the power source and farm size. They can be manually operated, hand-operated (shoulder-mounted), battery-operated, or tractor-operated for larger farms.

### Working Principle

Fertilizer broadcaster works on the principle of centrifugal force. The granular fertilizer from the hopper falls onto a rotating disc or spinner powered by hand, battery or tractor PTO. As the disc rotates rapidly, the flings of the disc throw fertilizer outward in a fan shaped pattern.

The uniformity of distribution depends in several factors:

1. Disc speed – higher speed increases spread width.
2. Flow gate opening – Regulated fertilizer flow.
3. Height and angle of the disc – Affects spread pattern and direction of fertilizer.

4. Fertilizer properties – Granular size, shape and density influence throw distance and evenness of the distribution.

By proper calibration, the operator can achieve an accurate and consistent application rate, minimizing overlap and fertilizer wastage.

#### **Types of Fertilizer Broadcasters**

Fertilizer broadcasters are available in different models to suit the needs of diverse farming systems. The main types are:

- a. **Hand-Operated (Shoulder-Mounted) Fertilizer Broadcaster:** Hand operated fertilizer broadcaster is suitable for small farmers. It consists of small hopper fitted with hand crank mechanism and an adjustable flow control system. The operator walks across the field while rotating handle, which spreads the fertilizer evenly.



**Figure 3. Hand Operated Fertilizer Broadcaster**

- b. **Battery-Operated Fertilizer Broadcaster:** This broadcaster is a step forward mechanisation of the hand operated fertilizer broadcaster. In this the hand crank mechanism is replaced by rechargeable batteries that drive the spinning disc automatically, eliminating drudgery for manual cranking.



**Figure 4. Battery Operated Fertilizer Broadcaster**

- c. **Tractor-Operated Fertilizer Broadcaster:** Tractor operated fertilizer broadcasters are designed for large scale field operations. They are attached to the three-point linkage of the tractor and powered by the PTO shaft. The fertilizer from the hopper is fed to one or two high speed spinning discs, which spread it uniformly over wide swaths.



**Figure 5. Tractor Operated Fertilizer Broadcaster**

Type of Fertilizer Broadcaster	Typical Specifications	Key Features	Advantages	Limitations
<b>Hand-Operated (Shoulder-Mounted) Broadcaster</b>	<ul style="list-style-type: none"> <li>Hopper capacity: 5–10 kg</li> <li>Operation: Manual handle rotation</li> <li>Coverage: 0.4–0.8 ha/day</li> <li>Weight: 3–5 kg</li> </ul>	<ul style="list-style-type: none"> <li>Worn on shoulder with adjustable strap</li> <li>Flow control lever for rate adjustment</li> <li>Rotary disc for even spread</li> </ul>	<ul style="list-style-type: none"> <li>Better uniformity than manual hand scattering</li> <li>Easy mobility in small or irregular fields</li> <li>Suitable for paddy and vegetable crops</li> </ul>	<ul style="list-style-type: none"> <li>Operator fatigue due to continuous cranking</li> <li>Limited field capacity</li> <li>Uneven distribution in windy conditions</li> </ul>
<b>Battery-Operated Broadcaster</b>	<ul style="list-style-type: none"> <li>Hopper capacity: 8–15 kg</li> <li>Power source: 12V/24V rechargeable battery</li> <li>Coverage: 2–3 ha/day</li> <li>Operating time: 4–6 hours per charge</li> </ul>	<ul style="list-style-type: none"> <li>Motor-driven spreading disc</li> <li>Adjustable flow and speed control</li> <li>Compact and lightweight</li> <li>Low noise and vibration</li> </ul>	<ul style="list-style-type: none"> <li>Reduces operator fatigue - Provides consistent and uniform application</li> <li>Environmentally friendly</li> <li>Suitable for small and medium farms</li> </ul>	<ul style="list-style-type: none"> <li>Requires battery charging and maintenance</li> <li>Higher initial cost than manual types</li> <li>Not suitable for very large areas</li> </ul>
<b>Tractor-Operated Broadcaster</b>	<ul style="list-style-type: none"> <li>Hopper capacity: 150–600 kg</li> <li>Power source: PTO (540 rpm)</li> <li>Coverage: 8–15 ha/day</li> <li>Spread width: 8–14 m</li> </ul>	<ul style="list-style-type: none"> <li>PTO-driven disc or twin-disc system</li> <li>Adjustable gate and spread width</li> <li>Rugged frame and large hopper</li> <li>Compatible with 20–60 HP tractors</li> </ul>	<ul style="list-style-type: none"> <li>Very high field capacity - Saves time and labour (70–80%)</li> <li>Ensures uniform and precise fertilizer placement</li> <li>Suitable for all major field crops</li> </ul>	<ul style="list-style-type: none"> <li>High initial investment - Requires tractor ownership</li> <li>Difficult to operate in small or uneven fields</li> <li>Needs regular maintenance to prevent corrosion</li> </ul>

### Advantages of Using Fertilizer Broadcasters

- Reduction in Drudgery and Labour Requirement:** Traditional method of fertilizer application involves heavy manual works like bending, carrying and walking under harsh conditions. Mechanised broadcasting eliminates most of this physical strain. A tractor operated broadcaster can complete in one hour what would take several labourers an entire day.
- Uniform and controlled Application:** Uniform nutrient distribution promotes balanced crop growth and avoids problems like localised deficiency or lodging due to over-application. By regulating application rate, farmers can reduce wastage and improve fertilizer use efficiency.
- Timely and Efficient Operation:** Time is crucial for fertilizer application, particularly during critical growth stages. Broadcasters allow speedy coverage ensuring timely top-dressing and improving crop response to nutrients.
- Cost Effective and Profitable:** By saving labour time and fertilizer, the broadcaster lowers the overall cost of cultivation. Many studies show that using a broadcaster can save up to 15% of fertilizer and 60 % labour costs while maintaining or even increasing yields.
- Safety and Operator Comfort:** The use of broadcasters minimizes direct contact between the operators and fertilizers, reducing health risks from chemical exposure. Farmers can work comfortably without handling heavy loads.

### Maintenance tips:

- To stop corrosion, thoroughly clean the disc and hopper after each use.
- Lubricate moving parts on a regular basis.
- Keep the apparatus in a dry location.
- Maintain charge cycles and inspect electrical connections (for battery models).

### Economic and Energy Benefits

Parameters	Manual Broadcasting (by hand)	Hand-Operated (Shoulder-Mounted) Broadcaster	Battery-Operated Broadcaster	Tractor-Operated Broadcaster
Labour Requirement (man-h/ha)	40–45	15–20	8–10	1 (operator only)
Time Required (h/ha)	6–8	3–4	1.5–2.0	0.5–1.0
Fertilizer Saving (%)	—	5–8	10–12	12–15
Operational Cost (₹/ha)	800–1000	500–700	350–500	250–400
Field Capacity (ha/day)	1.0–1.5	2.0–3.0	3.0–4.0	10–15
Energy Consumption (MJ/ha)	1600–1800	1200–1400	900–1100	700–900
Remarks / Overall Benefit	Very high labour and time demand; non-uniform application; suitable only for small plots.	Reduces labour drudgery; moderate uniformity; good for small to medium farms.	Consistent application; saves energy and fertilizer; ideal for small and medium holdings.	Very high efficiency; low operational cost per hectare; best suited for large farms.

### Conclusion

The fertilizer broadcaster is more than a mechanization tool it is a lever for sustainable agriculture. By reducing labour pressure, saving time, obtaining homogeneity in the application of fertilizers and increasing efficiency in the use of inputs, it puts higher production with lower costs in the reach of farmers. With increasing awareness, Government support and rapid technological progress fertilizer broadcaster are bound to become an essential part of the modern farm promoting cleaner and more efficient and as a result more profitable agriculture in the future.

## High-Pressure Processing: A Game Changer in Modern Seafood Preservation



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### Abstract

Fish and seafood are among the most nutritious products, but they spoil quickly after harvest due to microbial and enzymatic processes. While traditional preservation techniques like freezing and thermal processing increase shelf life, they frequently sacrifice flavour, texture, and nutritional value. A successful non-thermal substitute that satisfies consumer demand for minimally processed and fresh-like seafood is High-Pressure Processing (HPP). HPP improves food safety while maintaining sensory and nutritional qualities by using uniform hydrostatic pressure (300–600 MPa) to inactivate pathogenic microorganisms and spoilage without producing a lot of heat. In addition to causing controlled changes in muscle proteins and water distribution that differ among seafood species, the process damages microbial cell membranes and proteins. Commercial applications of HPP include the processing of shellfish, ready-to-eat goods, and chilled fish fillets. Ongoing research attempts to optimize processing conditions, despite the challenges of bacterial spore resistance and high equipment costs. All things considered, HPP is a viable and sustainable method of preserving seafood.

**Keywords:** Seafood, Preservation, High-Pressure Processing, Shelf-life, Sustainable

### Introduction:

Fish and seafood are highly valued for their nutritional benefits, yet they are among the most perishable foods (Kumar et al., 2024). Shortly after the harvest, freshness and quality start to be lost as microbes and enzymes start growing and acting. Traditional food preservation techniques like freezing, drying and thermal treatment delay food spoilage but usually compromise food texture, flavour and nutrients. Given the rising consumer demand for fresh-like and minimally processed seafood, the industry is also switching to adopting High-Pressure Processing (HPP) as a new and emerging non-thermal preservation technology.

### What Is High-Pressure Processing?

High-Pressure Processing is a more recent type of food preservation where the seafood items are placed under extremely high hydrostatic pressure; between 300 and 600 MPa of water is applied as the pressure-delivering medium. The pressure is also applied consistently and at a given moment irrespective of the size or shape of the product, and the treatment is uniform. Since HPP is not heat-based, it is useful in improving food safety without affecting sensory and nutritional quality (Kotadiya et al., 2025).

### How Does HPP Improve Seafood Safety?

The main advantage of HPP is the fact that it inactivates spoilage and pathogenic microorganisms. High pressure damages the cell membrane of microbes, denatures essential proteins and disrupts metabolism resulting in the death or retardation of the microbes. It has been shown that HPP has a strong effect of lowering the microbial load in refrigerated fresh fish fillets like salmon (*Salmo salar*) and plaice (*Pleuronectes platessa*) without adversely affecting product quality (Castrica et al., 2021).

HPP also affects muscle proteins and muscle tissue water distribution in addition to microbial control. Modifications in proteins and hydrostatic abilities differ across species, and the advantages of optimal pressure regimes of various seafood products are recognized (De Aguiar Saldanha Pinheiro et al., 2025).

### Fresh Taste and Nutritional Retention

The preservation of the fresh taste and the nutritional content of the seafood is one of the greatest benefits of High-Pressure Processing. As pressure has minimal impact on covalent bonds, delicate nutrients like omega-3 fatty acids, essential amino acids and vitamins are preserved. Recent research work on sardines revealed that well-

regulated HPP treatments can preserve colour, texture and volatile flavour compounds in chilled storage (Ismaiel et al., 2025).

HPP does not deactivate the property of proteins like in thermal processing, nor does it lead to the loss of moisture, as thermal processing does, and this feature makes HPP particularly appealing to the use of premium seafood products.

### **Applications in the Seafood Industry**

Already, the High-Pressure Processing has been applied in the seafood industry in various commercial uses. It is popular in prolonging the shelf life of chilled fish fillets, manufacture of ready to eat seafood products, and enhancing food safety in raw or low processed fish. HPP can also be applied when processing shellfish, which is the area where pressure is needed to separate the meat and minimise microbial contamination. The technologies have these benefits, which render it especially applicable to export and high-value seafood markets (Kotadiya et al., 2025).

### **Challenges and Future Prospects**

Although it has its advantages, the use of HPP is hindered by the expensive cost of equipment and the pressure-resistant packaging materials that are required. Also, the bacterial spores are stronger to pressure, and they might need combined treatments before they are eliminated. However, current studies are aimed at the optimization of processing parameters and the combination of HPP with other preservation systems and the cost efficiency. Having a tendency to the fresh, safe, and minimally processed foods, the High-Pressure Processing is likely to become more significant in the process of preserving seafood in the most sustainable way.

### **Conclusion**

High-Pressure Processing is a new non-thermal process that is effective in enhancing food safety and shelf life of seafood and maintains fresh-like quality. HPP preserves the natural texture, flavour and nutritional value of fish products by inactivating microorganisms without the use of heat. High initial cost is an issue, but with further research and technology, HPP is becoming a more viable solution to sustainable processing of seafood.

### **References**

- Castrica, M., Pavlovic, R., Balzaretto, C. M., Curone, G., Brecchia, G., Copelotti, E., ... & Chiesa, L. M. (2021). Effect of high-pressure processing on physico-chemical, microbiological and sensory traits in fresh fish fillets (*Salmo salar* and *Pleuronectes platessa*). *Foods*, *10*(8), 1775.
- De Aguiar Saldanha Pinheiro, A. C., Tappi, S., Soglia, F., Baldi, G., Hernandez, J. B. M., Laghi, L., ... & Rocculi, P. (2025). Effect of high hydrostatic pressure (HHP) on proteins, lipids, and water state of three different thawed seafood products. *Italian Journal of Food Science*, *37*(3), 80-95.
- Ismaiel, L., Nartea, A., Fanesi, B., Lucci, P., Pacetti, D., Jaeger, H., & Schottroff, F. (2025). Effect of High-Pressure Processing on Color, Texture and Volatile Profile During Sardine Refrigeration. *Foods*, *14*(2), 329.
- Kotadiya, D. P., Borichangar, R. V., Tandel, S. K., Parmar, J. N., Varma, R. B., & Sapra, D. H. (2025). A Review on High-pressure Processing for Seafood Preservation. *Journal of Biochemistry International*, *12*(1), 170-177.
- Kumar, P., Vaishnav, A., Chauhan, S., Lalbiaknguri, S., Lal, J., Singh, N. S. C., & Pati, B. K. (2024). Encapsulation techniques for enhancing the stability and bioavailability of food: A review. *Int. J. Adv. Biochem. Res*, *8*, 16-23.

## "Growing Green Gold: Production Technology of Ivy Gourd"



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### Introduction:

*Coccinia grandis* belongs to family Cucurbitaceae, commonly known as Ivy gourd or little gourd also known as baby watermelon, gentleman's toes and locally known as Kundru, is a tropical plant. It is native to Bengal and other parts of India. *Coccinia grandis* grows abundantly all over India, tropical Africa, Australia and throughout other oriental countries. The plant has also been used tremendously in Ayurvedic and Unani practice in the Indian subcontinent. Every part of the plant is beneficial in medicine and also in various preparations that have been mentioned in the indigenous system of medicine like the anti-inflammatory, analgesic and antipyretic activity of fruit and leaves have been studied so far and are found to be noteworthy. The plant contains secondary metabolites such as saponins, flavonoids, sterols, and alkaloids. The whole plant can be traditionally used for various curative purposes. Leaves are used in Indian traditional medicine for treatment of a number of maladies including diabetes, wounds, ulcers, inflammation, in eruptions of the skin, fever, asthma and cough.



**Botanical name:** *Coccinia grandis* or *Coccinia indica*

Family: Cucurbitaceae

Chromosome no:  $2n=24$

Common name: little gourd, Hindi: kundru,

Immature fruits of ivy gourd are used as a vegetable besides fruits young shoots and leaves are consumed as fried, blanched or boiled

The ripe fruits develop red colour and can be eaten raw

The carotenoid of ripe fruit is lycopene (5.68mg/ 100 g) and beta carotene (2.24 mg/100 g)

The flesh can be processed into fermented or dehydrated chips, which can be stored for a long period

**Description:** The description of different parts of *Coccinia grandis*.

Leaves are dark green in colour, the shape of the leaves varies from heart to pentagon and is upto 8 cm long in size. Its flowers are white in colour and shape like star. The corolla is white in colour and campanulate with a size of 2.5–5.5 cm. The ripe fruit of the herb is red in colour and unripe fruit is dark green in colour with yellow streaks and shape like ovoid to elliptical, size is 24–62 mm long, 14–36 mm in diameter.

The roots are light brown in colour and stems are light green in colour and are succulent, tuberous which likely facilitate the plant to survive in disaster like drought.



### Soil and climate:

The suitable soil was loamy-sandy soil and avoid heavy clay soil that hinder the drainage capability. Also it prefers a neutral soil. The ideal temperature for optimal growth ranges from 20°C- 32°C. It prefers 6-7 hours of full sunlight.

**Propagation:** ivy gourd can be propagated both by seed as well as by cuttings

1. **Seed propagation:** seed propagation is not in vogue because of its dioecious nature (50 %male plants). A ratio of 1:10 male to female plant is considered ideal for pollination
2. **By cuttings:** four to five months old vines are selected for making cuttings. Cuttings of 12- 15 cm length and pencil thickness having 5-6 leaves are taken and planted in basins of 60 cm diameter dug 175 apart about 2- 3 stem cuttings are transplanted 3 cm deep in each basin. Planting is done during rainy season.
3. **Varieties:** No improved varieties have been recommended, so far and only local collections are planted in different regions. At Indian institute of vegetable research, Varanasi 4 genotypes were selected from the locally collected germplasm on the basis of their fruit size and yield attributes.

VRK-20, VRK-31, VRK-35, VRK-37

**Arka Neelachal Sabuja:** The plants are very vigorous (>10m long) fruits are dark green in appearance with fractured stripe and conical in shape. It gives 70-80 harvest per season (10-11 months) and yield up to 20-25t/ha

**Arka Neelachal Kunkhi:** a dual purpose (salad as well as cooked) early variety with yield (20-25 t/ha). Fruits are extra-long (8.39 cm), weighing around 15-20g, uniform, cylindrical with attractive stripes.

### After Cultivation

**Manuring** - For a prolific growth, supplement the soil with well-rotted manure, compost or cow dung manure. Mix it with the soil before transplanting or sowing seeds. Also, side dress the soil with compost or cow dung manure twice a year, especially during flowering and fruiting period.

**Irrigation** – it is important and has to be done immediately after planting and need to irrigate at every 1-week interval. No need to irrigate in the rainy season. Maintain the drip irrigation to maintain the adequate moisture during the flowering stage. Maintain the proper drainage to avoid waterlogging

**Pruning** – It has invasive growth and can cover a lot of area if not trimmed. So, after harvesting, prune it back to control its growth. Using sanitized shear or knife, snuff off the branches, leaving only 2-3 feet stem vine.

**Harvesting and yield:** The vine starts bearing fruit within 3 – 4 months of planting. But it can differ in case of seed propagation, where it may take 1 year. It can be harvested by hand picking or snip off them. It can harvest, when fruits are young & look green and bulbous. The average yield can be around 9-12 kg/acre.

### Plant protection

The ivy gourd is a very tough and very strong climbing vegetable, so that cannot get affected by any serious pests and diseases. But, some pests like aphids, mites, thrips and whiteflies were found. It can control by the organic manures itself. In point of diseases, powdery mildew can occur, it can be controlled by 0.3% Wettable Sulfur.

## Artificial Intelligence Applications in Agricultural Pest Management



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### Abstract

Agriculture today facing many challenges due to climate change, pest outbreaks, rising production costs and excessive dependence on chemical pesticides. Insect pests cause heavy crop losses every year, forcing farmers to use pesticides repeatedly, which leads to problems such as pest resistance, environmental pollution and health risks to humans and animals. To overcome these issues, modern agriculture is moving towards smart and sustainable solutions. Artificial intelligence (AI) has emerged as an effective tool in agricultural pest management by enabling early detection, accurate identification and timely control of insect pests. AI technologies such as machine learning, deep learning and computer vision help farmers monitor crop health, predict pest outbreaks and apply pesticides only when necessary. The use of AI in agricultural entomology supports precision farming, reduces input costs, minimizes environmental damage and improves crop productivity. With proper training and awareness among farmers and extension workers, artificial intelligence can play a major role in achieving efficient, eco-friendly and sustainable pest management systems in agriculture.

### Introduction

Modern agriculture is facing many serious challenges. Farming has become a highly competitive and global activity, where farmers must aware with changing climate, diverse geographical conditions, fluctuating economic and political situations. Every year, insect pest destroys a large portion of crop production worldwide, causing huge economic losses. To reduce these losses, farmers often depend heavily on chemical pesticides to improve crop yield, quality and storage life. However, the repeated and excessive use of pesticides has created several problems. Pests have developed resistance to chemicals, secondary pests have emerged and the natural resistance of crops has weakened. In addition, more uses of pesticide led to environmental pollution and increased health risks for consumers. These challenges highlight the need to use water, energy, fertilizers and pesticides more carefully and efficiently. Early detection of pests is especially important to avoid unnecessary pesticide use and to protect crop productivity. In recent years, smart agriculture has emerged as a promising solution. It combines artificial intelligence with modern technologies such as sensors, wireless communication and digital tools to manage crops more precisely. Through this approach, farmers can monitor crop health, detect pest attacks at an early stage and apply control measures only when and where they are needed. This not only improves pest management efficiency but also reduces labour costs and input expenses. Identifying insect pests is often difficult because many species look very similar and traditional methods of manual inspection are slow, costly and unreliable. Artificial intelligence offers a powerful alternative by accurately recognizing pests at early stages and supporting timely decision making. By integrating artificial intelligence with entomology, farmers can forecast pest outbreaks, optimize pesticide use and achieve more sustainable and effective pest and disease management.

### What is Artificial Intelligence?

In computer science, artificial intelligence refers to the study of systems or machines that can sense their surroundings understand what is happening and take suitable actions to achieve specific goals successfully. Artificial intelligence is a broad concept that includes technologies such as machine learning, deep learning, computer vision and related fields.

### What is Machine Learning?

Machine learning is a field of science that focuses on creating computer systems that can learn from data and improve their performance over time. Instead of being programmed for every task, these systems analyse past information and use it to make better decisions in the future. Machine learning forms the core foundation of

artificial intelligence. In machine learning, algorithms are developed to identify patterns in existing data, learn from these patterns and use the acquired knowledge to predict results or solve problems. Various techniques are used in this process, including artificial neural networks, fuzzy logic systems, genetic algorithms and advanced deep learning methods such as convolutional neural networks and generative neural networks.

### Applications of Artificial Intelligence in Agricultural Entomology

The common uses of artificial intelligence in agricultural entomology can be grouped into three main categories.

#### 1. Taxonomic studies:

- Identification and classification of insects
- Phenotype quantification
- Understanding evolutionary variations in traits

#### 2. Ecological studies:

- Spatial and temporal distribution of insects
- Understanding changes in insect biomass
- Abundance and diversity
- Analysing nutritional ecology of insects
- Estimating microhabitat characters

#### 3. Pest management:

- Pest identification
- Classification
- Monitoring
- Control
- Developing pest warning
- Prediction systems and biosecurity

### Artificial Intelligence Apps

There are different AI apps are there which are going to be use in future agriculture they include.

- Plantix
- Leaf byte
- Bioleaf
- Cotton Ace
- Apizoom
- e-SAP

### Advantages and Disadvantages of Artificial Intelligence

#### ❖ Advantages:

- Reduction in Human Error
- Takes risks instead of Humans
- Available 24/7
- Faster Decisions
- Daily Application
- Economic impact
- Environmental impact
- Time saving

#### ❖ Disadvantages:

- High Costs of Creation
- Unemployment
- Lacking Out of Box Thinking
- Not full proof for diagnosis
- May affect birds and animals

### Conclusion:

Integrating artificial intelligence with entomology has the potential to bring major inputs in pest management. AI-based tools can help farmers protect crops from pests throughout the entire crop growth period, from sowing to harvest, by enabling timely detection, monitoring and decision-making. This leads to more efficient and sustainable crop protection with reduced losses. However, to fully benefit from these advanced technologies, it is essential that farmers and extension workers are properly trained and made aware of how to use AI tools effectively. With adequate knowledge and adoption, AI can play a key role in improving pest management and overall agricultural productivity.

### References:

Apizoom. Available: <https://www.apizoom.app/>

Bioleaf. Available: <https://www.quantitative-plant.org/software/bioleaf>

Chen, C. J., Huang, Y. Y., Li, Y. S., Chang, C. Y., & Huang, Y. M. (2020). An AIoT based smart agricultural system for pests detection. *IEEE access*, 8: 180750-180761.

FAO; 2020. Available: <https://www.fao.org/e-agriculture/news/fao-and-pennsylvania-state-university-launch-innovative-app-fight-fast-spreading-pest>.

Food and Agriculture Organization of the United Nations (FAO). 2020. New standards to curb the global spread of plant pests and diseases; 2020 Available: <http://www.fao.org/news/story/en/item/1187738/icode/>.

Karar, M. E., Alsunaydi, F., Albusaymi, S., & Alotaibi, S. (2021). A new mobile application of agricultural pests recognition using deep learning in cloud computing system. *Alexandria Engineering Journal*, 60(5): 4423-4432.

Leafbyte. Available: <https://zoegp.science/leafbyte>

PJTSAU. Available: <https://pjtsau.edu.in/mou-wadhani-doa-pjtsau-2021.html>

Plantix. Available: <https://plantix.net/en>

Wadhvani AI. Available: <https://www.wadhwaniai.org/programs/pest-management/>



## Climate-Resilient Agriculture Initiative (CRAI): A Path to Sustainable Farming



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### Abstract

Agriculture is central to India's socio-economic development, contributing substantially to GDP, employment, and food security. Yet, the sector is increasingly vulnerable to climate change, which manifests through unpredictable weather patterns, extreme temperatures, recurrent droughts, floods, and shifting rainfall cycles. These climatic stresses have resulted in declining crop yields, soil degradation, reduced livestock productivity, and economic instability, particularly in rainfed regions. The Intergovernmental Panel on Climate Change (IPCC) has identified agriculture as one of the most climate-sensitive industries, with water scarcity and soil erosion posing critical threats to sustainability. In response, the Climate-Resilient Agriculture Initiative (CRAI) has been introduced as a comprehensive framework to equip farmers with adaptive strategies, technological tools, and institutional support to mitigate climate risks while enhancing productivity and ecological balance.

**Key words** – Agriculture, soil degradation, sustainability, climate, productivity

### Introduction

Agriculture plays a pivotal role in India's socio-economic landscape, contributing significantly to GDP, employment, and food security. The interrelation between agriculture and climate change is crucial, as the agriculture sector is both victim and a contributor to climate changes. The Intergovernmental Panel on Climate Change (IPCC) recognized agricultural sector is one of the most vulnerable industries affected by climate change. Unpredictable weather patterns, extreme temperatures, more frequent drought, floods and changing rainfall cycles have led to declining crop yields, soil degradation, livestock production and economic losses for farmers in developing countries where agriculture is rainfed. It is anticipated that climate change will make water scarcity worse, which will have an even greater effect on agricultural systems (IPCC, 2019). Soil degradation significantly reduces the productivity of agricultural land, reducing crop yields and contributing to increased poverty, food insecurity, and rural displacement. Soil erosion is a widespread issue in many Indian states, especially in regions with steep topography or intensive agricultural activities. Advanced agricultural techniques include crop diversification, agro ecological techniques, and water management technologies have been implemented in response. Increasingly, strategies are being employed to increase climate variability resistance. In response to these challenges, the **Climate-Resilient Agriculture Initiative (CRAI)** has been introduced as a forward-thinking strategy to equip farmers with tools and knowledge necessary for adapting to environmental changes. This article delves into the significance, components, and impact of CRAI in transforming agriculture into a more sustainable and resilient sector.

### The Need for Climate-Resilient Agriculture

Agriculture is highly dependent on climatic conditions. Traditional farming methods, which were once effective, are proving inadequate in the face of increased droughts, floods, and temperature fluctuations. According to climate scientists, global temperatures have risen by approximately 1.1°C since the pre-industrial era, leading to increased instances of crop failures. Given that there are several abiotic pressures on crops and livestock, water scarcity, soil degradation, and other complicated issues brought on by climate change, loss of biodiversity, finding answers to the issues will require a concentrated and extended study. It is vital to set up the infrastructure required to conduct both strategic and fundamental research. At the same time, there is potential to increase agricultural resilience through the application of current technology and

knowledge to farmers' fields as a whole. The CRAI aims to address these challenges by encouraging farming practices that are adaptive to climate risks. The initiative focuses on enhancing productivity while ensuring ecological sustainability and food security for future generations.

### Core Components of CRAI

CRAI incorporates multiple strategies to empower farmers and make agricultural practices more climate-resistant. Some of the essential components of this initiative include:

#### 1. Smart Irrigation and Water Management

Water scarcity is one of the most critical challenges for farmers worldwide. CRAI promotes **efficient irrigation technologies** such as:

- **Drip irrigation** - Drip irrigation technique is a modern irrigation system which is developed **Simcha Blass** in the mid-20<sup>th</sup> century. Drip irrigation is slow application of water in the form of discrete, continuous drop, tiny streams or miniature sprays through mechanical device, which delivers water directly to plant roots, minimizing wastage of water.
- **Rainwater harvesting systems** - Rain water harvesting technique significantly contribute to the sustainability of urban and rural areas. Rain water harvesting is the most traditional and sustainable method, which could be easily used both in crop production and drinking purpose for animals and humans. Harvesting the rain water through roof and water harvesting structure to store and utilize rainwater effectively.
- **Soil moisture sensors** – Soil moisture sensors is a mechanical device that guide farmers on optimal water usage on the basis of water requirement of crops and scarcity of water in soil.

#### 2. Climate-Resilient Crop Varieties

Traditional crops may not withstand extreme climatic variations, making the adoption of drought-resistant and flood-tolerant varieties crucial. CRAI facilitates:

- **Genetically improved seeds** - Genetically improved seeds are crop seeds that have been designed to endure high temperatures and irregular rainfall.  
Ex. - Bt. Cotton in India resistant to bollworm pest, Golden rice – combat Vita. A deficiency.
- **Bio fortified crops** - Bio fortification is a potential strategy to enhance crop micronutrient content that ensure nutritional security while thriving in difficult environmental conditions.

#### 3. Soil Health and Conservation

Soil degradation due to excessive chemical fertilizers, erosion, and lack of organic matter severely impacts agricultural sustainability. CRAI advocates for:

- **Regenerative farming** - Regenerative farming represents a transformative approach to modern farming, emphasizing ecological sustainability, soil health and climate resilience. Unlike intensive agriculture practices, which often rely on excessive use of chemical inputs and can degrade natural ecosystems, regenerative methods aim to restores soil fertility by incorporating organic composts and natural fertilizers.
- **Cover cropping** – Cover cropping in planting non harvested crops such as legumes, grasses and brassicas to cover soil between main crop cycles, preventing soil erosion, improving soil health (fertility, structure, water retention), while enhancing its nutrient content.
- **Cover rotation** - Instead of continuous wheat-rice monoculture, farmers adopted legume-based crop rotation, intercropping with pulses improve soil quality.
- **Minimal tillage methods** – Minimum tillage is a farming method that minimizes soil disturbance, disturbing it only enough for planting, conserve soil moisture, reduce erosion and lower fuel/labour coats compared to conventional ploughing, preserving microbial life essential for soil health.

#### 4. Digital and Technological Support

Technology plays a pivotal role in modern agriculture. CRAI promotes **digital tools** such as:

- **Satellite-based weather forecasting** – Weather forecasting satellites are crucial space-based tools, like India's INSAT/INSAT-DR series, that provide continuous global views of Earth's atmosphere using visible, infrared and water vapour sensors to track clouds, temperature and moisture, feeding vital data for short term forecasting to help farmers plan their cultivation cycles.

- **AI-driven pest detection systems** – An AI-driven pest detection system uses machine learning, computer vision, and sensor data (sound, images, environmental) from source like drones, IoT devices and cameras to automatically and accurately identify pest in real-time, enabling early, targeted interventions, reducing pesticide use and supporting sustainable precision agriculture for better crop yield and to prevent crop damage.
- **Block chain-enabled supply chain management** – Create transparent, secure and efficient systems by using an immutable digital ledger to track food farm to table, boosting trust, reducing fraud (like adulteration), ensuring fair payments via smart contracts, enabling rapid recalls for contamination and giving consumers proof of origin/quality, ultimately supporting food security and sustainability by connecting farmers directly to markets and improving data flow with technologies like IoT for real-time monitoring.

### Impact of CRAI on Farmers and Food Security

The CRAI has already shown significant positive outcomes in regions adopting its principles. Some key benefits include:

- **Increased Crop Yield:** By using advanced farming techniques, farmers have reported improved productivity even in harsh climatic conditions.
- **Water Conservation:** Efficient irrigation methods have drastically reduced water usage, helping regions combat droughts.
- **Economic Stability:** Reduced crop losses and improved market access have enhanced financial security for farmers.
- **Environmental Protection:** By promoting sustainable land-use practices, CRAI contributes to biodiversity preservation and reduced greenhouse gas emissions.

### Future Prospects

- **Integration of Precision Agriculture** - CRAI is expected to increasingly adopt AI-powered precision farming tools, drones, and IoT sensors to optimize crop management, reduce input costs, and improve yields under variable climatic conditions.
- **Renewable Energy in Farming** - Solar-powered irrigation pumps, biogas plants, and wind energy solutions can reduce dependence on fossil fuels, making agriculture more sustainable and cost-effective.
- **Localized Crop Adaptations** - Development of region-specific crop varieties that are drought-tolerant, flood-resistant, or heat-resilient will strengthen food security across diverse agro-climatic zones in India.
- **Expansion of Digital Platforms** - Wider use of mobile apps, satellite data, and block chain systems will enhance farmer access to real-time weather forecasts, pest alerts, and transparent market transactions.
- **Policy and Institutional Support** - Stronger government backing through subsidies, insurance schemes, and farmer education programs will accelerate adoption of CRAI practices nationwide.

### Challenges

- **High Initial Investment Costs** - Advanced technologies like AI-driven pest detection, drip irrigation, and block chain systems require significant upfront capital, which may deter smallholder farmers.
- **Limited Awareness and Training** - Many farmers remain unaware of climate-resilient practices or lack the technical skills to implement them effectively.
- **Resistance to Change** - Traditional farming communities may be hesitant to adopt new methods, preferring conventional practices despite declining productivity.
- **Infrastructure Gaps** - Rural areas often lack reliable electricity, internet connectivity, and storage facilities, limiting the effectiveness of digital and technological solutions.
- **Policy Implementation** - Barriers While supportive policies exist, bureaucratic delays, uneven subsidy distribution, and weak monitoring can hinder progress.
- **Climate Uncertainty** - The unpredictability of climate change impacts—such as sudden floods or prolonged droughts—poses on-going risks that even resilient systems may struggle to fully mitigate.

## Conclusion

The **Climate-Resilient Agriculture Initiative (CRAI)** is a transformative approach that enables farmers to navigate climate challenges effectively. By incorporating sustainable practices, advanced technologies, and financial support, CRAI ensures agricultural resilience while securing food supplies for future generations. With continuous innovations and collaboration, climate-smart farming is set to become the cornerstone of global agricultural sustainability.

## References

- Ndubuisi, O. G., and FNisafetyE, F. I. S. P. O. N. 2025. Climate Change and Agriculture: Exploring Climate-Resilient Farming Practices.
- Roohi, Kamboj, P., Soni, P. G., Rani, S., Sukirtee, Kumar, R., and Mishra, A. K. 2025. Advancing Climate-Resilient Agriculture: Adaptive Strategies and Soil-Centric Approaches for Mitigation. In *Transition to Regenerative Agriculture: Principles and Indicators of Soil Health Management* (pp. 55-75). Singapore: Springer Nature Singapore.
- He, Q., Lu, C., Cowie, A., Zhao, S., Liu, D. L., Yi, B., and Li, L. 2025. Optimizing cover cropping application for sustainable crop production. *npj Sustainable Agriculture*, 3(1), 10.
- Stofferis, B. J., Baarsma, B. E., and Soltani, T. 2025. Adoption of Regenerative Farming Practices in Agriculture: A Real Option Analysis. *Research on World Agricultural Economy*, 187-206.
- Sahoo, S., Singha, C., Govind, A., and Moghimi, A. 2025. Review of climate-resilient agriculture for ensuring food security: Sustainability opportunities and challenges of India. *Environmental and Sustainability Indicators*, 25, 100544.
- Gautam, A., Sharma, V., Chauhan, C., Thakur, A., Pandey, M. K., Priscilla, K., and Kumar, R. 2025. Fortifying crops with micronutrients for sustainable global nutritional security. *Agronomy Journal*, 117(3), e70086.
- Marke, A. T. 2014. Climate-Resilient Agriculture and Food Security. *Global Solutions Network*, 1-43.



## Spray Drying: Bridging efficiency, quality, and sustainability



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### Abstract

Spray drying is a process used in the transformation of liquid feeds into stable powders through rapid atomization and evaporation; it revolutionized food, pharmaceutical, and chemical industries. This article describes the principles of the technology, its applications for amorphous solid dispersions and microencapsulation to enhance bioavailability, recent developments in novel atomizers and aseptic processing, and issues with scale-up. Based on recent scholarly reviews, spray drying has evolved into a biotechnology platform capable of enhancing drug solubility by up to 20-fold while addressing thermal stress and yield issues.

*Keyword: Spray drying, bioavailability, microencapsulation, yield.*

### Introduction

Spray drying is a precise particle-engineering technique that converts liquids into dry powders by atomization into hot gas streams, producing particles with controlled size (5–5000  $\mu\text{m}$ ), morphology, and low moisture content (<5%). Although patented in 1872, its industrial use expanded in the 1920s and now includes pharmaceutical, food, and chemical applications, such as inhalable powders, controlled-release systems, milk and fruit juice powders, and catalysts (Thakur et al., 2025). In pharmaceuticals, spray drying improves drug solubility and bioavailability through amorphization or encapsulation. Process optimization using Quality by Design (QbD) and real-time process control ensures robustness and consistency (Shinde et al., 2018).

### Process principle

#### Atomization phase

In spray drying, liquid feed is atomized into fine droplets to maximize surface area for efficient drying. Rotary atomizers use high centrifugal forces and are suitable for viscous feeds but require large drying chambers. Pressure nozzles operate at high liquid pressures yet are prone to clogging. Two-fluid nozzles, commonly used in laboratories, offer flexibility by adjusting gas–liquid ratios, though they produce broader particle size distributions. Ultrasonic atomizers generate highly uniform droplets via high-frequency vibrations but are limited to low-viscosity feeds. Droplet size strongly influences final powder characteristics, while pulsation-free peristaltic pumps ensure consistent feed rates (Cal and Sollohub, 2010).

#### Drying and evaporation

Droplets come into contact with hot air; co-current flow for heat-sensitive materials undergoes constant-rate evaporation to wet-bulb temperature, then a falling rate as a crust forms. Residence time is in seconds, preventing wall deposition through airflow dynamics modeled by CFD (Milanesi et al., 2025). Co-current flow dries gently, while counter-current flow intensifies the drying. Parameters such as air velocity increase drying rates according to the Nešić-Vodnik equations. Thermal stress on proteins and incomplete drying may further cause stickiness (Hohne and Gaukel, 2024).

#### Powder recovery

Cyclones separate via centrifugal force; filters catch fines, achieving 90%+ yields. Deposits form from moisture equilibration or turbulence, addressed by inert shutdowns (Hohne and Gaukel, 2024).

### Applications

#### Pharmaceuticals

Spray drying enables production of inhalable powders (1–5  $\mu\text{m}$ ) and amorphous solid dispersions that significantly enhance bioavailability. Notable improvements include 9-fold AUC increase for oxyberberine and 20-fold for quercetin formulations. It also stabilizes proteins and oils, reducing oxidation, while excipients

improve powder flow and compressibility. Aseptic spray drying further supports parenteral applications by minimizing cold-chain requirements (Baumann et al., 2021).

#### **Food and nutraceuticals**

Produces powdered milk, juices, probiotics via microencapsulation, retaining bioactives. Pulse combustion variants enhance fruit powders. Stickiness in sugar-rich feeds is mitigated by high-DE maltodextrins (Dantas et al., 2024).

#### **Fish Oils Encapsulations**

Spray drying is a widely adopted, practical, and economical technique for microencapsulation of food ingredients, particularly for stabilizing omega-3 oils in foods and infant formulas (Kumar et al., 2025). The method involves emulsification, atomization, and rapid drying, producing powders with minimal thermal damage due to short heat exposure (Schuck et al., 2009; Kumar et al., 2024). Compared with freeze drying, spray drying is 30–50 times more cost-effective for oil encapsulation (Ng et al., 2013). The process includes emulsion formation, homogenization, atomization, and dehydration, and drying conditions may influence powder crystallization and final product properties (Bakry et al., 2016).

#### **Oyster cooking soup by-product**

Oysters are nutritionally valuable seafood, with about half of global production processed into products such as fresh, fermented, smoked, dried, canned forms, and oyster sauce (Chen et al., 2008). Spray drying parameters—including total solids, hot air temperature, and atomization pressure—have been optimized using Response Surface Methodology (RSM) to improve oyster powder yield and quality (Ke and Chen, 2016). Optimal conditions (30% solids, 197 °C air temperature, 92 MPa pressure) achieved yields of ~63% and moisture content of ~4%, closely matching pilot-scale results (Chen et al., 2017). Enzymatic hydrolysis enhanced flavor and antioxidant activity, demonstrating spray drying as an effective method for converting oyster cooking byproducts into value-added powders.

#### **Encapsulation of *Channa striatus* extract**

Spray drying is a widely used technique for converting liquid materials into dry powders with low moisture content, suitable particle size, and improved handling, storage, and transportation properties (Tonon et al., 2008). Haruan fish (*Channa striatus*) extract is prepared by pressure cooking fillets, filtering the liquid, and adding κ-carrageenan prior to spray drying under controlled operating conditions (Jais et al., 1994). Spray drying parameters such as inlet air temperature, feed flow rate, and air flow significantly influence powder characteristics. Lower feed and air flow rates and higher inlet temperatures result in reduced particle size and moisture content, while protein content increases with higher temperatures and reduced flow rates (Hui et al., 2010).

#### **Powdered protein hydrolysate from Yellowstripe scad (*Selaroides leptolepis*) fish**

Spray drying of Yellowstripe scad protein hydrolysate was performed using an ultrasonic spray dryer at a feed rate of 1 L/h and an inlet air temperature of 80 °C. Protein hydrolysate produced using 2.0% Alcalase for two hours achieved a high yield (16%) and degree of hydrolysis (95%), resulting in enhanced functional properties. Spray-dried samples exhibited significantly higher water-holding capacity compared to non-dried hydrolysates, indicating improved protein recovery and functionality. These spray-dried protein hydrolysates show potential application as oil-reducing agents in batter formulations for fried foods (Hau et al., 2018).

#### *Effects of Osmotic Stress and Encapsulation Materials on the Post-Spray Drying Stability of Autochthonous*

#### ***Lactobacillus plantarum***

Spray drying was used to stabilize the autochthonous probiotic *Lactobacillus plantarum* LPS 47 isolated from healthy Chilean salmon for potential fish feed applications. The effects of osmotic stress during fermentation and different protective agents were evaluated to improve thermal resistance during drying. Spray drying with cheese whey (20% w/w) as a protective agent, without applying osmotic stress, resulted in optimal bacterial viability, low moisture content, and high storage stability. The dehydrated product maintained approximately 10<sup>9</sup> CFU/g viability and less than 5% moisture after 10 weeks of storage at 4 °C, demonstrating the effectiveness of spray drying for producing stable probiotic formulations (Bustos and Bórquez, 2013).

### Recent innovations

Nano-into-micro strategy embeds nanoparticles in inhalable microparticles. Electrostatic spray drying yields well-defined PSD. Biopharma field is also advanced in stabilizing mRNA/LNP excipients, vaccines independent of cold chain, as by Celik and Wandel (2005). QbD-defined design space ensures consistency. CFD optimizes trajectories as done by Cal and Sollohub (2005). Aseptic closed-loop system enables sterile parenterals. Future: AI-PAT integration, sustainable gases, multi-functional inorganics (Zhang et al., 2025).

### Future impacts

Spray drying is an advanced and attractive technology for pharmaceutical applications, enabling precise control over particle size distribution, moisture content, density, and morphology. Recent research focuses on particle formation mechanisms and the development of multistage processes, innovative spray techniques, and temperature-gradient systems. Conventional spray-drying equipment is increasingly used in the United States due to its continuous operation, process control, and flexibility in production capacity (Masters, 1991).

### Drawbacks

As was discussed in the previous sections, spray drying has various difficulties. It is important to draw attention to problems such product loss caused by particle deposition inside the drying chamber's walls and by the separation devices' incapacity to remove the smallest particles. As a result, even though under ideal circumstances the process yield would be close to 100%. Furthermore, it is significant to note that the inability of the collecting devices as well as the inherent difficulty of atomizing the feedstock solution into submicron droplets make it extremely difficult to obtain very small particles (nanometer scale) by spray drying (Santos et al., 2018).

### Conclusion

Spray drying is an efficient and cost-effective technique for producing free-flowing particles with controlled sizes in the submicron to micron range. Its versatility in feed materials, high productivity, and broad applicability have increased its popularity in research and industrial applications. Spray-drying performance is governed by interdependent processing parameters that collectively influence product quality, requiring holistic optimization rather than isolated evaluation. Owing to its scalability and economic viability, spray drying is increasingly favored for producing functional dried products, particularly for applications in the fish feed industry.

### References

- Thakur, C., Kaushal, M., Vaidya, D., Verma, A. K., Gupta, A., & Sharma, R. (2025). Unlocking the potential of spray drying for agro-products: exploring advanced techniques, carrier agents, applications, and limitations. *Food and Bioprocess Technology*, 18(2), 1181-1220.
- Shinde, S. S., Mandake, G. R., & Nitalikar, M. M. (2018). Spray Drying: A Promising Technique to Enhance Solubility. *Asian Journal of Pharmacy and Technology*, 8(4), 255-260.
- Cal, K., & Sollohub, K. (2010). Spray drying technique. I: Hardware and process parameters. *Journal of pharmaceutical sciences*, 99(2), 575-586.
- Milanesi, A., Diana, G., Candiani, A., Sodano, A., Rassè, P., Bonda, A. F., ... & Giovannelli, L. (2025). Spray drying: From a traditional technology to modern biotechnological applications. *International Journal of Pharmaceutics*: X, 100449.
- Höhne, S., & Gaukel, V. (2024). Impact of the drying rate on product properties of spray dried emulsions to enable a targeted product design. *Drying Technology*, 42(14), 2080-2086.
- Celik, M., & Wendel, S. C. (2005). Spray drying and pharmaceutical applications. *DRUGS AND THE PHARMACEUTICAL SCIENCES*, 154, 129.
- Baumann, J. M., Adam, M. S., & Wood, J. D. (2021). Engineering advances in spray drying for pharmaceuticals. *Annual review of chemical and biomolecular engineering*, 12(1), 217-240.
- Dantas, A., Piella-Rifà, M., Costa, D. P., Felipe, X., & Gou, P. (2024). Innovations in spray drying technology for liquid food processing: Design, mechanisms, and potential for application. *Applied Food Research*, 4(1), 100382.
- Zhang, S., Gong, G., Wang, H., Chen, S., Wang, J., & Qi, J. (2025). Advances and challenges of the spray drying technology: Towards accurately constructing inorganic multi-functional materials and related applications. *Sustainable Materials and Technologies*, e01250.

- Schuck, P., Dolivet, A., Méjean, S., Zhu, P., Blanchard, E., & Jeantet, R. (2009). Drying by desorption: a tool to determine spray drying parameters. *Journal of Food Engineering*, 94(2), 199-204.
- Ng, S. K., Jessie, L. Y. L., Tan, C. P., Long, K., & Nyam, K. L. (2013). Effect of accelerated storage on microencapsulated kenaf seed oil. *Journal of the American Oil Chemists' Society*, 90(7), 1023-1029.
- Bakry, A. M., Abbas, S., Ali, B., Majeed, H., Abouelwafa, M. Y., Mousa, A., & Liang, L. (2016). Microencapsulation of oils: A comprehensive review of benefits, techniques, and applications. *Comprehensive reviews in food science and food safety*, 15(1), 143-182.
- Chen HuiBin, C. H., Wang MeiYing, W. M., Chen ShaoJun, C. S., Chen LiJiao, C. L., & Chen Yong, C. Y. (2008). Effects of different atmospheres on qualities of oyster during frozen storage.
- Ke, L., & Chen, H. (2016). Homogenate extraction of crude polysaccharides from *Lentinus edodes* and evaluation of the antioxidant activity. *Food Science and Technology (Campinas)*, 36(3), 533-539.
- Chen, H., Wang, M., & Lin, X. (2017). Optimization and application of spray-drying process on oyster cooking soup byproduct. *Food Science and Technology*, 38(3), 407-412.
- Masters, K. (1985). *Spray Drying Handbook*, 1991.
- Tonon, R. V., Brabet, C., & Hubinger, M. D. (2008). Influence of process conditions on the physicochemical properties of açai (*Euterpe oleracea* Mart.) powder produced by spray drying. *Journal of food engineering*, 88(3), 411-418.
- Jais, A. M. M., McCulloch, R., & Croft, K. (1994). Fatty acid and amino acid composition in haruan as a potential role in wound healing. *General Pharmacology: The Vascular System*, 25(5), 947-950.
- Hui, L. Y., Jais, A. M. M., Krishnaiah, D., Sundang, M., Ismail, N. M., Hong, T. L., & Bono, A. (2010). Encapsulization of *Channa striatus* extract by spray drying process.
- Hau, E. H., Mohd Zin, Z., Zuraidah, N., Shaharudin, N. A., & Zainol, M. K. (2018). Physicochemical properties of powdered protein hydrolysate from Yellowstripe scud (*Selaroides leptolepis*) fish. *International Food Research Journal*, 25(6).
- Bustos, P., & Bórquez, R. (2013). Influence of osmotic stress and encapsulating materials on the stability of autochthonous *Lactobacillus plantarum* after spray drying. *Drying Technology*, 31(1), 57-66.
- Kumar, P., Vaishnav, A., Chauhan, S., Lalbiaknguri, S., Lal, J., Singh, N. S. C., & Pati, B. K. (2024). Encapsulation techniques for enhancing the stability and bioavailability of food: A review. *Int. J. Adv. Biochem. Res*, 8, 16-23.
- Kumar, P., Dhar, B., Ghosh, S. K., Shivbhajan, Gore, S. B., Das, R., & Chanu, L. N. (2025). Valorization of Pangas By-product Generated Oil in Encapsulation by Integrating Maltodextrin and Whey Protein Isolate. *Waste and Biomass Valorization*, 16(3), 1229-1239.

## Analytical Orphans in Aquatic Environmental Monitoring: Contaminants We Measure Poorly, Rarely, or Not at All



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### Abstract

Recent advances in environmental analytical techniques have significantly enhanced the ability to detect chemical contaminants in aquatic systems. However, reports of ecological degradation persist even in waters that meet established chemical quality standards, suggesting a discrepancy between analytical measurements and ecosystem condition. This paradox highlights the existence of contaminants that conventional analytical frameworks either fail to detect, monitor infrequently, or completely ignore. These substances, referred to here as *analytical orphans*, escape routine monitoring due to methodological constraints, matrix complexity, regulatory focus on target compounds, and limitations in sample preparation and detection strategies. Analytical orphaning is particularly pronounced in complex aquatic environments such as estuaries, wetlands, and aquaculture-influenced waters. Failure to account for these contaminants can lead to underestimation of chronic stressors and misinterpretation of ecosystem health. Addressing analytical orphaning requires a shift toward problem-driven and ecologically informed analytical strategies.

**Keywords:** analytical orphans, aquatic ecosystems, emerging contaminants, monitoring limitations, environmental assessment

### Introduction

Agriculture, industry, urban runoff, wastewater discharge, and aquaculture activities increasingly expose aquatic ecosystems to a diverse array of chemical stressors. Environmental analytical science plays a critical role in identifying and quantifying these stressors through routine monitoring programs. Advances in instrumental sensitivity, selectivity, and automation have expanded the analytical capacity to detect contaminants at trace and ultra-trace levels. These developments have strengthened regulatory compliance frameworks and improved chemical surveillance in freshwater and marine environments.

Despite these analytical advancements, numerous aquatic systems continue to exhibit ecological impairment, biodiversity loss, and altered trophic structure even when monitored contaminant concentrations fall within acceptable limits. This discrepancy highlights limitations in current monitoring approaches that rely heavily on predefined target compounds and standardized methods. Analytical, methodological, and regulatory constraints leave many environmentally relevant substances inadequately represented in routine analyses. The concept of analytical orphans provides a useful framework for understanding why certain contaminants evade detection and how this invisibility affects environmental assessment and management.

### Concept of Analytical Orphans

"Analytical orphans" is a conceptual term for environmental contaminants that are present in the aquatic environment but are not routinely monitored or detected by standard analytical methods. These substances often go unnoticed due to limitations in current technology, the complexity of environmental samples, or a lack of regulatory requirements for their analysis. Analytical orphaning can occur when compounds fall outside regulatory priority lists, lack standardized analytical methods, or exhibit chemical properties that complicate detection.

Unlike well-studied regulated pollutants, analytical orphans often include transformation products, highly polar or reactive compounds, low-concentration chronic stressors, and complex chemical mixtures. Their ecological relevance may only become evident through biological responses rather than direct chemical measurement, contributing to gaps between chemical compliance and ecosystem health indicators.

## Technical Causes of Analytical Orphaning

### Target-Compound Bias and Instrument Selectivity

Routine environmental monitoring is largely based on target-compound analysis, where a limited number of chemicals are selected prior to analysis. While this approach ensures precision and reproducibility, it inherently excludes unknown, unexpected, or newly formed compounds. Instrumental selectivity optimized for specific analytes reduces the likelihood of detecting structurally diverse or non-target substances.

### Sample Preparation Constraints

Sample preparation steps such as filtration, extraction, and preservation are major sources of analytical loss. Processing may degrade or lose volatile, unstable, or highly polar compounds, resulting in systematic underestimation. These losses contribute to analytical orphaning even when advanced detection instruments are employed.

### Matrix Interference in Aquatic Systems

Aquatic environments often present complex matrices characterized by high organic matter content, salinity variation, suspended solids, and biological activity. Matrix interference can suppress analytical signals, increase background noise, and reduce method sensitivity. Estuaries, wetlands, and sediment-rich waters are particularly prone to such effects, increasing the likelihood that contaminants remain analytically invisible.

### Regulatory and Methodological Rigidity

Standardized regulatory methods frequently guide environmental monitoring programs, prioritizing consistency over adaptability. While such standardization facilitates long-term comparison, it limits the incorporation of new analytical approaches and emerging contaminant classes. This rigidity perpetuates analytical orphaning by maintaining a narrow analytical focus despite changing environmental conditions.

### Analytical Orphans in Aquatic Environments

Aquatic ecosystems are especially vulnerable to analytical orphaning due to their dynamic nature and multiple contaminant inputs. Wetlands act as biogeochemical reactors, generating transformation products that monitoring programs rarely target. Estuarine systems integrate freshwater and marine contaminants, creating complex chemical mixtures. Aquaculture-influenced waters introduce pharmaceuticals, disinfectants, and feed-derived compounds that are often excluded from routine analysis.

In such systems, organisms are exposed to contaminant mixtures over long periods, resulting in chronic and sub-lethal effects that may not correlate with measured concentrations of individual compounds. Analytical orphaning thus obscures cumulative and synergistic impacts that are critical for understanding ecosystem responses.

### Toward Problem-Driven Analytical Strategies

Reducing analytical orphaning requires a transition from method-driven monitoring to problem-driven analytical strategies. Monitoring designs should be guided by ecosystem characteristics, dominant stressors, and biological responses rather than solely by analytical convenience. Integrating effect-based tools, non-target screening concepts, and adaptive monitoring frameworks can improve the ecological relevance of analytical data.

Recognizing analytical limitations and uncertainties is essential for advancing environmental assessment. Acknowledging what is not measured is as important as reporting what is detected, particularly in complex aquatic systems where chemical and biological interactions are tightly coupled.

### Conclusion

Analytical orphaning represents a critical limitation in contemporary aquatic environmental monitoring. Despite technological advancements, many environmentally relevant contaminants remain poorly detected due to methodological constraints, matrix complexity, and regulatory focus on a narrow set of target compounds. This invisibility contributes to discrepancies between chemical assessments and observed ecological degradation. Addressing analytical orphaning requires a shift toward adaptive, ecologically informed analytical strategies that prioritize environmental relevance alongside analytical precision. Improving the alignment between chemical measurements and ecosystem responses is essential for more effective aquatic environmental management and sustainable resource protection.

## References

- Brack, W., Escher, B. I., Müller, E., Schmitt-Jansen, M., Schulze, T., Slobodnik, J., & Hollert, H. (2019). Effect-based methods are key to tackle the challenges of chemical pollution in the aquatic environment. *Environmental Sciences Europe*, 31(1), 1–11.
- Escher, B. I., Ait-Aïssa, S., Behnisch, P. A., Brack, W., Brion, F., Brouwer, A., ... Scholze, M. (2018). Effect-based trigger values for in vitro and in vivo bioassays. *Environmental Science & Technology*, 52(9), 4981–4991.
- Escher, B. I., Stapleton, H. M., & Schymanski, E. L. (2020). Tracking complex mixtures of chemicals in our changing environment. *Science*, 367(6476), 388–392.
- Hollender, J., van Bavel, B., Dulio, V., Farmen, E., Furtmann, K., Koschorreck, J., ... Brack, W. (2019). High-resolution mass spectrometry-based non-target screening can support regulatory environmental monitoring. *Environmental Sciences Europe*, 31(1), 1–18.
- Kummerer, K. (2010). Pharmaceuticals in the environment. *Annual Review of Environment and Resources*, 35, 57–75.
- Richardson, S. D., & Kimura, S. Y. (2020). Water analysis: Emerging contaminants and current issues. *Analytical Chemistry*, 92(1), 473–505.
- Schymanski, E. L., Singer, H. P., Longree, P., Loos, M., Ruff, M., Stravs, M. A., ... Hollender, J. (2014). Strategies to characterize polar organic contamination in wastewater. *Environmental Science & Technology*, 48(3), 1811–1818.
- Schwarzenbach, R. P., Escher, B. I., Fenner, K., Hofstetter, T. B., Johnson, C. A., von Gunten, U., & Wehrli, B. (2006). The challenge of micropollutants in aquatic systems. *Science*, 313(5790), 1072–1077.
- Van Wezel, A. P., Ter Laak, T. L., Fischer, A., Bäuerlein, P. S., Munthe, J., Posthuma, L., ... Slobodnik, J. (2017). Mitigation options for chemicals of emerging concern in surface waters. *Environmental Science & Technology*, 51(13), 7155–7165.
- Wilkinson, J. L., Boxall, A. B. A., Kolpin, D. W., Leung, K. M. Y., Lai, R. W. S., Galbán-Malagón, C., ... Sumpter, J. P. (2022). Pharmaceutical pollution of the world's rivers. *Proceedings of the National Academy of Sciences*, 119(8), e2113947119.

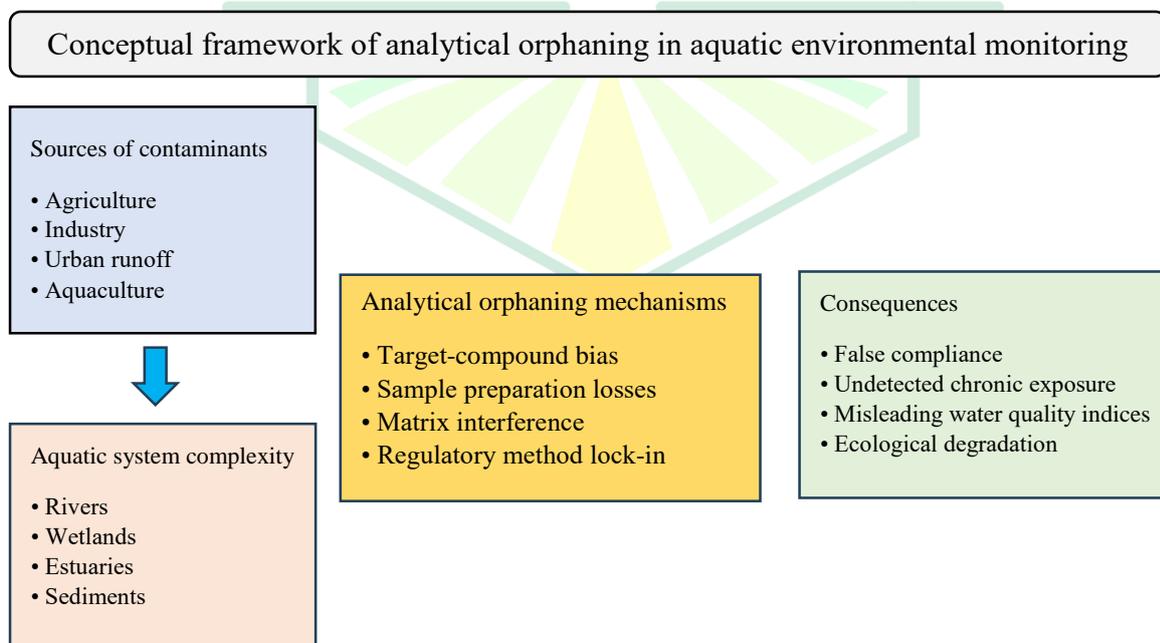


Fig 1: Conceptual framework illustrating the formation of analytical orphans in aquatic environmental monitoring due to source complexity, analytical limitations, and regulatory constraints, leading to underestimation of ecological stressors.

## Flower Thrips (*Frankliniella intonsa*): Major biotic threat in dragon fruit production and its integrated pest management (IPM)



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### Abstract

In dragon fruit (*Hylocereus* spp.), flower thrips (Thysanoptera) are a serious pest that damages blossoms and affects fruit quality, resulting in financial losses. To reduce their effects and guarantee sustainable production, effective management techniques are crucial. In order to control flower thrips in dragon fruit farming, this study investigates integrated pest management (IPM) strategies. Advanced methods like botanical pesticides and pheromone traps are also included. In order to minimize thrips in dragon fruit farming, this review article also highlights the damage symptoms and distribution of the thrips which causes economic loss in dragon fruit farming.

**Key words:** Thrips, dragon fruit, IPM, economic loss

### Introduction

Pitaya, often known as dragon fruit, is a newly popular tropical fruit that is cultivated in several nations. Asia's dragon fruit cultivation area has grown significantly during the past ten years. The flower thrips (*Frankliniella intonsa*), are the most common thrips species occurring on dragon fruit in China (Fig. 1). The unsightly damage has rendered 20% to 80% of the fruit unmarketable during years with high populations. For controlling the thrips the IPM strategy is the most eco-friendly method for farmer benefits as well as the agro-ecosystem.



Fig. 1. Female flower Thrips (*Frankliniella intonsa*) (Credit: Dr. Manfred Ulitzka)

### Damage symptoms

Small, sucking insects called thrips like to live in and harm flowers and developing tissues. They are thought to be one of the most significant insect pests of dragon fruit, and they regularly infest it. Their eating causes chlorosis and scarring on afflicted plant parts, and dozens to hundreds of thrips typically gather on delicate branches and fruit. Fruit quality is frequently significantly reduced as a result of heavy infestation (Fig. 2).



Fig. 2. Unmarketable dragon fruit due to scarring from thrips (Source: Mitra, 2024).

### Integrated pest management

Both nymphs and adults conceal themselves in comparatively small areas, such as buds, flowers, and axils, making it challenging to reach their habitat while applying insecticides. An effective thrips management program uses a mix of techniques, including cultural, mechanical, biological and chemical methods which is effective for dragon fruit farming.

- **Cultural method**

1. Cultural strategies include intercropping, trap cropping, soil improvement and weed control.
2. Phosphate fertilizer augmentation can enhance soil quality and help plants obtain adequate nutrients, which helps offset pest damage.
3. As a part of agronomical measures, the use of row covers or reflective mulch should be explored in thrips management.

- **Mechanical method**

1. According to color experiments using sticky card traps, *F. intonsa* is more responsive to blue and white traps.
2. Pheromone trapping is harmless for the environment, species-specific, and active at very low quantities (Sampson and Kirk, 2013).
3. Olfaction (odour) are important in the development of insect repellents for monitoring and/or controlling thrips.

- **Biological method**

1. The two most significant groups of predators that are efficient against sucking pests like thrips are predatory mites and *Orius* species.
2. The entomopathogenic fungi mainly *Beauveria bassiana*, *Metarhizium anisopliae* are used for controlling flower thrips (Wu *et al.*, 2018).

- **Chemical method**

1. The adult and larval thrips are best controlled by the application of spinetoram.
2. Application of spinosad because of its low toxicity which helps to reduce thrips.
3. Spirotetramat application reduces the thrips egg.

**Conclusion**

Since dragon fruit is a tropical fruit crop, one of the main issues with its production is pest control. Thrips and other pests are common in orchards and result in significant financial losses. In order to increase dragon fruit production and quality and support the sustainable growth of the dragon fruit industry, it will be necessary in the future to implement integrated control strategies, build a reliable detection and monitoring system, and deepen growers' scientific understanding of pests.

**References**

- Mitra, S. (Ed.). (2024). Dragon Fruit: Botany, Production and Uses. CABI.
- Sampson, C., & Kirk, W. D. (2013). Can mass trapping reduce thrips damage and is it economically viable? Management of the western flower thrips in strawberry. PLoS One, 8(11), e80787.
- Wu, S., Tang, L., Fang, F., Li, D., Yuan, X., Lei, Z., & Gao, Y. (2018). Screening, efficacy and mechanisms of microbial control agents against sucking pest insects as thrips. *Advances in Insect Physiology*, 55, 199-217.

## Stoichiometric Constraints (C: N:P Ratios) in Plankton Ecology



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### Abstract

Ecological stoichiometry provides a quantitative framework for understanding how the balance of carbon (C), nitrogen (N), and phosphorus (P) regulates plankton structure, productivity, and ecosystem functioning in aquatic environments. The classical Redfield ratio (C:N:P = 106:16:1) has long served as a benchmark for interpreting nutrient limitation and biogeochemical cycling; however, increasing empirical evidence demonstrates substantial variability in planktonic elemental composition across taxa, ecosystems, and environmental gradients. This article examines the stoichiometric constraints governing plankton ecology, with emphasis on the physiological, environmental, and ecological drivers of C:N:P variability. Factors such as nutrient availability, light, temperature, and species composition influence intracellular allocation of elements, thereby shaping growth rates, nutrient limitation patterns, and competitive interactions within plankton communities. Stoichiometric imbalances further affect trophic transfer efficiency by altering food quality for zooplankton and higher consumers, ultimately influencing energy flow and nutrient recycling in aquatic food webs. Additionally, variations in plankton stoichiometry play a critical role in biogeochemical processes, including carbon sequestration via the biological pump and nutrient regeneration in marine and freshwater systems. Understanding these stoichiometric dynamics is essential for predicting ecosystem responses to eutrophication, climate change, and anthropogenic nutrient enrichment, highlighting the central role of elemental balance in plankton ecology.

### Keywords

Ecological stoichiometry; C:N:P ratios; Redfield ratio; plankton ecology; nutrient limitation; phytoplankton; zooplankton; trophic interactions; biogeochemical cycles; aquatic ecosystems

### 1. Introduction

Ecological stoichiometry refers to the balance of multiple chemical elements in ecological interactions and processes, emphasizing how elemental composition affects growth and nutrient cycling in ecosystems. In aquatic environments, carbon (C), nitrogen (N), and phosphorus (P) are central to plankton physiology and ecosystem function. The classical concept of stoichiometry in plankton stems from the Redfield ratio, which describes average molar proportions of C: N:P  $\approx$  106:16:1 in marine phytoplankton and deep ocean waters, representing a foundational benchmark in bio-geochemistry. Understanding variations from this canonical ratio and how stoichiometric constraints influence plankton

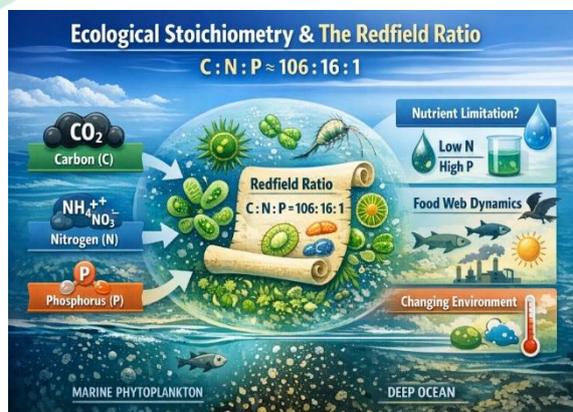


Fig 1: The Redfield ratio of carbon, nitrogen and phosphorus

growth, nutrient limitation, and food web dynamics is critical in plankton ecology, especially under changing environmental conditions.

## 2. Theoretical Basis of Plankton Stoichiometry

### 2.1 The Redfield Ratio and Its Foundations

Alfred C. Redfield first observed that the N:P ratio in marine plankton biomass closely matched that of deep ocean inorganic nutrients, suggesting biological regulation of elemental cycles. This ratio (16:1 for N:P) provided a baseline for interpreting nutrient limitation and cycling in the oceans. Redfield's insight laid the basis for ecological stoichiometry, suggesting that the elemental composition of plankton both reflects and regulates nutrient availability and cycling in aquatic ecosystems.

### 2.2 Variability and Plasticity in Elemental Ratios

Although useful, the Redfield ratio is not universal. Laboratory and field studies show that C: N:P ratios can deviate widely depending on species, environmental conditions, and nutrient supply. For example, optimal N:P stoichiometry in phytoplankton has been shown to range approximately from 8.2 to 45.0, depending on nutrient limitation and ecological context. These deviations arise from physiological adjustments within cells (e.g., allocation to protein vs ribosomal RNA) and community composition shifts. Phytoplankton can adjust their resource allocation strategies: in nutrient-limited conditions, cells may invest more in nutrient acquisition machinery, altering their internal stoichiometry.

### 2.3 Drivers of Stoichiometric Variability

Several environmental factors determine planktonic C: N:P ratios:

**Nutrient Availability:** Variations in N and P supply directly influence cellular composition. Higher nutrient availability generally increases P:C and N:C ratios, reflecting increased protein and RNA content in fast-growing cells.

**Light and Temperature:** Light affects photosynthesis and thus C fixation relative to nutrient incorporation. Temperature changes can also shift stoichiometric ratios by altering metabolic demands and nutrient uptake.

**Species Composition:** Different taxa possess inherent stoichiometric traits. For instance, eukaryotic phytoplankton often show greater sensitivity to nutrient shifts compared to prokaryotes, leading to broader variations in elemental ratios across communities.

## 3. Ecological Implications of Stoichiometric Constraints

### 3.1 Nutrient Limitation and Growth

Plankton growth is constrained by the availability of N and P relative to cellular demands. Stoichiometric imbalances between environmental nutrient supply and cellular nutritional requirements can limit growth rates, influence species competition, and determine community structure. Low N:P ratios in water may indicate N limitation, whereas high ratios can indicate P limitation. These nutrient limitations impact productivity: nutrient-poor environments often show elevated C:nutrient ratios, reflecting lower protein and nutrient content in biomass relative to carbon. This stoichiometric plasticity affects not only growth but also trophic interactions.

### 3.2 Trophic Transfer and Food Quality

Stoichiometric balance affects trophic transfer efficiency. Consumers such as zooplankton require specific C: N:P proportions for growth and reproduction; prey with high C: N or C:P ratios provide lower nutritional quality, reducing assimilation efficiency. Plankton stoichiometry can thereby regulate energy transfer efficiency across trophic levels. A mismatch between prey stoichiometry and consumer requirements can lead to slower growth, altered feeding behaviour, and changes in nutrient recycling, ultimately shaping food web dynamics.

### 3.3 Biogeochemical Cycling and Carbon Export

Plankton elemental composition influences nutrient cycling and carbon sequestration. Variations in stoichiometry affect the stoichiometry of exported organic matter, with implications for the biological carbon pump — the process by which organic carbon is transported to ocean depths. Elevated C:N or C:P ratios can influence the efficiency of carbon export and nutrient remineralization pathways. Long-term datasets indicate that planktonic C:N and C:P ratios vary temporally and spatially across ocean basins, reflecting both ecological and environmental drivers. These changes have consequences for global nutrient cycles and ecosystem responses to climate change.

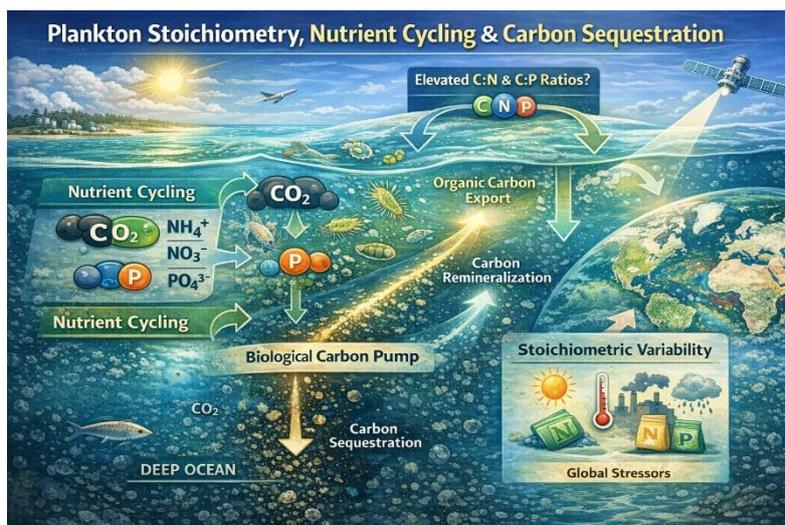


Fig 2: Plankton stoichiometry, Nutrient cycling and Carbon sequestration

## 4. Case Studies and Patterns

### 4.1 Marine Ecosystems

Studies from global ocean time-series stations show systematic deviations from the Redfield ratio, with regionally varying stoichiometric patterns. Planktonic C:N and N:P ratios have changed over decades, likely driven by shifts in nutrient availability and anthropogenic inputs, suggesting that oligotrophic gyres and coastal regions respond differently in stoichiometric dynamics.

### 4.2 Freshwater and Coastal Systems

In estuarine and freshwater ecosystems, stoichiometric ratios are often more variable due to fluctuating nutrient inputs, terrestrial organic matter influence, and shorter residence times. C:N:P ratios in seston and plankton may respond strongly to episodic nutrient loading or freshwater inflows, impacting trophic interactions and nutrient cycling.

## 5. Conclusion

Stoichiometric constraints in plankton ecology provide a mechanistic link between elemental composition, nutrient dynamics, and ecosystem processes. While the Redfield ratio serves as a useful baseline, deviations driven by environmental conditions and physiological adaptation illustrate the dynamic nature of C:N:P stoichiometry in aquatic ecosystems. These elemental ratios influence nutrient limitation, trophic transfer, and biogeochemical cycling — making stoichiometry a central concept for understanding both local ecosystem functioning and global nutrient cycles. Advances in observational and modelling approaches continue to refine our understanding of how stoichiometric constraints respond to changing climate and nutrient regimes, with implications for predicting ecosystem productivity and nutrient cycling in the Anthropocene.

## References

1. Redfield, A. C. (1958). The biological control of chemical factors in the environment – foundational stoichiometry concept. [Springer Link](#)
2. Klausmeier, C. A., Litchman, E., Daufresne, T., & Levin, S. (2004). Optimal N:P stoichiometry of phytoplankton: ecological modeling showing variable optimal ratios under different conditions. [PubMed](#)
3. Tanioka, T. & Matsumoto, K. (2020). Meta-analysis on environmental drivers of marine phytoplankton C:N:P. [bg.copernicus.org](#)
4. Global shifts in planktonic C:N:P over decades demonstrate ecological changes in nutrient cycling. [Nature](#)
5. Variability in elemental composition across plankton populations and implications for biogeochemical cycles. [Nature](#)
6. Stoichiometric effects on trophic transfer and consumer growth efficiency.

## “Moths: The Silent Heroes of Night Biodiversity”



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### Abstract

Moths (Lepidoptera: Heterocera) are essential but overlooked architects of nocturnal biodiversity, performing vital roles as pollinators, herbivores, and primary prey. Their sensitivity to habitat loss, climate shifts, and light pollution makes them indispensable bioindicators of environmental health. By anchoring complex food webs and driving nutrient cycling, moths maintain the ecological integrity of diverse terrestrial landscapes. Despite their significance, they remain undervalued compared to diurnal species, facing steep population declines worldwide. This study emphasizes the urgent need for targeted conservation strategies to safeguard these silent ecosystem engineers. Protecting moth diversity is fundamental to ensuring the long-term resilience of global nocturnal ecosystems.

### 1. Introduction

Moths (Lepidoptera: Heterocera) are essential architects of nocturnal biodiversity, serving as vital pollinators for night-blooming plants and a primary food source for predators like bats and birds. Their unique mobility facilitates critical long-distance pollen dispersal, maintaining the genetic resilience of global plant populations (Macgregor *et al.*, 2015). Beyond pollination, they drive nutrient cycling and act as sensitive bioindicators of environmental health. However, anthropogenic threats like habitat loss and light pollution are causing rapid population declines (Lewis *et al.*, 2018). These losses risk destabilizing nocturnal food webs and compromising essential ecosystem services. Often overlooked as "silent heroes," moths require urgent conservation to prevent cascading ecological failures. Safeguarding these insects is paramount to maintaining the integrity of life under the cover of darkness.

### 2. Moth Diversity and Distribution

Moths are among the most diverse nocturnal insects, with over 160,000 described species worldwide. They inhabit nearly all terrestrial ecosystems, ranging from tropical and subtropical forests to alpine, temperate, and arid regions. Tropical and subtropical areas harbor the highest moth diversity, supported by stable climates and a rich diversity of host plants, whereas temperate regions exhibit seasonally fluctuating communities (Kawahara *et al.*, 2023). As primarily nocturnal insects, moths contribute significantly to night-time pollination, serve as prey for a wide array of predators, and play crucial roles in energy flow and nutrient cycling within ecosystems.

Their distribution is shaped by vegetation, climate, altitude, and human impacts such as habitat fragmentation and artificial night lighting (ALAN). Recent studies indicate that land-use changes and light pollution are altering moth communities, resulting in declines of sensitive species and homogenization of nocturnal assemblages (Owens *et al.*, 2020). These shifts highlight the ecological significance of moths and underscore the need for conservation strategies at the landscape level.

### 3. Ecological Importance of Moths

Moths are essential components of terrestrial ecosystems, contributing as pollinators, herbivores, and prey. Many nocturnal plants depend on moths for pollination, enhancing reproductive success and maintaining plant diversity, particularly in tropical, subtropical, and Himalayan forests (MacGregor *et al.*, 2015). Moth larvae regulate plant communities through herbivory, while both larvae and adults serve as critical food sources for birds, bats, and other predators, linking multiple trophic levels (Merckx *et al.*, 2013). Additionally, moths are sensitive bioindicators of environmental change, reflecting habitat quality and anthropogenic impacts, and thus play a key role in biodiversity monitoring and ecosystem conservation.

#### 4. Moths as Nocturnal Pollinators

Moths are key nocturnal pollinators that play a critical role in the reproductive success of many night-blooming plants by transferring pollen when diurnal pollinators are inactive. In agricultural and natural landscapes, moths have been shown to transport pollen from a broad range of plant species, often including those less frequently visited by bees and butterflies, with pollen commonly adhering to the moths' bodies and facilitating effective cross-pollination. This nocturnal pollination service complements daytime pollinators, maintaining plant diversity and ecosystem resilience. In agricultural ecosystems, macro-moths contribute substantial pollen transport that underpins complex plant-pollinator networks, highlighting their overlooked but essential ecological function (Walton *et al.*, 2020).



Figure 1. Moths as Nocturnal Pollinators

#### 5. Moths as Bioindicators

Moths (Order: Lepidoptera) are highly sensitive to environmental changes, making them excellent bioindicators of ecosystem health. Their diversity, abundance, and community composition reflect habitat quality, pollution levels, and the effects of climate change. Light-trap sampling allows efficient monitoring of moth populations, which respond rapidly to changes in vegetation and habitat structure (Summerville, Ritter & Crist, 2004).

In the Himalayan region, moth assemblages have been used to assess forest degradation, pesticide impacts, and climate-induced shifts in species composition. Changes in nocturnal moth communities often precede visible ecosystem decline, providing an early-warning system for conservation planning. Their dependence on host plants and microhabitats makes them ideal for detecting ecological stressors and long-term environmental changes (New, 2014; Kishore, Sharma & Singh, 2022).

#### 6. Major Threats to Moth Diversity

Moth diversity is declining due to habitat loss and fragmentation from deforestation, urbanization, and agriculture, which reduces food plants and shelter (Lepidoptera conservation studies, 2024). Light pollution disrupts nocturnal activity, mating, and feeding, while pesticides and chemical pollutants harm both larvae and adults (ecological news, 2025).

Climate change causes mismatches between moths and host plants and increases exposure to extreme weather (Climate Impact Studies, 2023). Invasive species and predators further threaten native populations, collectively reducing moth diversity and affecting their ecological roles as pollinators and food-web contributors (Global Insect Biodiversity Research, 2024).

#### 7. Conservation Significance of Moths

Moths are important pollinators, prey, and bioindicators, playing a key role in maintaining ecosystem functions and biodiversity. They support nocturnal pollination, including wild plants and crops, and act as food for birds, bats, and other wildlife (Ellis *et al.*, 2023; Mathews *et al.*, 2023). Their sensitivity to environmental changes makes them useful for monitoring habitat quality and climate impacts. Conserving moths helps protect nocturnal pollination networks and overall ecological stability (Pradhan *et al.*, 2024).

## 8. Future Perspectives

The future of moth conservation lies in integrating research, monitoring, and habitat management to mitigate the threats of habitat loss, light pollution, pesticides, and climate change. Advanced techniques such as DNA barcoding, remote sensing, and citizen science programs can improve species identification, track population trends, and detect early warning signals of ecosystem decline (Hausmann *et al.*, 2023). In the Himalayan region and other biodiversity hotspots, restoration of native habitats, creation of ecological corridors, and reduction of artificial night lighting are essential to support moth populations and their ecological functions. Conservation strategies should also incorporate community engagement, sustainable agriculture, and ecotourism, linking moth conservation to local livelihoods while promoting awareness (Kishore *et al.*, 2024).



**Figure 2. Major Threats to Moth Diversity**

## 9. Conclusion

Moths are vital yet often overlooked components of terrestrial ecosystems, serving as nocturnal pollinators, herbivores, prey, and bioindicators. Their sensitivity to habitat loss, climate change, light pollution, and other anthropogenic pressures highlights both their ecological importance and their vulnerability. Conserving moth diversity through habitat protection, monitoring, and community-based strategies is crucial for sustaining biodiversity, ecosystem functions, and nocturnal pollination networks, particularly in biodiversity hotspots like the Himalayas. Protecting these “silent heroes of the night” ensures resilient ecosystems and long-term environmental health.

## References

- Bertin, R. I. & Willson, M. F. (1980). Effectiveness of diurnal and nocturnal pollination of two milkweeds. *Canadian Journal of Botany*, 58, 1744-1746.
- Devoto, M., Bailey, S. & Memmott, J. (2011). The ‘night shift’: nocturnal pollen-transport networks in a boreal pine forest. *Ecological Entomology*, 36, 25-35.
- Kishore, A., Sharma, R. & Singh, N. (2022). Settling moths are the vital component of pollination in the Himalayan ecosystem of North-East India, as the pollen transfer network approach revealed. *Scientific Reports*, 12, 2716.
- Kawahara, A. Y., et al. (2023). A global phylogeny of butterflies reveals their evolutionary history and biogeographic origins. *Nature Ecology & Evolution*, 7, 903-913.
- Owens, A. C. S. & Lewis, S. M. (2018). *The impact of artificial light at night on nocturnal insects: a review and synthesis*. *Ecology and Evolution*, 8(22), 11337-11358.
- MacGregor, C. J., Pocock, M. J. O., Fox, R. & Evans, D. M. (2015). Pollination by nocturnal Lepidoptera, and the effects of light pollution: a review. *Ecological Entomology*, 40(3), 187-198.
- Merckx, T., Riutta, T., Bebber, D. P., Redhead, D., Riordan, P., & Macdonald, D. W. (2013). *Life-history traits and landscape characteristics predict macro-moth responses to forest fragmentation*. *Ecology*, 94(7), 1519-1530

- Pradhan, I., Sethi, J., Rout, S., & Kumar, S. (2024). *Common moths and their ecological importance in Bisra Range, Rourkela Forest Division, Odisha, India*. Asian Journal of Biology, 20(1), 1-6.
- Ramirez, N. (2004). Pollination specialization and time of pollination on a tropical Venezuelan plain: Variations in time and space. *Botanical Journal of the Linnean Society*, 145, 1-16.
- Ribas-Marquès, E., Díaz-Calafat, J. & Boi, M. (2022). *The role of adult noctuid moths (Lepidoptera: Noctuidae) and their food plants in a nocturnal pollen-transport network on a Mediterranean island*. Journal of Insect Conservation, 26, 243-255.
- Singh, N., Lenka, R., Chatterjee, P., et al. (2022). Settling moths are the vital component of pollination in the Himalayan ecosystem of North-East India, pollen transfer network approach. *Scientific Reports*, 12, 2716.
- Summerville, K. S., Ritter, L. M., & Crist, T. O. (2004). *Forest moth taxa as indicators of lepidopteran richness and habitat disturbance: a preliminary assessment*. Biological Conservation, 116(1), 9-18.
- Walton, R. E., Sayer, C. D., Bennion, H. & Axmacher, J. C. (2020). Nocturnal pollinators strongly contribute to the pollen transport of wild flowers in an agricultural landscape. *Biology Letters*, 16: 20190877.
- Young, H. J. (2002). Diurnal and nocturnal pollination of *Silene alba* (Caryophyllaceae). *American Journal of Botany*, 89, 433-440.



## Flourish Through Change: Regenerative Gardening for a Warming World



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### Introduction

In the current age of rapidly changing climate patterns, gardeners are presented with a host of fresh challenges and opportunities. The art of climate-resilient gardening has taken on heightened significance as it strives to guarantee that our green spaces not only endure but flourish amid these shifts. Climate-resilient gardening has emerged as an essential practice for homeowners aiming to maintain vibrant and productive gardens amidst changing environmental conditions. At the core of climate-resilient gardening lies regenerative gardening, which prioritizes the restoration and enhancement of soil health, the promotion of biodiversity, and the carbon sequestration. By adopting sustainable practices and carefully selecting plants, we have the potential to craft gardens that are not only visually captivating but also incredibly sturdy. Whether one is an experienced or novice gardener, the incorporation of climate-resilient techniques will prove invaluable in establishing gardens that stand the test of time.

### Soil preparation

It is essential to conduct a soil test to determine its pH and nutrient levels, allowing for a better understanding of the necessary amendments to create a healthy growing environment. The incorporation of organic matter such as compost, well-rotted manure, or leaf mold into the soil can effectively improve soil structure, enhance water retention, and provide essential nutrients. Additionally, minimizing soil disturbance through the adoption of no-till or low-dig gardening practices can help maintain soil structure, reduce erosion, and preserve beneficial soil organisms. Mulching should be done with help of straw, grass clippings, or wood chips, to the soil surface. It helps retain moisture, suppress weeds, and regulate soil temperature. These protect the soil from erosion, improve soil fertility, and enhance soil structure.

In order to prevent erosion, maintain a moderate soil temperature, and slow down the evaporation of water, cover the soil with plants or organic mulch throughout the year. If your soil is prone to waterlogging, make sure appropriate drainage is achieved by adding sand or gravel. This helps avoid water-related problems such as root rot. To increase soil biodiversity, plant a wide variety of plants. Various plants improve the general health of the soil by contributing different organic components and root structures.

### Choosing the right plants

When selecting vegetation for resilient gardening in varying and extreme conditions, it is crucial to prioritize species that can thrive under such circumstances. Native plants are an optimal choice due to their natural adaptation to local climate and soil, rendering them more resistant to weather fluctuations. Additionally, the inclusion of drought-tolerant plants such as succulents, lavender, and Mediterranean herbs can fortify the garden against periods of low water availability. In regions susceptible to high temperatures, heat-tolerant species like agave, yucca, and select ornamental grasses are recommended. Conversely, in areas characterized by cold winters, consideration should be given to cold-hardy perennials such as hostas, daylilies, and coneflowers.

Diversity is important in gardening. Planting a variety of species creates a more resilient ecosystem that can resist pests, diseases, and extreme weather. Perennials and plants with deep root systems are beneficial as they can access water and nutrients from deeper soil layers, enhancing their resilience. Including pollinator-friendly plants supports local biodiversity and aids in the pollination of other garden plants. Adaptable plants like sedums and echinaceas, which thrive in various environments, are valuable additions to a climate-resilient garden.

**Drought and Heat Tolerant plants**



**Agave**



**Echeveria**



**Sedum**



**Gaillardia**



**Bougainvillea**



**Lavender**



**Plumeria**



**Cactus**



**Snake plant**

**Cold Tolerant Plants**



**Peony**



**Calendula**



**Snap dragon**



**Geranium**



**Dav lilles**



**Hostas**

### **Irrigation management**

Effective irrigation management is crucial for climate-resilient gardening. Here are some strategies to help you manage water efficiently and sustainably

Drip irrigation is a method of delivering water directly to the plant roots, which minimizes evaporation and runoff. This approach is known for its water efficiency compared to traditional sprinklers, making it particularly suitable for regions facing water scarcity. Consider implementing rain barrels or cisterns to capture rainwater from your roof. This collected water can be utilized during periods of low precipitation. The utilization of harvested rainwater reduces dependence on municipal water supplies and contributes to a decrease in your water expenses.



Soil moisture sensors play a crucial role in accurately determining the optimal timing and quantity of water for plants, thereby preventing over- or under-watering. By providing real-time data, these sensors ensure that plants receive the precise amount of water at the appropriate time. Application of organic mulch around plants aims to reduce evaporation and maintain soil moisture status. Mulch helps keep the soil cool in summer and warm in winter, and protects the plant roots.

Smart irrigation systems use weather data and soil moisture levels to adjust watering schedules automatically. These systems can be controlled remotely via smartphone apps, allowing for precise irrigation management. Choose plants that are naturally drought-resistant and require less water. These plants are better suited to withstand periods of low rainfall and high temperatures. Create irrigation zones based on the water requirements of different plants. This ensures that each plant receives the appropriate amount of water. Zoning helps prevent water waste and promotes healthier plant growth

### **Microclimate in the garden**

Creating microclimates can significantly enhance its resilience to climate change. This include strategic Planting which include planting trees and shrubs to act as windbreaks. This reduces wind speed, protecting more delicate plants and reducing water loss through evaporation. Planting trees that provide shade can help cool the garden, reducing heat stress on plants during hot weather Incorporating water Features such as ponds and water gardens as these can create a cooling effect in your garden, moderating temperatures and increasing humidity in the immediate area.

Designing a rain garden to capture and slowly release rainwater, these gardens help manage water runoff and create a moist microclimate for water-loving plants. Using greenhouses and cold Frames can extend your growing season by protecting plants from extreme weather and creating a controlled environment. Use light-coloured or reflective materials to increase light and warmth in specific areas of your garden. Creating terraces on slopes to reduce erosion and manage water flow, creating different microclimates at various levels. Utilize south-facing slopes for plants that require more sunlight and warmth.

### **Implementing sustainable practices**

Turn kitchen scraps, garden clippings, and other organic waste into nutrient-rich compost, and using this compost improves soil structure, fertility, and moisture retention. Efficient water management using drip irrigation or soaker hoses to minimize water wastage. Avoid tilling operations frequently to maintain soil structure and health. Planting cover crops also helps in the prevention of soil erosion, improving soil fertility, and suppressing weeds.

Encouraging beneficial insects like ladybugs and predatory beetles which controls the pests. Avoid the use of chemical fertilizers or pesticides. Use natural pest control methods such as neem oil, insecticidal soaps, and diatomaceous earth. The wide variety of the of the plant species planted in the garden attract bees, butterflies, and other pollinators.

Using solar-powered garden lights and water features helps to minimize energy consumption. Opt for manual or battery-operated tools instead of gas-powered ones to reduce carbon emissions. Use recycled or repurposed materials for garden structures, containers, and pathways. Avoid single-use plastics and opt for biodegradable or reusable alternatives.

By incorporating these sustainable practices, you can create a garden that is not only beautiful but also environmentally friendly and resilient to climate change

### **Promoting biodiversity**

Enhancing biodiversity is crucial to making it more resilient to climate change. You may establish a stable ecosystem that is more resilient to pests, illnesses, and harsh weather by planting a wide variety of species, including native plants. Native plants are especially advantageous since they need less water and upkeep because they are tailored to the local temperature and soil conditions. A healthy garden ecology depends on pollinator-friendly plants like milkweed and lavender, which also attract butterflies and other helpful insects.

The need of chemical pesticides can be naturally decreased by companion planting, which is the practice of growing beneficial plants together. Furthermore, techniques that promote mycorrhizal fungus and cover crops enhance the health of the soil and the intake of nutrients. Further increasing the resilience of the garden are many habitats created using elements such as ponds, birdbaths, and layered plants that offer resources and cover to a range of creatures. Fostering biodiversity makes your garden a vibrant, climate-resilient refuge by supporting nearby ecosystems and wildlife in addition to making it more sustainable.



### **Conclusion**

The practice of climate-resilient gardening presents a proactive approach to fostering garden vitality in the face of climate change challenges. By integrating a diverse range of plant species, particularly those that are native and drought-resistant, a stable and adaptable ecosystem can be established. The implementation of efficient water management techniques, such as drip irrigation and rainwater harvesting, ensures optimal hydration for the garden even during dry periods. Furthermore, soil health can be enhanced through the adoption of composting, no-till gardening, and the utilization of cover crops, resulting in improved fertility and water retention. Additionally, the reinforcement of biodiversity by introducing pollinator-friendly species and creating habitats for beneficial insects and wildlife serves to fortify the garden's resilience. The adoption of sustainable practices, including the use of organic fertilizers and natural pest control methods, not only reduces environmental impact but also promotes long-term health. By integrating these strategies, a beautiful, sustainable, and resilient garden can be cultivated, one that not only withstands the impact of climate change but also provides support for local ecosystems and wildlife.

## Plant Hormones: The Chemical Messengers That Control Crop Yield



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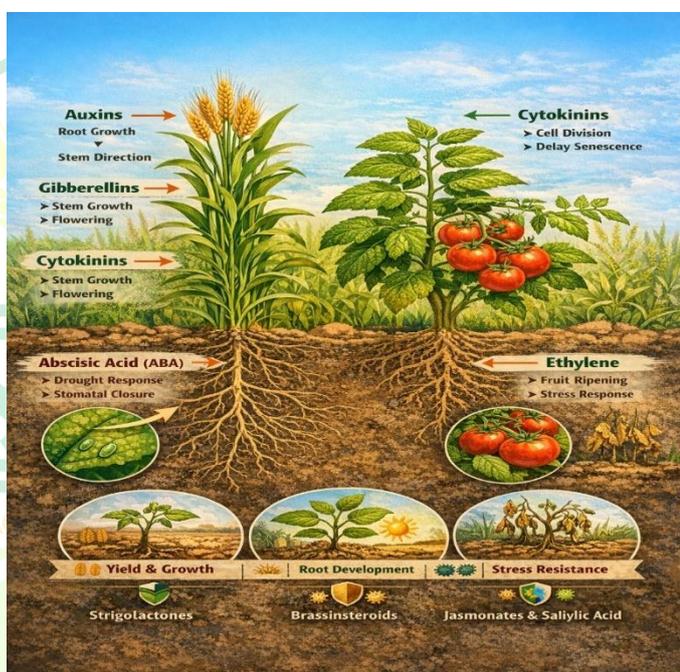
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### Introduction

Plant hormones, also known as phytohormones are organic compounds produced within plants that, even in tiny amounts, coordinating growth, regulate almost every aspect of plant life, responding to stress, and ultimately determining how big the harvest will be. These molecules are the chemical messengers that control crop yield. Plant hormones move from cell to cell or through fluids to influence growth, development, and responses to the environment. There are five classical plant hormones viz., Auxins, Gibberellins, Cytokinins, Abscisic Acid and Ethylene, plus emerging hormones viz., Brassinosteroids, Jasmonates, Salicylic Acid, and Strigolactones are gaining attention. Each hormone has unique roles, but they also interact in complex networks.



### Why Hormones Matter for Crop Yield

Yield is not just about how many seeds a crop makes, but it is about how a plant allocates its resources, from roots to stems to grains under changing conditions. Hormones influence this allocation in fundamental ways such as

- Timing of flowering
- Size and number of fruits or grains
- Branching and tillering
- Root development and nutrient uptake
- Stress resilience (heat, drought, salinity)
- Senescence (aging)

In essence, hormones determine a plant's strategy: how it grows under favourable conditions and how it compromises under stress. For crop breeders and agronomists, understanding these signals is key to unlocking higher yields without unsustainable resource inputs.

### Auxins:

Auxins were the first plant hormones ever discovered, and they are central to growth orientation, especially cell elongation and organ formation. Key functions of auxins include

- Directing root and shoot growth

- Influencing apical dominance
- Initiating root formation, especially adventitious roots
- Guiding phototropism (growth toward light) and gravitropism (growth responding to gravity)

In agriculture, synthetic auxins are used as rooting hormones to improve crop establishment and also as herbicides (2,4-D, dicamba, and mecoprop). Manipulating auxin pathways has been key in developing crops with ideal plant architecture that supports higher yields.

#### **Gibberellins:**

Gibberellins are best known for stimulating stem elongation, seed germination, and flower development. The key roles of Gibberellins are

- Breaking seed dormancy
- Triggering germination
- Promoting stem growth
- Influencing flowering time in certain species

In cereal crops, gibberellins influence plant height. In fact, one of the landmark achievements of the Green Revolution was the development of semi-dwarf wheat and rice varieties that have mutations in Gibberellin response pathways, plants that stay shorter and sturdier yet allocate more energy to grain. Taller plants are prone to lodging, which reduces yield and makes harvesting difficult. Semi-dwarf varieties resist lodging, supporting higher fertilizer use and bigger grain yields.

#### **Cytokinins:**

Cytokinins are named for their ability to promote cell division (cytokinesis). They work in tandem with auxins to regulate organ development. Major effects of cytokinins are

- Stimulating shoot formation
- Regulating leaf expansion
- Delaying leaf senescence (aging)

By delaying senescence, cytokinins help leaves stay green longer, which can sustain photosynthesis and energy production during critical yield formation stages. Enhancing cytokinin activity in crops can improve stay-green traits, leading to longer grain filling periods and potentially higher yield. However, balance is crucial, as too much cytokinin can disrupt root growth.

#### **Abscisic Acid (ABA):**

Contrary to its name (which historically implied a role in abscission), abscisic acid is best known as a stress hormone. Primary functions of ABA are

- Regulating stomatal closure during drought
- Mediating seed dormancy
- Controlling responses to salt and cold stress

When plants face water scarcity, ABA levels spike, causing stomata to close, reducing water loss but also reducing the rate of photosynthesis. This trade-off is a survival strategy, not a growth strategy. Modulating ABA responses can help develop varieties that better manage water use under drought. However, because ABA induces stress responses that reduce growth, achieving the right balance between stress resistance and yield is challenging.

#### **Ethylene:**

Ethylene is a gaseous hormone with diverse functions such as

- Fruit ripening
- Leaf and flower senescence
- Response to mechanical stress
- Regulating root and shoot growth

Ethylene plays a critical role during fruit ripening and abscission (leaf or fruit drop). For crops like apples, bananas, and tomatoes, managing ethylene can influence shelf life and marketability. However, ethylene is also produced in response to stress (e.g., flooding, salinity), sometimes accelerating undesirable senescence that can

reduce yield. Ethylene inhibitors (like 1-MCP) are used post-harvest to delay ripening and extend shelf life. In the field, understanding ethylene dynamics helps manage stress responses.

### **Brassinosteroids, Jasmonates, Salicylic Acid, and Strigolactones**

- **Brassinosteroids:** Promote cell expansion and stress tolerance; influence yield components.
- **Jasmonates:** Mediate defenses against insects and pathogens, and regulate fertility.
- **Salicylic Acid:** Central to disease resistance, plays a role in systemic acquired resistance.
- **Strigolactones:** Regulate shoot branching and root architecture; also signal symbiotic fungi.

These emerging hormones form cross-talk networks with classical hormones, adding layers of complexity that scientists are just beginning to understand.

### **Hormonal Cross-Talk:**

Plant hormones rarely act in isolation. Instead, they engage in cross-talk, complex interactions where the presence or level of one hormone affects the functioning of the another hormone.

- Auxin and cytokinin interplay determines whether a plant focuses on roots or shoots.
- ABA and ethylene together influence how plants balance stress tolerance with growth.
- Gibberellins and DELLA proteins (growth repressors) interact to fine-tune growth in response to environmental signals.

This hormonal integration allows plants to adapt dynamically.

### **Harnessing the Plant Hormones**

Understanding plant hormones has enabled both subtle and dramatic innovations in agriculture.

#### **1. Chemical Regulators in the Field**

Synthetic hormones are widely used as the growth regulators (compounds that mimic or inhibit hormones) in the field:

- Auxin analogues as rooting agents or selective herbicides
- Gibberellin treatments to improve seed germination or enhance fruit size in grapes and other crops
- Ethylene-inhibitors to delay ripening and reduce pre-harvest fruit drop
- Cytokinin sprays to delay leaf aging and sustain photosynthesis

#### **2. Breeding Hormone-Responsive Varieties**

Modern plant breeding often targets hormone pathways:

- Semi-dwarf wheat and rice (reduced GA response) enabled the Green Revolution
- Stay-green sorghum lines that modify cytokinin and ABA dynamics
- Root architecture traits shaped by auxin and strigolactone pathways for improved nutrient and water uptake

With advanced genomics and gene editing tools (e.g., CRISPR), scientists can create precise changes in hormone regulation without introducing foreign DNA.

#### **3. Precision Agriculture**

Sensors and imaging technologies (like chlorophyll fluorescence, thermal imaging) can detect hormonal signals indirectly, such as stress-induced stomatal closure and help farmers adjust irrigation, nutrient applications, and stress mitigation strategies.

### **Hormones and Stress:**

Climate change intensifies heat waves, drought spells, and erratic rainfall. Hormones are central to how crops perceive and respond to these stresses.

- Modulating ABA pathways can improve drought responsiveness without overly compromising growth.
- Balancing ethylene responses may mitigate heat and flooding damage.
- Enhancing brassinosteroid activity could support both growth and stress tolerance.

The challenge lies in optimizing hormone networks so crops yield well under both favorable and adverse conditions.

### Hormonal Mastery for Sustainable Agriculture

Plant hormones are not magic bullets, but they are essential levers for improving crop performance. The coming decade promises:

- Smart breeding that rewires hormonal responses for diverse environments
- Biological regulators sourced from microbes or natural compounds
- AI-guided hormone modeling for precision crop management
- Education and extension to translate hormone science into farmer-friendly practices

As the world aims to feed nearly 10 billion people by 2050 with minimal environmental cost, understanding how tiny chemical messengers shape vast fields of crops becomes not only scientifically fascinating but socially vital.

#### Conclusion:

Plant hormones are the invisible architects of plant life, governing the crop growth, adaptation, and produce the food we rely on. From root tips reaching for nutrients to grains filling with starch, hormones coordinate every step with astonishing precision. It steers breeders toward better varieties, guides farmers toward smarter practices, and opens pathways to crops that thrive in a changing climate scenario. Hormones play a vital role to attain crop resilience, sustainability, and a future where food security and environmental harmony can coexist.

#### References:

1. Fahad, S., Nie, L., Chen, Y., Wu, C., Xiong, D., Saud, S., Hongyan, L., Cui, K. and Huang, J., 2014. Crop plant hormones and environmental stress. Sustainable Agriculture Reviews: Volume 15, pp.371-400.
2. Davies, P.J. ed., 2012. Plant hormones and their role in plant growth and development. Springer Science & Business Media.
3. Khan, M.I.R., Singh, A. and Poor, P. eds., 2023. Plant hormones in crop improvement. Elsevier.
4. Jiang, K. and Asami, T., 2018. Chemical regulators of plant hormones and their applications in basic research and agriculture. Bioscience, biotechnology, and biochemistry, 82(8), pp.1265-1300.

## “Golden Spice, Great Health: The Magic of Turmeric”



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### Abstract

Turmeric (*Curcuma longa*), widely known as the “Golden Spice of India,” has been valued for thousands of years for its medicinal, cultural, and culinary significance. Originating in South and Southeast Asia, turmeric has played an important role in traditional systems of medicine such as Ayurveda and Siddha, as well as in Indian rituals and daily life. The golden-yellow colour and therapeutic properties of turmeric are mainly due to curcumin, a bioactive compound known for its strong antioxidant, anti-inflammatory, antimicrobial, and disease-preventive effects. Regular consumption of turmeric supports immunity, digestion, skin health, and overall well-being. Modern scientific research has further highlighted the potential of curcumin in managing chronic diseases such as cancer, diabetes, arthritis, and cardiovascular disorders. In addition, growing demand for organic turmeric and value-added products has created new opportunities for farmers and entrepreneurs. This article highlights the history, health benefits, modern applications, market potential, and smart consumption practices of turmeric, emphasizing its importance as a traditional spice with modern relevance.

**Keywords:** Curcumin, Medicinal Properties, Health Benefits, Organic Turmeric, Value Addition

### History and Cultural Importance

Turmeric (*Curcuma longa*), lovingly known as the “Golden Spice of India,” carries a story that began over 4,000 years ago in the lush tropical landscapes of South and Southeast Asia. Ancient Ayurvedic and Siddha healers trusted this humble yellow rhizome for almost everything from soothing wounds and stomach troubles to cleansing the body and mind. As people and cultures connected through early trade routes, turmeric travelled far beyond India, reaching China, Africa, and eventually Europe, where explorers like Marco Polo were amazed by its saffron-like glow and value. In India, turmeric became more than just a spice; it became a symbol of purity, health, and celebration, finding a place in kitchens, medicines, rituals, and wedding traditions. Even today, this golden spice continues to shine brightly, cherished worldwide for its blend of ancient wisdom and modern scientific benefits.

### What Makes Turmeric “Golden”?

Curcumin is the natural compound that gives turmeric (*Curcuma longa*) its bright golden-yellow colour and much of its healing power. Often called the “heart of turmeric,” this plant-based polyphenol is well known for its ability to fight inflammation and neutralize harmful free radicals in the body. Beyond this, curcumin shows impressive antimicrobial, anticancer, and liver-protective properties, which is why it has been treasured in Ayurveda for centuries and continues to attract attention in modern medical research. Along with its health benefits, curcumin is also valued as a safe, natural food colour and preservative, adding both colour and wellness to our everyday diet.

### Health Benefits in Daily Life

Turmeric is valued mainly for its active compound **curcumin**, which has strong antioxidant and anti-inflammatory properties. Regular use of turmeric in daily food helps the body **fight free radicals, reduce oxidative stress, and slow down premature ageing**. It also strengthens the immune system, helping the body resist common infections like colds, coughs, and seasonal illnesses. This is why turmeric milk, popularly known as *golden milk*, is widely consumed in Indian households as a natural remedy to improve immunity.

In addition to boosting immunity, it supports healthy digestion by stimulating bile production, improving liver function, and reducing bloating and indigestion. Its antimicrobial and antiseptic properties help protect the gut, promote wound healing, and improve skin health by reducing acne and inflammation.

#### **Turmeric in Modern Medicine and Research**

In recent years, scientists around the world have shown great interest in **curcumin**, the active compound in turmeric, because of its potential role in preventing and managing serious diseases. Laboratory and clinical studies suggest that curcumin can slow the growth of cancer cells by blocking inflammation and neutralizing harmful free radicals. Researchers are also studying how curcumin may support cancer treatment by reducing side effects of chemotherapy and protecting healthy cells, making it a promising natural compound in modern medical research.

Curcumin is also being widely studied for lifestyle and chronic diseases such as diabetes, arthritis, and heart disorders. Research indicates that curcumin can help control blood sugar levels, improve insulin sensitivity, and reduce joint pain and stiffness by lowering inflammation. Scientists are working on new ways to improve curcumin absorption in the body, such as combining it with black pepper or developing advanced formulations. These studies highlight how a traditional kitchen spice is gaining recognition in modern science for its potential health benefits.

#### **Everyday Uses in Kitchen**

In everyday kitchen practices, turmeric is one of the **most used spices**, adding **both colour and health benefits to our meals**. A pinch of turmeric is added to milk to prepare **golden milk**; a comforting drink often consumed at night for better immunity and recovery. It is a key ingredient in curries and vegetable dishes, giving them their rich yellow colour and distinctive flavour. Turmeric is also used in herbal teas for digestion and relaxation, and in pickles to enhance taste while acting as a natural preservative. Through these simple daily uses, turmeric becomes an easy and natural way to support good health.

#### **Turmeric in Beauty and Skin Care**

Turmeric has been used for generations as a natural beauty and skin-care ingredient, valued for its healing and protective properties. Traditional face packs made with turmeric help **reduce acne, control excess oil, and give the skin a natural glow**. Its antiseptic nature makes turmeric effective in healing small cuts, wounds, and burns by preventing infection and speeding up recovery. Rich in antioxidants, turmeric also helps slow down signs of ageing such as fine lines and dullness by protecting the skin from damage. Whether used in home remedies or modern beauty products, turmeric continues to be a trusted, natural solution for healthy and radiant skin.

#### **Organic Turmeric and Market Demand**

Organic turmeric has gained strong demand in both Indian and global markets due to growing awareness about health, food safety, and chemical-free products. India is the world's largest producer, consumer, and exporter of turmeric, supplying **major markets such as the USA, Europe, the Middle East, and Southeast Asia**. Indian turmeric is especially valued for its high curcumin content, rich colour, and traditional cultivation practices. In recent years, the demand for organically grown turmeric has increased, leading to better price realization for farmers. Although turmeric prices fluctuate depending on production, quality, and export demand, organic turmeric generally fetches a premium price, encouraging farmers to adopt sustainable and eco-friendly cultivation methods.

#### **Value Addition and Entrepreneurship**

Value addition in turmeric has opened new opportunities for entrepreneurship, especially for farmers and young startups. Turmeric is processed into products such as **turmeric powder, capsules, essential oils, herbal teas, cosmetics, and health supplements**, which have higher market value than raw turmeric. With the growing demand for natural and herbal products, many small-scale enterprises and startups are entering this sector by promoting organic and traditionally processed turmeric products. These value-added products not only increase income but also create employment opportunities, making turmeric a promising crop for agribusiness and rural entrepreneurship.

## Value addition of turmeric



Powder



Essential oil



Cosmetics



Capsules



Herbal tea



Golden milk

### Tips for Smart Consumption

For best health benefits, turmeric should be consumed in the right amount and in the right way. A small quantity used daily in cooking or a pinch mixed in warm milk is generally sufficient for regular use. Curcumin is better absorbed by the body when turmeric is taken along with **black pepper**, which contains piperine, a natural compound that enhances absorption. Consuming **turmeric with healthy fats such as milk, ghee, or oil also improves its effectiveness**. Whether used as fresh turmeric, dried powder, or in traditional home remedies, moderate and regular intake is the key to gaining benefits without overuse.

### Reference

- 1) Jaiswal, S. G., & Naik, S. N. (2021). **Turmeric oil: composition, extraction, potential health benefits and other useful applications.**
- 2) Sowbhagya, H. B. (2019). **Value-added processing of by-products from spice industry.** *Food Quality and Safety*, 3(2), 73-80.
- 3) Verma, R. K., Kumari, P., Maurya, R. K., Kumar, V., Verma, R. B., & Singh, R. K. (2018). **Medicinal properties of turmeric (*Curcuma longa L.*): A review.** *Int. J. Chem. Stud.*, 6(4), 1354-1357.

## Cassava Starch-Based Biodegradable Hydrogel for Water-Smart Farming and Low-Carbon Irrigation



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### Abstract

Hydrogels have emerged as innovative tools for water-smart agriculture, enabling moisture retention, nutrient-use efficiency, and improved plant resilience under climate stress. Cassava starch, an abundant and renewable biomass resource, offers an eco-friendly feedstock for hydrogel production owing to its high amylose content, biodegradability, and non-toxic nature. Cassava starch-based hydrogel acts as a miniature water reservoir in soil—absorbing and storing irrigation or rainwater and releasing it gradually to plant roots. This reduces water loss, minimizes irrigation frequency, and enhances crop yield under water-scarce conditions. Moreover, it promotes low-carbon farming by lowering groundwater extraction, pumping energy, and fertilizer runoff. This article highlights the development, working mechanism, agronomic value, and environmental potential of cassava starch hydrogels as a green technology for climate-smart irrigation systems.

### Introduction

Agriculture today is confronted with escalating water scarcity, erratic rainfall, and the growing need for sustainable production systems. With nearly 70% of global freshwater being consumed by agriculture, the demand for water-efficient cultivation strategies is greater than ever. Hydrogels water-absorbent polymeric networks have gained recent attention as soil conditioners that hold water like a sponge and release it gradually depending on crop demand. While synthetic hydrogels exist, their petroleum origin, slow degradation, and microplastic concerns have shifted research towards natural polymers. Cassava (*Manihot esculenta*) stands out as a promising source of biodegradable starch for hydrogel synthesis. Rich in amylose and amylopectin, cassava starch swells efficiently and forms strong cross-linked gels when modified with natural or semi-synthetic monomers. The resulting biodegradable hydrogel improves soil moisture status, enhances root interaction, and supplies organic carbon upon decomposition making it a perfect candidate for green farming and low-carbon irrigation.

### Why Cassava Starch?



Cassava starch is an accessible agricultural commodity widely cultivated across tropical countries, making it a reliable raw material for hydrogel production. Unlike costly synthetic polymers, cassava is inexpensive, farmer-friendly, and locally available, encouraging

rural processing and value addition. Its natural composition rich in amylose and amylopectin imparts exceptional water-swelling capability, allowing hydrogels to absorb many times their weight in water. Being biodegradable and non-toxic, cassava starch breaks down safely in soil without leaving microplastic residues, posing zero harm to plants, microbes, or the environment. This makes cassava starch an ideal base for developing green hydrogels suited for sustainable agriculture.

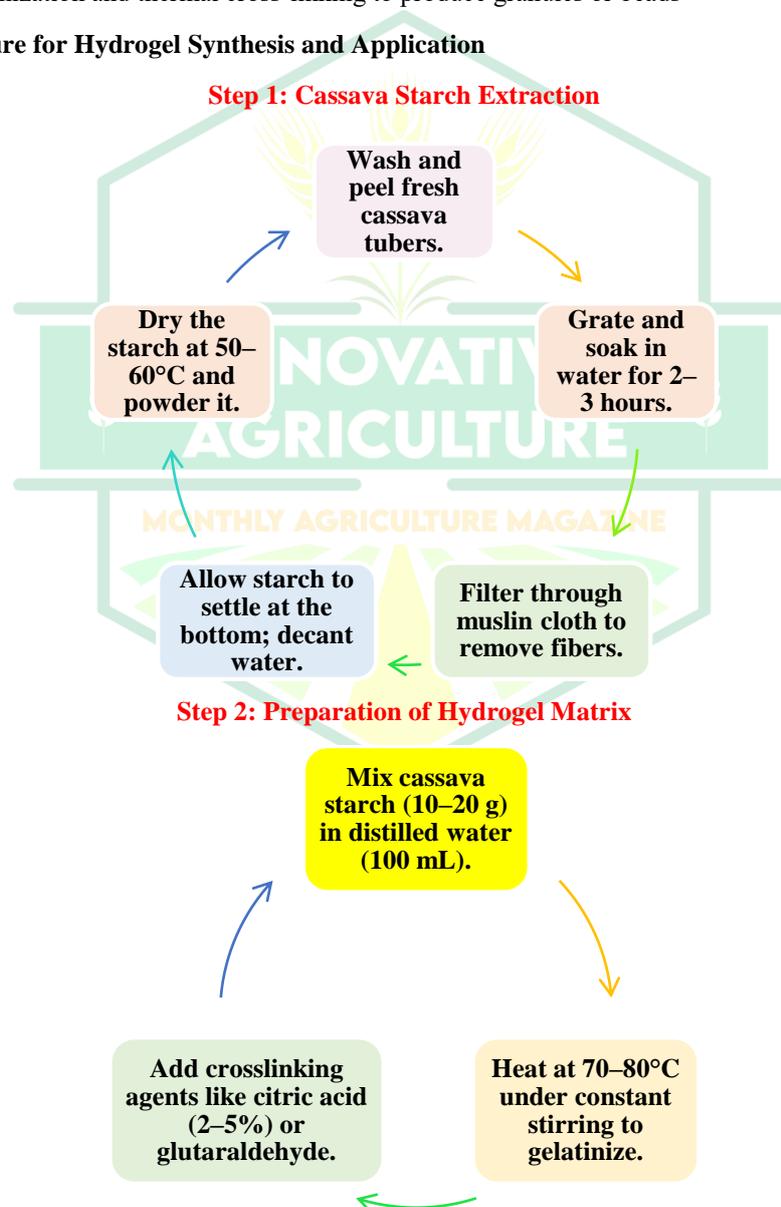
## Synthesis of Cassava Hydrogel

The hydrogel production process typically begins with extraction and gelatinization of cassava starch, where heat disrupts granular structure to allow polymer bonding. This is followed by cross-linking with eco-compatible agents such as citric acid, borax, chitosan or glycerol materials chosen for biocompatibility and low environmental impact. For enhanced functionality, nutrients or micronutrients can be embedded during synthesis to create smart hydrogels capable of slow-release fertilization. After curing, drying, and conditioning, the final product forms a soft but stable matrix that expands rapidly upon water contact. The resulting hydrogel blends modern polymer technology with traditional starch resources a fine example of bio-based innovation for agriculture.

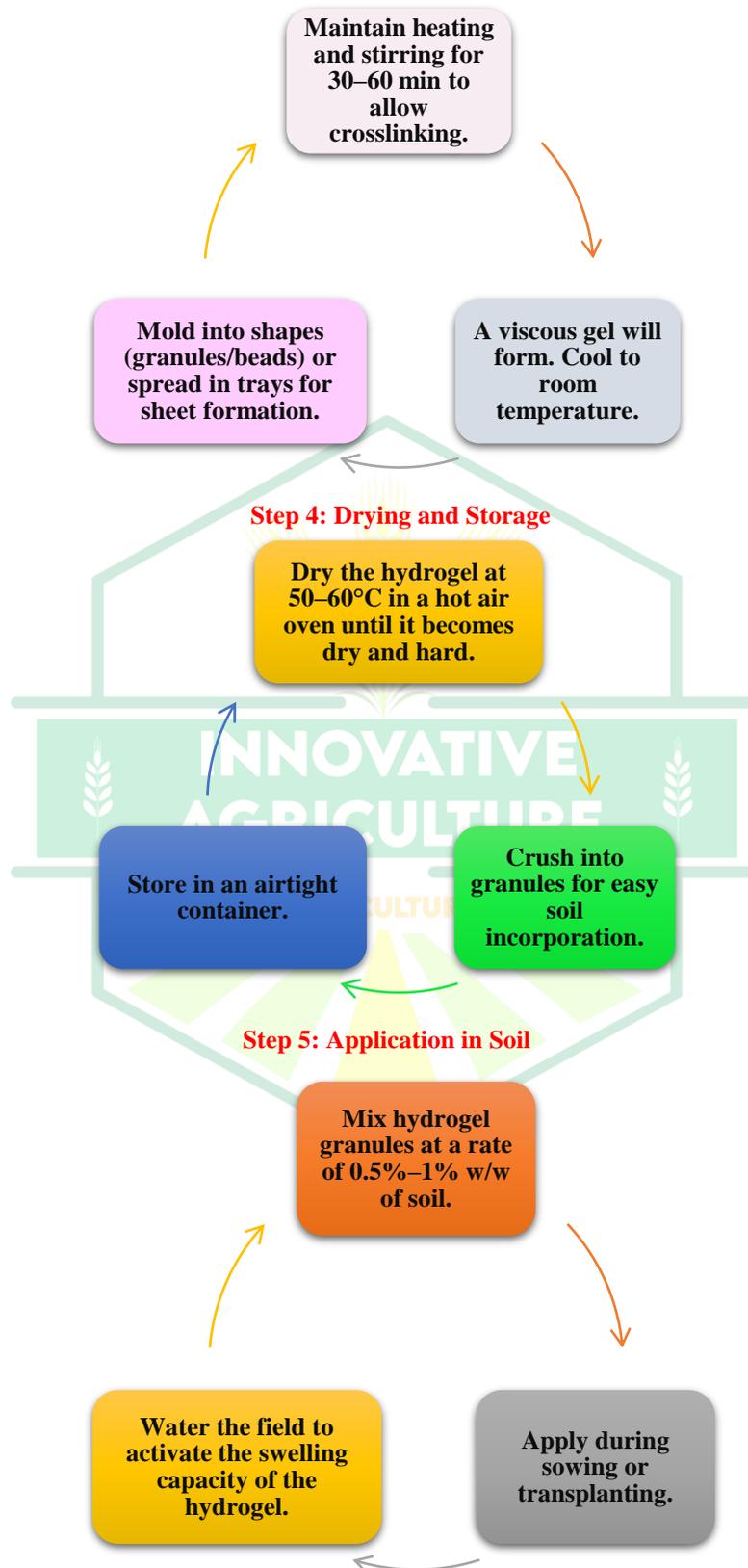
### Methodology

- ✓ Hydrogel Synthesis
- ✓ Raw material: Cassava starch
- ✓ Plasticizer: Glycerol
- ✓ Cross-linking agent: Citric acid or borax
- ✓ Process: Gelatinization and thermal cross-linking to produce granules or beads

### Stepwise Procedure for Hydrogel Synthesis and Application



### Step 3: Crosslinking and Gelation



### **Mechanism of Water Retention in Soil**

Once applied to soil, the hydrogel granules behave like tiny sponges, absorbing rain or irrigation water and swelling many times their original size. The absorbed moisture is locked within the polymer matrix, creating a temporary in-soil reservoir accessible to plant roots during dry periods. As the soil dries, the hydrogel gradually releases this stored water, sustaining crop growth when natural moisture is scarce. This mechanism slows down evaporation losses, reduces deep percolation, and minimizes runoff helping crops survive stress spells with fewer irrigation cycles. In simple terms, hydrogel acts as a water bank beneath the soil surface, supplying moisture on demand.

### **Role in Water-Smart Farming**

Hydrogels significantly reduce irrigation frequency often by 30–60% making them a valuable tool in water-scarce agriculture. Enhanced soil moisture availability encourages quicker germination, uniform crop establishment, and vigorous early growth, especially in moisture-sensitive crops like vegetables, maize, groundnut and cotton. Their ability to buffer drought stress makes them highly suitable for sandy soils where water drains rapidly, and for regions facing uncertain rainfall. By maintaining root-zone hydration longer, cassava hydrogels promote better nutrient uptake, canopy development, and yield performance under climate variability. This positions hydrogels as a promising technology for future-ready water-smart farming systems.

### **Low-Carbon Irrigation Benefits**

Water saving translates directly to reduced pumping requirements, lowering electricity or diesel consumption and cutting carbon emissions from farm operations. The gradual nutrient release prevents fertilizer runoff and nitrous oxide emissions, contributing to a lesser environmental footprint across the production cycle. Cassava hydrogels therefore align with climate-smart agriculture policies and sustainable development pathways. They help smallholders cope with irregular monsoon patterns without increasing irrigation dependency, supporting resilient crop production under a warming climate. With rising interest in low-carbon farming, cassava hydrogel stands out as a practical, field-applicable climate mitigation tool.

### **Additional Agronomic and Soil Benefits**

Beyond water retention, hydrogels improve soil structure by enhancing aggregation, aeration, and porosity properties crucial for robust root development. As hydrogels gradually degrade, they contribute organic carbon to soil, feeding beneficial microbes and stimulating biological activity. Their compatibility with fertilizers enables micronutrient or biofertilizer fortification, ensuring a controlled and sustained nutrient supply with reduced wastage. This improves nutrient-use efficiency (NUE), lowers application rates, and promotes healthy root-microbe interactions. Overall, cassava hydrogels function not just as moisture enhancers but as soil health boosters.

### **Applications Beyond Soil Moisture Conservation**

The utility of cassava hydrogels extends far beyond field irrigation. In nurseries and horticultural media, they improve water availability in potting mix and reduce transplant shock. As mulching gels, they protect seedlings during transport and maintain hydration for extended periods. Hydrogel-coated seeds enable direct sowing in drylands by ensuring moisture support during germination. They are also emerging as carriers for bioinoculants and smart fertilizer blends, enabling gradual nutrient and microbe release synchronized with plant demand. Such applications make cassava hydrogels versatile for multiple sectors of modern agriculture, from crop fields to protected cultivation.

### **Advantages**

- 30–50% reduced irrigation frequency.
- 3,000–5,000 kg CO<sub>2</sub>/ha reduced via water-pumping minimization.
- Improved plant growth and yield under drought/limited water.
- Completely biodegradable - no microplastic pollution.

### **Conclusion**

Cassava starch-based biodegradable hydrogels present a sustainable pathway towards water-wise agriculture, especially in regions facing frequent droughts and irrigation constraints. By functioning as in-soil water banks, they help crops endure moisture stress, reduce irrigation demand, and lower the energy footprint associated with



water pumping and fertilizer applications. Their biodegradability ensures zero microplastic residue, making them ideal for green, climate-resilient farming systems. As the agricultural sector moves toward low-carbon irrigation strategies, cassava hydrogels offer a promising technology that combines eco-friendly material science with practical field benefits—bringing innovation from laboratory to soil.



## Nature's Boosters: Unlocking Plant Resilience Through Biostimulants



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### Abstract:

Ensuring safe crop production in the coming years is a major challenge for humanity. Pesticides are widely used to manage external stress factors and supply nutrients, helping crops maintain growth and defense mechanisms. However, the application of synthetic chemicals poses serious risks to environmental standards essential for sustainable agriculture. In recent years, natural inputs such as biostimulants have gained attention for their ability to enhance plant growth and defense responses. The advancement of biostimulants offers promising solutions for improving agricultural product safety and has become an increasingly adopted approach in modern farming. This article outlines the major classes of biostimulants and highlights their role in mitigating both biotic and abiotic stresses in plants. It also discusses the practical applications of biostimulants in agriculture, emphasizing their relevance and benefits for farmers in improving crop resilience and productivity.

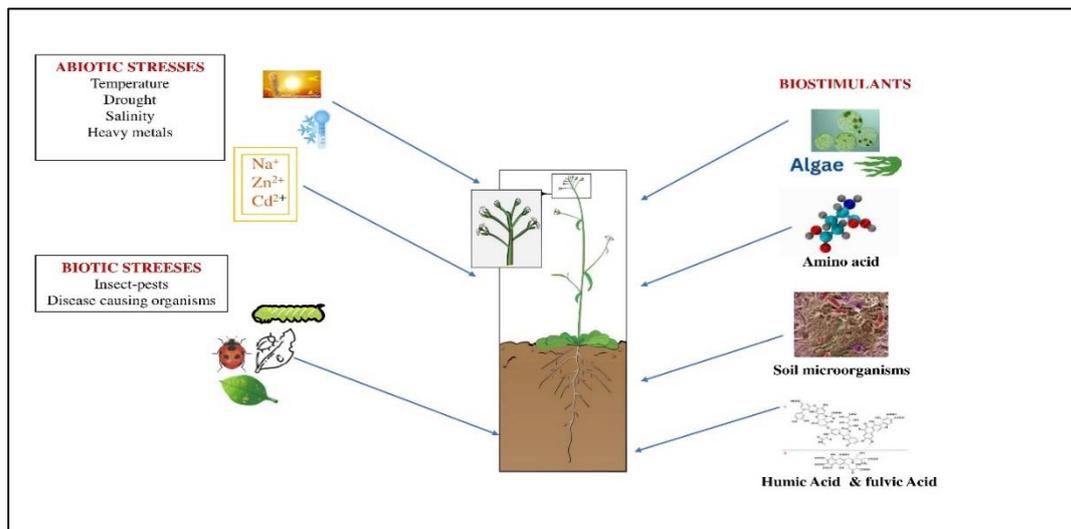
**Keywords:** Abiotic, Biotic, Biostimulants, Productivity, Sustainable

### Introduction:

Climate change driven abiotic and biotic stresses coupled with progressive soil fertility decline pose serious threats to global food security and place intense pressure on modern agriculture to sustain crop productivity. To compensate farmers increasingly rely on high inputs of chemical fertilizers and pesticides and their prolonged and indiscriminate use has resulted in soil degradation loss of beneficial microorganisms, water pollution, pesticide resistance, greenhouse gas emissions and human health risks. In India, fertilizer consumption has reached critically high levels, further accelerating environmental and agronomic constraints, in response, the Government of India has promoted biostimulant as sustainable agricultural inputs through policy support industry participation and extension programs (Nephali et al., 2020). Biostimulant defined as a non-nutrient substances or beneficial microorganisms enhance plant growth by regulating nutrient-use efficiency, stress tolerance, metabolic reprogramming and yield stability under both optimal and stress conditions. Advanced tools such as metabolomics provide mechanistic insights into biostimulant plant interactions enabling rational product development. To ensure quality and farmer safety, biostimulant were brought under the Fertiliser Control Order, 1985, allowing only scientifically validated products. Among approved categories, seaweed-based bioactive extracts are especially promising due to their natural growth regulators and stress-protective compounds which enhance plant metabolism, resilience and sustainable crop productivity.

**Classification of plant biostimulants:** Plant biostimulants has been divided into several categories viz.,

**a. Protein hydrolysates:** Protein hydrolysates enhance crop performance by modulating physiological, biochemical, and metabolic processes rather than supplying nutrients directly. They improve nutrient use efficiency, stress tolerance, antioxidant capacity, and soil biological activity, while reducing reliance on chemical fertilizers and mitigating their negative environmental and soil health impacts. (Colla et al., 2015; du et al., 2015; Roupheal et al., 2020).



**Fig. 1: Interaction of Biostimulants with Plant Responses Under Stress Conditions**

**b. Seaweed extract:** Seaweed and plant-derived biostimulant enhance crop performance primarily by regulating plant physiological and molecular pathways rather than by supplying mineral nutrients. Through low-dose applications, these biostimulant improve nutrient-use efficiency, stimulate root development, and activate rhizosphere processes, thereby supporting beneficial soil microbial communities and overall soil biological functioning. The diverse bioactive constituents of seaweed extracts such as polysaccharides, phenolic compounds, and hormone-like molecules strengthen plant soil interactions and promote sustainable nutrient cycling without impairing soil enzymatic or microbial activity (Bhattacharya et al., 2015). Moreover, seaweed-based biostimulant increase plant tolerance to abiotic stresses including drought, salinity, and temperature extremes, reducing the dependence on high chemical fertilizer inputs under adverse conditions. Collectively, these attributes make seaweed and plant extract biostimulant as environmentally sustainable alternatives to synthetic agrochemicals, enabling stable productivity while preserving soil health and minimizing ecological pollution (Khan et al., 2009; Ali et al., 2021).

**c. Humic substance:** These are stable organic constituents of soil organic matter formed through microbially mediated transformation of plant and animal residues. They enhance soil structure, porosity, water retention, and cation exchange capacity, thereby improving nutrient availability. By stimulating root H<sup>+</sup>-ATPase activity and supporting beneficial microbial communities, humic substances promote nutrient uptake, rhizosphere efficiency, plant growth, productivity, and resilience to environmental stresses (Canellas et al., 2015).

**d. Soil microorganisms:** Soil microorganisms play a pivotal role in plant growth by regulating rhizosphere processes that enhance nutrient availability, root architecture, and overall plant health. Beneficial fungi, particularly arbuscular mycorrhizal fungi (AMF), and plant growth-promoting rhizobacteria (PGPR) function as microbial biostimulant by improving water and nutrient uptake, nutrient solubilization, phytohormone production, and stress tolerance. Unlike chemical fertilizers, microbial biostimulants enhance nutrient use efficiency, improve soil structure and microbial diversity, maintain ecological balance, and provide a sustainable, long-term strategy for resilient crop productivity under stress conditions (Kumari et al., 2023).

**e. Chitin:** Chitin is a natural biopolymer from crustacean waste that is converted into chitosan through deacetylation increasing solubility and biological activity. Chitosan functions as a sustainable biostimulant by enhancing stress signalling antioxidant capacity photosynthesis, osmotic regulation and metal chelation thereby improving nutrient-use efficiency and soil health. Unlike excessive inorganic fertilizers that cause pollution and soil degradation, chitosan-based inputs support long-term crop resilience and environmental sustainability (Kumaresapillai et al., 2011).

**Biostimulants in abiotic stress management:**

Unlike chemical fertilizers that degrade soil and pollute ecosystems, biostimulant provide a sustainable long-term strategy for resilient crop production and soil health. Biostimulants enhance tolerance to these abiotic stresses by

promoting root architecture, nutrient use efficiency, antioxidant defense, osmolyte synthesis, water use efficiency, ion balance, and soil rhizosphere function, while improving germination, growth, photosynthetic performance, recovery, and overall crop quality under water-limited, high/low temperature, or saline conditions. Unlike chemical fertilizers, which may exacerbate environmental risks such as metal accumulation, biostimulants—particularly humic substances, algal and seaweed extracts, AMF, protein hydrolysates, and PGPR which offer sustainable, resilience-boosting strategies that mitigate effects through osmotic adjustment, microbial-assisted detoxification, and climate-resilient productivity, as seen in applications like PGPR for heavy metal stress in date palm.

#### **Biostimulants in biotic stress management:**

**a. Induced systemic resistance (ISR):** Plants activate multilayered induced resistance against biotic stress, primarily through induced systemic resistance (ISR) and systemic acquired resistance (SAR), mediated by PTI/ETI and signalling networks involving SA, JA, ET, phytoalexins, and defences enzymes. Biostimulant, especially beneficial microbes (PGPR, mycorrhizae, endophytes), effectively induce ISR by priming plant immunity, enhancing defences gene expression, oxidative balance, and broad-spectrum resistance to pathogens and pests. In contrast, chemical fertilizers may transiently support stress tolerance via improved nutrition but prolonged use degrades soil health, disrupts microbial communities, and poses risks to environmental and human health, ultimately reducing plant resilience and productivity.

**b. Root colonisation:** Root colonisation is essential for ISR activation, requiring a stable mutualistic interaction between beneficial microbes and plant roots. This interaction is driven by reciprocal signalling between root exudates and microbes, leading to symbiosis-related responses. PGPR modulate genes involved in chemotaxis, biofilm formation, and metabolism, while cell wall-degrading enzymes aid root entry. *Trichoderma* spp. preferentially colonizes root hairs, with plant-derived sucrose signalling promoting effective symbiotic establishment and ISR induction (Lugtenberg et al., 2009).

**c. Beneficial microbe-triggered SAR:** Although ISR is typically regulated through SA-independent pathways, certain beneficial microbes can activate an SA-dependent defences response resembling pathogen-induced SAR. Specific PGPR and PGPF strains, including *Pseudomonas*, *Paenibacillus*, and *Trichoderma*, have been shown to induce systemic resistance via SA signalling, often requiring host SA accumulation. However, microbially produced SA usually does not directly trigger SAR due to its sequestration in siderophores. In such cases, localized accumulation of reactive oxygen species during root or tissue colonization acts as a key signal initiating SA-dependent SAR pathways. (De et al., 1999; Audenaert et al., 2002).

**d. Microbial Elicitors of Induced Systemic Resistance:** ISR-inducing beneficial microbes function as **biostimulant** by modulating plant immune responses rather than directly activating strong local defences. These microbes suppress root immunity to establish mutualism while releasing diverse elicitors that trigger long-distance systemic immunity. In PGPR, ISR is induced by MAMPs and metabolites such as lipopolysaccharides, siderophores, antibiotics, flagella, quorum-sensing molecules, biosurfactants, and volatile organic compounds. In plant growth-promoting fungi, enzymatic proteins and elicitors such as Sm1 from *Trichoderma* activate defences signalling. The functional redundancy of these microbial elicitors ensures reliable ISR induction, analogous to PTI, highlighting beneficial microbes as effective biostimulant for enhancing plant resistance to biotic stresses. (Sun et al., 2011).

**Mechanism of biostimulants to tolerate stress:** Biostimulants help plant to tolerate stress mainly via antioxidant defence, hormonal balance, root growth, osmoregulation.

**a. Antioxidant defence:** Biostimulants boost the plant stress tolerance capacity due to reinforcing the antioxidant defense system. Under stress plant start overproduction of reactive oxygen species (ROS), hydrogen peroxide and superoxide radical that is cause adverse effects by damage the plant membranes, protein and DNA (Hasanuzzaman et al., 2021). Biostimulants helps in maintaining the redox equilibrium by activating enzymatic (CAT, SOD, POD, GR, APX) and non-enzymatic antioxidant including ascorbic acid, glutathione, phenolics, flavonoids. During biotic stress caused by insect herbivory or pathogen infection, they enhance defense-related oxidative signalling, enabling controlled ROS production that acts as a signalling molecule rather than a damaging

agent. This balanced ROS signalling supports the activation of defense pathways such as salicylic acid- and jasmonic acid-mediated responses, leading to strengthened plant resistance while minimizing oxidative injury.

**b. Hormonal balance:** Biostimulants enhance plant stress tolerance by regulating phytohormonal homeostasis, a key factor governing plant growth, defense and adaptive responses. Environmental stresses such as drought, salinity, extreme temperatures and herbivore or pathogen attack often disrupt endogenous hormone levels resulting in impaired growth and physiological dysfunction. Biostimulants influence the biosynthesis, signal transduction and interaction (cross-talk) of major plant hormones thereby re-establishing hormonal equilibrium and enabling plants to coordinate growth and defense processes more efficiently under stress conditions (Jahan et al., 2024).

**c. Promote root growth:** Biostimulants increase root growth via regulating physiological, biochemical and molecular processes. They trigger the root initiation, elongation and balancing ultimately large and more efficient root system (Hamza and Suggars 2001).

**d. Osmoregulation:** Biostimulants improve the cell ability to maintain water balance and cell turgor potential by accumulation of osmoprotectant (prolin, polyols, glycine betaine) they allowing to plant sustain growth and physiological function (Rouphael and Colla 2020).

#### Field application and benefits of biostimulants:

Biostimulants are utilized in agriculture through multiple application methods, including seed treatment, soil application, fertigation, and foliar spray to enhance plant tolerance to both biotic and abiotic stresses (Table 1). Their application is typically most effective during the early vegetative stage, although the optimal dose and method vary according to crop type, growth stage, and product formulation (Table )2. Utilization of biostimulants face many problems with their agronomical potential the effectiveness of biostimulants is often variable under field conditions, as their performance depends on crop species, growth stage, environmental factors and soil characteristics. Lack of standardized formulations and application protocols makes it difficult to compare results across studies and regions (Khoulati et al., 2025).

**Conclusion:** Biostimulants act as natural enhancers that strengthen plant physiological and biochemical processes under stress conditions. By improving nutrient efficiency, hormonal balance, antioxidant defense, and osmoregulation, they help plants maintain growth and productivity during adverse environments. Their eco-friendly nature makes biostimulants a promising tool for sustainable and climate-resilient agriculture.

**Table 1. General field application dosage of biostimulants**

Biostimulants	Method of application	Dosage	References
Seaweed extracts	Foliar spray	2–5 ml L <sup>-1</sup>	Khan et al., 2009; Rouphael and Colla 2020
Humic / Fulvic acids	Soil application	2–4 kg ha <sup>-1</sup>	du Jardin, 2015; Nardi et al., 2016
Humic / Fulvic acids	Foliar spray	1–2 ml L <sup>-1</sup>	Calvo et al., 2014
Microbial biostimulants (PGPR, Mycorrhiza)	Soil application	2–5 kg ha <sup>-1</sup>	du Jardin, 2015; Rouphael and Colla 2020
Microbial biostimulants (PGPR, Mycorrhiza)	Seed treatment	5–10 g kg <sup>-1</sup> seed	Vessey, 2003; Bhattacharyya and Jha 2012
Amino acid formulations	Foliar spray	1–3 ml L <sup>-1</sup>	Colla et al., 2017

**Table 2. Crop-wise application of biostimulants**

Crop	Biostimulant used	Benefits	References
Rice	Seaweed extracts, amino acids	Improved root growth, increased tillering, enhanced tolerance to drought and salinity	Khan et al., 2009
Wheat	Humic substances	Improved nutrient uptake, better grain filling, increased yield	Nardi et al., 2016
Tomato, Chilli	Amino acids, seaweed extracts	Improved flower retention, fruit set, and fruit quality	Ertani et al., 2013
Horticulture Crops	Microbial biostimulants (PGPR, mycorrhiza)	Enhanced root colonization, improved stress resilience, higher productivity	Vessey, 2003

## References

- Ali, O. Ramsubhag, A. and Jayaraman. J. (2021). Biostimulant properties of seaweed extracts in plants: implications towards sustainable crop production. *Plants*. 10 (3): 531-41.
- Audenaert, K. Pattery, T. Cornelis, P. and Hofte. M. (2002). Induction of systemic resistance to " Botrytis cinerea in tomato by *Pseudomonas aeruginosa* 7NSK2: role of salicylic acid, pyochelin, and pyocyanin. *Mol. Plant Microbe Interact*. 15 (11): 1147-56.
- Battacharyya, D. Babgohari, M Z. Rathor, P. and Prithiviraj. B. (2015). Seaweed extracts as biostimulants in horticulture. *Scientia Horticulturae*. 196: 39-48.
- Bhattacharyya, P N. and Jha. D K. (2012). Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. *World Journal of microbiology and biotechnology*. 28(4): 1327-1350.
- Calvo, P. Nelson, L. and Kloepper. J W. (2014). Agricultural uses of plant biostimulants. *Plant and soil*. 383(1): 3-41.
- Canellas, L P. Olivares, F L. Aguiar, N O. and Jones. D L. (2015) Humic and fulvic acids as biostimulants in horticulture. *Scientia Horticulture*. 196: 15-27.
- Colla, G. Hoagland, L. Ruzzi, M. Cardarelli, M. Bonini, P. Canaguier, R. and Roupheal. Y. (2017). Biostimulant action of protein hydrolysates: Unraveling their effects on plant physiology and microbiome. *Frontiers in plant science*. 8, 2202.
- Colla, G. Nardi, S. Cardarelli, M. and Ertani. A. (2015). Protein hydrolysates as biostimulants in horticulture. *Scientia Horticulture*. 196: 28-38.
- De, M G. Capiéau, K. Audenaert, K. Buchala, A. Metraux, J P. and ofte. M. (1999). Nanogram amounts " of salicylic acid produced by the rhizobacterium *Pseudomonas aeruginosa* 7NSK2 activate the systemic acquired resistance pathway in bean. *Mol. Plant-Microbe Interact*. 5(12): 450-58.
- Du Jardin P. (2015). Plant biostimulants: Definition, concept, main categories and regulation. *Scientia Horticulturae* 196, 3-14.
- Ertani, A. Pizzeghello, D. Altissimo, A. Nardi, S. (2013). Use of protein hydrolysates as biostimulants in horticulture. *Journal of Agricultural and Food Chemistry*. 61(36): 8680-8686.
- Hamza, B. and Suggars. A. (2001). Biostimulants: myths and realities. *TurfGrass Trends*. 8(5) 6-10.
- Hasanuzzaman, M. Parvin, K. Bardhan, K. Nahar, K. Anee, T I. Masud, A A C. and Fotopoulos. V. (2021). Biostimulants for the regulation of reactive oxygen species metabolism in plants under abiotic stress. *Cells*. 10(10) :2537.
- Jahan, M S. Hasan, M M. and Rahman. M A. (2024). Hormones and biostimulants in plants: physiological and molecular insights on plant stress responses. *Frontiers in plant science*. 15(8): 1413659.
- Khan, W. Rayirath, U P. Subramanian, S. and Jithesh. M. N. (2009). Seaweed Extracts as biostimulants of plant growth and development. *Journal of Plant Growth Regulation* 28 (4): 112-134.
- Khoulati, A. Ouahhoud, S. Taibi, M. Ezrari, S. Mamri, S. Merah, O. and Saalaoui. E. (2025). Harnessing biostimulants for sustainable agriculture: innovations, challenges, and future prospects. *Discover Agriculture*. 3(1): 56.
- Kumaresapillai, N. Basha, R A. and Sathish. R. (2011). Production and evaluation of chitosan from *Aspergillus niger* MTCC strains. *Iranian Journal of Pharmaceutical. Research*. 10 (3): 553-58.
- Kumari, M. Swarupa, P. Kesari, K K. and Kumar. A. (2023). Microbial inoculants as plant biostimulants: A review on risk status. *Life (Basel)*. 13 (1): 12.
- Lugtenberg B and Kamilova. F. (2009). Plant-growth-promoting rhizobacteria. *Annu. Rev. Microbiol.* (63): 541- 56.
- Nardi, S. Pizzeghello, D. Schiavon, M. and Ertani. A. (2016). Plant biostimulants: physiological responses induced by protein hydrolyzed-based products and humic substances in plant metabolism. *Scientia Agricola*. 73(1): 18-23.
- Nephali, L. Piater L A. Dubery, I A. Patterson, V. Huyser, J. Burgess, K. and Tugizimana. F. (2020). Biostimulants for Plant Growth and Mitigation of Abiotic Stresses: A Metabolomics Perspective. *Metabolites*. 10(12): 505.
- Roupheal, Y. and Colla, G. (2020). Biostimulants in agriculture. *Front Plant Science* 11, 40.
- Sun, J Q. Jiang, H L. and Li. C Y. (2011). Systemin/jasmonate-mediated systemic defense signaling in tomato. *Mol. Plant* 4(4): 607-15.
- Vessey. J. K. (2003). Plant growth promoting rhizobacteria as biofertilizers. *Plant and soil*. 255(2): 571-586.

## Blue Economy: Riding the Waves of Sustainable Growth



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### Abstract

The Blue Economy has emerged as a strategic framework for balancing economic development with the conservation of marine and coastal ecosystems. As oceans face increasing pressures from climate change, pollution, overexploitation, and rapid coastal development, the Blue Economy promotes integrated approaches that link growth, sustainability, and social inclusion. This article outlines the global relevance of the Blue Economy, its key sectors, and prevailing challenges, while highlighting the roles of climate-resilient ocean governance, marine biotechnology, and ocean observation systems in informed decision-making. It also addresses emerging concerns related to maritime security, geopolitics, and coastal urbanization, particularly within the Indian Ocean region. With special reference to India, the article reviews current initiatives, technological advancements, and policy frameworks, emphasizing the need for equitable outcomes for coastal communities. Realizing the full potential of the Blue Economy depends on integrated governance, scientific innovation, inclusive participation, and international cooperation, all of which are essential for healthy oceans and sustainable livelihoods.

**Keywords:** Blue Economy, Climate change, Ocean governance, Inclusive participation

### Introduction

Oceans are the lifeline of the planet. They regulate the global climate, sustain rich biodiversity, provide food and energy, facilitate trade, and support millions of livelihoods worldwide. Yet today, marine ecosystems are under mounting pressure from overfishing, pollution, habitat degradation, and the accelerating impacts of climate change. Addressing these challenges without halting economic development has become one of the defining policy questions of our time. In this context, the concept of the Blue Economy has gained growing global attention. The Blue Economy advocates the sustainable use of ocean and coastal resources to generate economic growth while safeguarding environmental integrity and social well-being. Evidence from global studies suggests that when marine resources are managed responsibly, oceans can deliver long-term economic value alongside ecological resilience (Wenhai et al., 2019). As a result, the Blue Economy is increasingly viewed not merely as an environmental agenda, but as a transformative development pathway for coastal and maritime nations.

### Insights on the Blue Economy

The Blue Economy encompasses all economic activities linked to oceans, seas, and coastlines, guided by the principle that marine resources must be used in ways that are environmentally sustainable, socially inclusive, and economically viable. It spans a wide range of sectors—from fisheries and aquaculture to marine biotechnology, coastal tourism, shipping, offshore renewable energy, seabed resources, and ocean research. Importantly, the Blue Economy is not simply about extracting value from the ocean, but about managing it responsibly for long-term benefits. As highlighted by Lee, Noh, and Khim (2020), the Blue Economy is closely aligned with the United Nations Sustainable Development Goals, particularly SDG 14 (Life Below Water), while also supporting broader goals related to food security, poverty reduction, clean energy, and climate action. Patil et al. (2018) further describe the Blue Economy as a transition away from conventional, exploitative practices toward a model that integrates conservation, equity, and innovation. In simple terms, the **Blue Economy is about using the ocean wisely, fairly, and sustainably so that economic progress and ocean health advance together.**

### Importance of Blue Economy

**1. Economic importance:** Marine and coastal industries make a substantial contribution to both national and global economies. Sectors such as shipping, marine fisheries, coastal tourism, and marine biotechnology generate

employment for millions of people worldwide and support critical trade networks. Experience from several countries shows that when ocean resources are managed sustainably, they can drive long-term and resilient economic growth rather than short-lived gains (Wenhai et al., 2019).

**2. Environmental importance:** Oceans play a central role in regulating the Earth's climate by absorbing nearly one-third of global carbon dioxide emissions, moderating temperatures, and sustaining immense biological diversity. Healthy marine ecosystems are therefore essential not only for ocean life, but also for climate stability and planetary health. Protecting these ecosystems lies at the heart of a sustainable Blue Economy.

**3. Social importance:** For millions of people, particularly in coastal regions, the ocean is a primary source of food, income, and cultural identity. An effective Blue Economy must ensure that economic benefits are shared fairly and do not exclude vulnerable groups. As emphasized by Bennett et al. (2019), equity and inclusion—especially for small-scale fishers, coastal communities, and indigenous populations—are critical to making the Blue Economy socially just and sustainable.

**4. Scientific and technological importance:** Advances in ocean observation systems, marine genomics, renewable energy technologies, and climate modelling are transforming how countries understand and manage their marine environments. These tools enable evidence-based planning, early warning of environmental change, and more sustainable use of ocean resources. Rayner et al. (2019) underline the growing importance of ocean monitoring in supporting informed decision-making within the Blue Economy.

#### Global Innovations Driving the Blue Economy

**1. Sustainable fisheries management:** Countries such as Norway and Iceland have demonstrated how science-based fisheries management—through catch quotas, strict monitoring, and ecosystem-based approaches—can rebuild fish stocks while maintaining economic returns. These examples show that sustainability strengthens long-term productivity rather than limiting growth (Wenhai et al., 2019).

**2. Marine renewable energy:** Nations like Denmark and the United Kingdom are global leaders in offshore wind energy, illustrating how oceans can support the transition to low-carbon economies. Their experience highlights the growing role of marine renewable energy in achieving clean-energy and climate goals.

**3. Ocean-based tourism:** Several Pacific and Caribbean island nations are adopting eco-friendly marine tourism models that combine coral reef restoration, marine protected areas, and responsible boating practices. These approaches demonstrate how conservation-focused tourism can generate economic benefits while protecting fragile marine ecosystems.

**4. Marine spatial planning:** European countries have advanced marine spatial planning frameworks to balance competing ocean uses, including fisheries, conservation, tourism, and industrial development. As noted by Martínez-Vázquez et al. (2021), such planning tools help reduce conflicts and promote more efficient and sustainable ocean governance.

#### Advancing India's Blue Economy Through Innovation and Policy

With a coastline stretching 11,098.81 km and an Exclusive Economic Zone (EEZ) of 2.02 million km<sup>2</sup>, India possesses vast marine resources that hold immense economic, ecological and strategic value. In recent years, national initiatives have increasingly focused on integrating ocean-based sectors into the country's economic growth model, climate resilience planning and maritime security architecture. As highlighted by Upadhyay and Mishra (2020), India's expanding Blue Economy is anchored by several priority sectors, including marine biotechnology and bioresources, deep ocean mining, port-led development through the Sagarmala programme, shipping and logistics, offshore renewable energy such as wind and tidal power, marine fisheries and aquaculture, and a rapidly growing coastal tourism industry. Together, these sectors support millions of livelihoods while contributing significantly to national GDP. India has also made notable advancements in marine science and technology. Vedachalam, Ravindran and Atmanand (2019) point to major achievements such as the establishment of sophisticated tsunami early-warning systems, the development of deep-sea mining technologies and robotic exploration tools, and extensive ocean observation networks that include ARGO floats and coastal buoy systems. Furthermore, progress in marine robotics, offshore engineering and data-driven monitoring systems has strengthened India's preparedness for climate-related events and enhanced maritime domain awareness.

Complementing scientific progress, India is pursuing a range of policy initiatives and institutional reforms aimed at strengthening its ocean governance. These include the Deep Ocean Mission for mineral exploration, the National Fisheries Policy focused on sustainability and fisher welfare, Coastal Regulation Zone (CRZ) frameworks to protect fragile shorelines, maritime security strategies, and various marine ecosystem restoration programmes. According to Mohanty (2024), realising the full potential of India's Blue Economy will require greater policy integration, enhanced scientific capacity and stronger governance mechanisms, while Mehrotra (2025) emphasizes the need for socially inclusive, climate-resilient development pathways. India also plays an active international role in advancing ocean cooperation. Through platforms such as the Indian Ocean Rim Association (IORA), BIMSTEC, SAGAR (Security and Growth for All in the Region), and the Indo-Pacific Oceans Initiative (IPOI), the country contributes to regional marine research, disaster response coordination, maritime security partnerships and sustainable ocean development (Upadhyay & Mishra, 2020). These collaborative efforts underscore India's commitment to shaping a resilient and responsible Blue Economy that balances growth with environmental stewardship.

### **Blue Economy and Climate Change Mitigation**

Oceans play a vital role in regulating the Earth's climate by absorbing heat and carbon dioxide. A sustainable Blue Economy can strengthen climate change mitigation through nature-based solutions such as mangrove restoration, seagrass conservation, and coral reef protection. These ecosystems act as important carbon sinks while enhancing coastal resilience to storms and sea-level rise. Rayner et al. (2019) emphasize that ocean observing systems are critical for tracking climate-driven changes and guiding adaptation strategies. In addition, climate-resilient ocean development supports multiple Sustainable Development Goals, reinforcing the Blue Economy's importance in global climate policy (Lee et al., 2020).

### **Role of Marine Biotechnology in the Blue Economy**

Marine biotechnology has emerged as a key pillar of the Blue Economy, with applications in pharmaceuticals, nutraceuticals, biofuels, and environmental remediation. Vedachalam et al. (2019) note that advances in marine biotechnology can generate economic returns while maintaining ecological balance when guided by scientific oversight and regulatory frameworks. In the Indian context, rich marine bioresources offer significant opportunities for sustainable growth when supported by targeted research investment and sound policy measures (Mohanty, 2024).

### **Ocean Observation, Data, and Decision-Making**

Reliable ocean data forms the backbone of effective Blue Economy governance. Ocean observing systems provide continuous information on sea temperature, currents, biodiversity patterns, pollution levels, and extreme events such as cyclones and storm surges. This data supports fisheries management, disaster preparedness, climate prediction, and maritime safety. Strong monitoring infrastructure enables informed, adaptive, and timely decision-making, particularly under increasing climate variability (Rayner et al., 2019).

### **Blue Economy, Maritime Security, and Geopolitics**

The Blue Economy is increasingly shaped by maritime security considerations and geopolitical dynamics. Growing competition over shipping routes, seabed minerals, offshore energy resources, and strategic ports has intensified, particularly in the Indian Ocean region. Asif (2022) explains that Blue Economy initiatives are often influenced by power politics, requiring nations to balance economic development with national security interests.

### **Social Inclusion in the Blue Economy**

Social inclusion is fundamental to a sustainable Blue Economy. Millions of people—especially small-scale fishers, women, and indigenous communities depend directly on marine resources for livelihoods and cultural identity. Bennett et al. (2019) stress that equity, justice, and meaningful participation are essential for effective ocean governance. Community-based management, stakeholder engagement, and benefit-sharing mechanisms are critical to ensure that blue growth is both socially just and environmentally sustainable globally.

### **Strategic Pillars for an Equitable and Resilient Blue Economy Framework**

**1. Strengthening ocean governance:** Effective Blue Economy implementation depends on robust and integrated ocean governance. This includes ecosystem-based management, harmonized marine policies, and strong

regulatory frameworks that balance economic use with environmental protection. Marine spatial planning should be treated as a national priority to reduce sectoral conflicts and ensure sustainable use of ocean space.

**2. Empowering coastal communities:** Social equity is central to sustainable blue growth. Bennett et al. (2019) emphasize that coastal communities must be active participants rather than passive beneficiaries of the Blue Economy. Recognizing traditional fishing rights, improving access to markets, and supporting alternative and supplementary livelihoods are essential to ensure that development benefits reach small-scale fishers and vulnerable groups.

**3. Investing in research and innovation:** Scientific knowledge and technological innovation form the foundation of informed ocean governance. Rayner et al. (2019) highlight that advanced ocean observation systems are critical for effective fisheries management, climate prediction, and environmental monitoring. Sustained investment in marine research strengthens adaptive decision-making and long-term resilience.

**4. Restoring marine ecosystems:** Healthy ecosystems are the backbone of a resilient Blue Economy. Protecting and restoring mangroves, seagrass meadows, coral reefs, and coastal wetlands enhances biodiversity, strengthens coastal protection, and supports fisheries productivity.

**5. Promoting sustainable marine industries:** Transitioning to sustainable marine industries is essential for long-term ocean health. Practices such as green shipping, cleaner and energy-efficient ports, plastic-free coastlines, and eco-friendly tourism models reduce environmental pressures while maintaining economic viability.

**6. Enhancing international cooperation:** Oceans transcend political boundaries, making international cooperation indispensable. As noted by Patil et al. (2018), effective Blue Economy development requires collaboration in marine research, climate adaptation, and shared resource management to address transboundary challenges and promote collective benefits.

### Conclusion

The Blue Economy offers a powerful framework for aligning economic development with environmental stewardship and social equity. Global experience demonstrates that sustainable ocean practices can generate economic growth, create employment, and strengthen climate resilience when guided by science and inclusive governance. For India, with its strategic location in the Indian Ocean and abundant marine resources, the Blue Economy presents a unique opportunity to drive long-term growth while safeguarding coastal ecosystems and livelihoods. Realising this potential will depend on stronger policy coherence, meaningful community participation, and sustained investment in science and innovation. Ultimately, the Blue Economy is more than an economic strategy—it represents a shared vision of healthy, productive, and equitable oceans. By embracing fair, science-based, and sustainable marine development, nations can chart a path of prosperity that respects ecological limits and secures the ocean for future generations.

**“Blue prosperity begins with blue responsibility”**

### References

- Bennett, N. J., Cisneros-Montemayor, A. M., Blythe, J., Silver, J. J., Singh, G., Andrews, N., ... & Sumaila, U. R. (2019). Towards a sustainable and equitable blue economy. *Nature Sustainability*, 2(11), 991–993. <https://www.nature.com/articles/s41893-019-0404-1>
- Asif, M. (2022). Blue Economy and Power Politics in the Indian Ocean: Challenges and Opportunities. *Journal of Nautical Eye and Strategic Studies*, 2(2), 2–37. <https://ojs.mul.edu.pk/index.php/J-NESS/article/view/182>
- Lee, K. H., Noh, J., & Khim, J. S. (2020). The Blue Economy and the United Nations’ sustainable development goals: Challenges and opportunities. *Environment International*, 137, 105528. <https://www.sciencedirect.com/science/article/pii/S0160412019338255>
- Martínez-Vázquez, R. M., Milán-García, J., & de Pablo Valenciano, J. (2021). Challenges of the Blue Economy: Evidence and research trends. *Environmental Sciences Europe*, 33(1), 61. <https://link.springer.com/article/10.1186/s12302-021-00502-1>
- MEHROTRA, D. S. M. S. (2025). Blue Economy and Its Potential for Sustainable Development in India. *Motherhood International Journal of Research & Innovation*, 2(01), 1–22. <https://mhujournal.in/MIJRI/index.php/MIJRI/article/view/69>

- Mohanty, S. K. (2024). Prospects of the blue economy in India: Emerging policy challenges and the way forward. *Current Science*, 126(2). <https://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=00113891&AN=174995330>
- Patil, P. G., Virdin, J., Colgan, C. S., Hussain, M. G., Failler, P., & Vegh, T. (2018). *Toward a blue economy*. <https://www.sidalc.net/search/Record/dig-okr-1098630014/Description>
- Rayner, R., Jolly, C., & Gouldman, C. (2019). Ocean observing and the blue economy. *Frontiers in Marine Science*, 6, 330. <https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2019.00330/full>
- Upadhyay, D. K., & Mishra, M. (2020). Blue economy: Emerging global trends and India's multilateral cooperation. *Maritime Affairs: Journal of the National Maritime Foundation of India*, 16(1), 30–45. <https://www.tandfonline.com/doi/abs/10.1080/09733159.2020.1785087>
- Vedachalam, N., Ravindran, M., & Atmanand, M. A. (2019). Technology developments for the strategic Indian blue economy. *Marine Georesources & Geotechnology*, 37(7), 828–844. <https://www.tandfonline.com/doi/abs/10.1080/1064119X.2018.1501625>
- Wenhai, L., Cusack, C., Baker, M., Tao, W., Mingbao, C., Paige, K., ... & Yufeng, Y. (2019). Successful blue economy examples with an emphasis on international perspectives. *Frontiers in Marine Science*, 6, 261. <https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2019.00261/full>



## Deep-sea creatures at the surface: natural behaviour or warning sign?



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### Abstract

The deep sea, one of Earth's least explored frontiers, hosts a range of bizarre and uniquely adapted creatures such as the strawberry squid, barreleye fish, vampire squid, and yeti crab. Normally confined to extreme depths, these species occasionally appear near the ocean surface due to natural behaviours like diel vertical migration. However, climate change, ocean warming, oxygen depletion, and anthropogenic disturbances are increasingly forcing deep-sea organisms to surface, signaling profound disruptions in marine ecosystems. Understanding these movements highlights the urgent need for sustainable ocean management, conservation of deep-sea habitats, and caution against activities like deep-sea mining that threaten this fragile environment.

**Keywords:** Deep sea, vertical migration, ocean warming, hypoxia, marine conservation, deep-sea mining, ocean ecosystems, climate change

### 1. Introduction

The Earth is often called the "blue planet" for a reason. Nearly 71% of our planet is covered by water, and about 97% of this water lies in the world's five major oceans viz the Pacific, Atlantic, Indian, Arctic, and Southern oceans (Li *et al.*, 2025). Together, these vast water bodies support an astonishing 94% of Earth's living species. Yet, despite their size and importance, the oceans remain one of the least explored frontiers on the planet. Scientists estimate that less than 5% of marine life has been discovered so far, leaving most oceanic species still unknown to science (NOAA, 2022).

Humans have sailed and fished across the ocean's surface for tens of thousands of years, but the world beneath the waves tells a very different story. According to 2022 estimates from the National Oceanic and Atmospheric Administration, only about 20% of the seafloor has been mapped. To put this in perspective, researchers often remark that traveling to space is easier than reaching the deepest parts of the ocean. While 12 astronauts spent over 300 cumulative hours on the Moon, only three people have ever visited the Challenger Deep, the deepest known point of the ocean, and they remained there for just a few hours.

The ocean is not a single uniform body of water but a vertically layered world divided into distinct depth zones, each with its own physical conditions and life forms. The Epipelagic or Sunlight Zone, extending from the surface to about 200 meters, is the only layer where sunlight penetrates sufficiently to support photosynthesis, making it the most biologically productive region of the ocean. Below this lies the Mesopelagic or Twilight Zone (200–1,000 m), where sunlight fades and plant life disappears, yet bioluminescent creatures thrive in the dimness. Deeper still, the Bathypelagic or Midnight Zone (1,000–4,000 m) exists in complete darkness, under crushing pressure, where life depends largely on falling organic matter known as "marine snow." Beyond this are the icy, low-energy plains of the Abyssopelagic Zone (4,000–6,000 m), and finally the Hadalpelagic Zone, extending below 6,000 meters into deep-sea trenches, the most extreme and least explored habitats on Earth.

Understanding this hidden, layered world is essential to appreciating why the sudden appearance of deep-sea creatures at the ocean's surface captures so much attention. When organisms adapted to darkness and pressure emerge into daylight, it raises an important question: what is happening in the depths of our oceans?

### 2. Life in the Ocean's Dark Interior

As we descend beyond the sunlit surface into the deeper layers of the ocean, life begins to change in remarkable and often surreal ways, shaped by fading light, increasing pressure, and limited food availability. In the mesopelagic or twilight zone (200–1,000 m), where sunlight barely penetrates, organisms rely heavily on vision, camouflage, and bioluminescence. The strawberry squid (*Histioteuthis heteropsis*) exemplifies this world with its mismatched eyes, one scanning upward for silhouettes and the other detecting bioluminescent flashes below,

while its red, photophore-studded body provides near-perfect concealment in dim blue light. Sharing this zone, the barreleye fish (*Macropinna microstoma*) uses its transparent head and rotating tubular eyes to spy on prey above, often stealing food from the tentacles of siphonophores, whereas the blood-belly comb jelly (*Lamproteuthis cruentiventer*) employs a deep red gut to hide the glow of its bioluminescent prey, avoiding detection as it drifts using shimmering ciliary combs. Adding to this twilight drama, the sea angel (*Clione limacina*), despite its delicate appearance, is a fierce shell-less snail that hunts sea butterflies with precision, while the vampire squid (*Vampyroteuthis infernalis*), adapted to oxygen-poor waters, abandons active predation altogether and instead feeds on marine snow, organic debris slowly falling from above. Descending further into the bathypelagic or midnight zone (1,000–4,000 m), where absolute darkness reigns, survival depends on ambush strategies and extreme energy efficiency. Here, the black sea devil fish (*Melanocetus johnsonii*) uses its bioluminescent lure to draw prey close, while the legendary giant squid (*Architeuthis dux*), armed with enormous eyes capable of sensing faint light disturbances, occupies a pivotal role as both predator and prey in deep-sea food webs, linking fish communities with deep-diving sperm whales. Gliding calmly through these depths is the dumbo octopus (*Grimpoteuthis* spp.), whose ear-like fins and sensitive cirri allow it to detect and capture prey on the dark seafloor. At the deepest extremes, in the abyssal regions and hydrothermal vent systems, life takes an even more extraordinary turn. The yeti crab (*Kiwa hirsuta*), blind and adapted to toxic, superheated environments, survives not on sunlight or falling debris but by farming bacteria on its hairy claws, microorganisms that convert chemical energy from vents into food. Together, these creatures illustrate how the ocean's layered depths host uniquely adapted life forms, each finely tuned to its environment. Their occasional appearances near the surface are not random curiosities but potential signals of disturbance in these fragile, hidden ecosystems, reminding us how much of the ocean remains unexplored, and how deeply connected its darkest realms are to the health of the planet as a whole.

### 3. The Ocean's Biological Heartbeat

Every day, the planet witnesses its largest movement of biomass through a survival strategy called Diel Vertical Migration. During daylight hours, a vast array of marine life, including fish, squid, and zooplankton, retreats into the "Deep Scattering Layer." By remaining in these dark, abyssal reaches, they stay invisible to visual predators. Under the cover of night, these organisms ascend to the surface to feast on nutrient-rich plankton, a tactic that allows them to forage while minimizing their risk of being hunted (Thibault *et al.*, 2025). By daybreak, they return to the depths, maintaining a precarious but effective balance between survival and energy gain.

### 4. Climate Change and the "Stifling" of the Deep

This ancient natural rhythm is currently under threat from anthropogenic global warming. Because the oceans absorb the vast majority of the Earth's excess heat, surface waters are becoming increasingly warm and buoyant. This leads to stratification, where the warm upper layer acts as a lid, preventing it from mixing with the cold, oxygen-rich waters below.

#### The Rise of Hypoxia

As vertical mixing declines, the deep and mid-water zones suffer from oxygen depletion (hypoxia) (Hauss *et al.*, 2023). This lack of "breathable" water creates a physiological crisis for deep-sea inhabitants. Consequently, these creatures are being forced out of their natural habitats and toward the surface for longer periods just to survive.

### 5. The Warning Signs of a Shifting Ecosystem

The abnormal or permanent surfacing of deep-sea life is far more than a biological anomaly; it is an ecological red flag. When these organisms are pushed into the surface layers, they become:

- a) **Highly Visible:** Increasing their vulnerability to predators and human interference.
- b) **Ecologically Displaced:** Disrupting complex predator-prey dynamics.
- c) **Systemically Unstable:** Destabilizing the global marine food web.

Ultimately, the sight of deep-sea creatures in shallow waters is a stark warning that the ocean's internal environment is changing faster than its inhabitants can adapt.

### 6. The Rise of the "Sea Serpent": A Global Timeline

Over the past two years, the mysterious oarfish, a creature traditionally confined to the dark, crushing depths of the midnight zone, has been making startling appearances at the surface, often appearing more like a mythological

sea serpent than a modern fish. The trend gained momentum in 2023 when divers in Taiwan filmed a rare, silver-bodied oarfish swimming vertically, its body riddled with mysterious bite marks. By January 2024, the phenomenon reached the Andaman coast of Thailand for the first time in recorded history, followed shortly by a sighting in the Philippines in July that coincided with a local earthquake. The summer of 2024 saw a bizarre "cluster" in California, where two massive specimens washed ashore in La Jolla and Encinitas within just three months, sparking a media frenzy. The mystery deepened in August 2024 as fishermen in Vietnam discovered a "Lord of the Sea" near their shores. Most recently, the arrival of this deep-sea messenger in 2025 near Rameswaram, Tamil Nadu, has brought the mystery to the doorstep of the Indian Ocean. From the Pacific "Ring of Fire" to the tropical waters of the Gulf of Mannar, these sightings are no longer isolated curiosities; they are a global pattern of deep-sea displacement.

These appearances are no longer isolated events. They reflect a broader pattern driven by multiple stressors: oxygen loss, disrupted food migration, abnormal ocean currents during **El Niño and marine heatwaves**, physical exhaustion, disease, parasite infections, predator injuries, and even **anthropogenic noise** from sonar, drilling, and seismic surveys that disorient deep-sea animals in their normally silent world.

### 7. Myth, Meaning, and a Modern Warning

In Japanese folklore, the oarfish is known as Ryūgū no tsukai, the "Messenger from the Sea God's Palace", believed to foretell earthquakes and tsunamis. While science finds no evidence linking these fish to seismic activity, it offers a more sobering interpretation.

Today, deep-sea creatures surfacing are best understood as climate sentinels, biological indicators of stress in the ocean's interior. Their appearance signals warming waters, oxygen loss, and a system pushed beyond its natural limits.

When life from the darkest depths rises into the light, it is not a mystery to fear, but a message to heed. The deep ocean, long hidden from human eyes, is telling us that it is changing—and faster than its inhabitants can adapt.

### 8. Conclusion

The unusual surfacing of deep-sea creatures is more than a curiosity, it is a wake-up call. Our oceans are under unprecedented stress from global warming, oxygen depletion, and human interference. Activities like deep-sea mining, which disturb fragile benthic habitats and release toxic sediments, threaten to accelerate the displacement of these uniquely adapted species (**Dowd et al., 2025** and **IUCN, 2025**). Protecting the deep sea is not just about preserving mysterious creatures like oarfish, dumbo octopus, or yeti crabs; it is about maintaining the delicate balance of marine ecosystems that sustain life on Earth. Sustainable practices, stricter regulation of extractive activities, and global conservation efforts are essential to ensure that the oceans' hidden realms remain intact, not just for the creatures that live there, but for the health and future of our planet.

### References

- Dowd, M., Goetze, E., & Drazen, J. (2025). Deep-sea mining discharge can disrupt midwater food webs. *Nature Communications*.
- Hauss, H., et al. (2023). Deep-sea mining and warming trigger stress in midwater jellies. *Nature Communications*.
- International Union for Conservation of Nature (IUCN). (2025). *The impact of deep-sea mining on biodiversity, climate, and human cultures*.
- Li, J. H., Yang, J., & Chen, G. (2025). Temporal and spatial influences of environmental factors on the distribution of mesopelagic organisms in the North Atlantic Ocean. *Biogeosciences*, 22, 5635–5650. <https://doi.org/10.5194/bg-22-5635-2025>
- National Oceanic and Atmospheric Administration (NOAA) Ocean Exploration. (2022). *Seafloor mapping*.
- Thibault, H., Ménard, F., Abitbol-Spangaro, J., Poggiale, J.-C., & Martini, S. (2025). Modeling the contribution of micronekton diel vertical migrations to carbon export in the mesopelagic zone. *Biogeosciences*, 22, 2181–2201. <https://doi.org/10.5194/bg-22-2181-2025>

## Durable Disease Resistance Strategies in Crop plants: Gene Deployment and Gene Pyramiding



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### Abstract

Plant diseases, driven by the ongoing battle between crops and pathogens, remain a major and evolving threat to crop production. Reliance on chemical control is highly unsustainable, highlighting the urgent need for environment-friendly and long-lasting solutions. Genetic resistance is a fundamental component of integrated disease management; however, resistance conferred by single genes is often short-lived due to the rapid adaptation of pathogen populations. To overcome this limitation, breeders have adopted two key strategies, namely gene deployment and gene pyramiding, to enhance and sustain crop resistance. Gene deployment involves the spatial and temporal arrangement of resistance genes to reduce selection pressure on pathogen populations, whereas gene pyramiding focuses on combining multiple resistance genes within a single genotype to achieve broad-spectrum and durable resistance. Pyramided lines carrying stacked resistance genes have proven valuable in genetic improvement programs and have supported the development of profitable, multi-disease resistant varieties. Advances in molecular markers and genomic tools, such as marker-assisted backcrossing (MABC), have further facilitated the development of durable resistance. The integration of these genetic strategies offers strong potential for safeguarding crop health and productivity.

### Introduction:

Crop production is essential for feeding the rapidly increasing global population and supporting economies across the world. Crop improvement has played a major role in strengthening global food security; however, it has also led to unintended problems such as genetic erosion and increased genetic vulnerability of modern cultivars. Today, crops form the backbone of global food security, feeding billions of people worldwide. With the combined challenges of population growth, climate change, and shrinking arable land, improving crop productivity has become more urgent than ever. Despite significant advances in breeding, modern crop production faces several serious threats. The use of genetically uniform cultivars has increased their vulnerability to diseases and other biotic and abiotic stresses. Plant pathogens evolve rapidly and can easily overcome resistance bred into crop varieties, making disease management increasingly difficult. In addition, heavy reliance on chemical pesticides poses risks to the environment, human health, and long-term agricultural sustainability.

Genetic vulnerability in crops mainly arises from a narrow genetic base, large-scale cultivation of single cultivars, and the introduction of desirable traits that sometimes induce susceptibility to diseases. Genetic resistance, which refers to the inherited ability of plants to reduce or prevent disease damage, remains one of the most effective approaches to crop protection. It is, therefore, preferred due to its cost-effectiveness and ecological safety. Genetic resistance can be of two types: Vertical resistance (race-specific) and Horizontal resistance (broad-spectrum).

**Durable Resistance:** Even resistant varieties may become susceptible to newly emerging or previously unrecognized pathogen strains, leading to the failure of vertical resistance. Thus, there is a need for durable resistance that remains effective in a cultivar over a relatively large zone and for a relatively prolonged duration, under favorable environment (Adugna, 2004).

### Mechanisms for Durable Resistance:

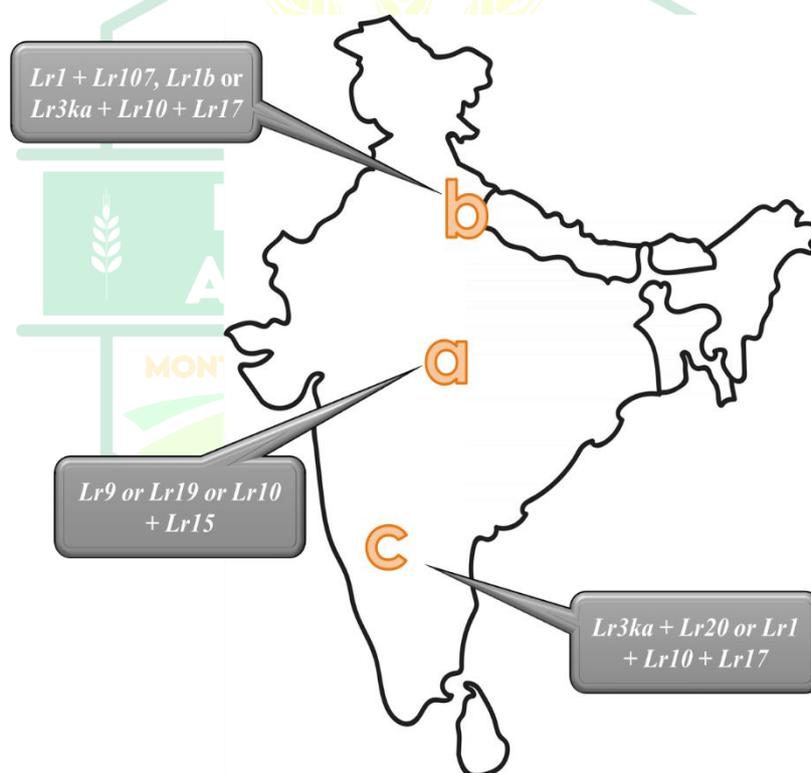
Resistance controlled by single major genes often does not provide long-term disease control. When the same major resistance gene is used over large areas, it can lead to the development of severe disease epidemics (Gnanamanickam *et al.*, 1999). To achieve durable resistance, several strategies can be adopted. These include

transfer of resistance (R) genes, use of already known durable resistance, pyramiding of major genes to create multiple barriers, combining different major resistance genes, using partial or polygenic resistance, and applying biotechnological tools to improve resistance durability. According to Parlevliet (1993), when non-durable major genes are used together, it becomes more difficult for pathogens to develop races with a wide range of virulence. Such genes can be used in two main ways: through gene deployment or through gene pyramiding.

### 1. Understanding Gene Deployment:

Gene Deployment refers to the planned distribution of resistance genes in space and time to manage disease effectively. Gould (1983) classified gene deployment into spatial and temporal approaches.

**i. Spatial Gene Deployment:** It involves the planned geographical use of different resistance genes in varietal development and cultivation. In India, this approach has been successfully used to manage all three wheat rusts by disrupting the “*Puccinia* path” (Tomar *et al.*, 2014). At the field level, spatial gene deployment involves using different resistance genes within a small area, such as a single field. Growing heterogeneous plant populations, like variety mixtures, species mixtures, or multiline, can slow disease spread and reduce selection pressure on the pathogen. While at the regional level, deploying different resistance genes in different areas includes the creation of gene zones, where specific resistance genes are grown in defined regions. This approach helps delay the development of complex pathogen races. Reddy and Rao (1981) proposed dividing India into 3 gene zones, viz. a) Central plains, b) North Himalayan region and, c) Southern Nilgiri and Palani hills, to manage wheat leaf rust (*Puccinia recondita*) effectively (Fig 1).



**Figure 6: Gene zones to control leaf rust of wheat (Reddy & Rao, 1981)**

**ii) Temporal gene deployment:** It involves the stepwise release of resistant varieties, where each variety is cultivated only until its resistance breaks down, after which it is promptly replaced with another variety carrying a different resistance gene. This approach has been successfully used at IRRI to manage resistance against brown planthopper (*Nilaparvata lugens*). Another method is rotating varieties from one season to the next, or recycling resistance genes, which helps in limiting the spread of soil-borne pathogens.

## 2. Gene pyramiding/Gene stacking:

Gene pyramiding is a plant breeding strategy that includes incorporation of two or more major genes into a single variety to enhance traits such as durable disease resistance, stress tolerance, or improved yield.

### Approaches for Gene Pyramiding:

**1. Conventional technique:** This approach utilizes sequential gene pyramiding within a single plant using natural breeding processes. Conventional crop breeding involves traditional and relatively obsolete techniques compared to modern and advanced technologies, yet it remains effective and widely used. It can be applied to develop a diverse range of elite cultivars exhibiting resistance to multiple abiotic stresses and diseases. In contemporary conventional breeding, backcrossing, recurrent selection, and pedigree selection have emerged as the principal techniques. Backcross breeding involves repeated crossing of a donor genotype with a popular cultivar to transfer a specific target gene. The primary objective is to reduce the genetic background of the donor parent while achieving efficient incorporation of the desired trait into the recipient parent. Pedigree breeding is used when resistance is governed by polygenes or minor genes in self-pollinated species and involves careful selection of superior genotypes from segregating generations. For example, the rice genotype IET-14726, showing multiple resistance to bacterial leaf blight and blast, was used to develop the rice variety GAR-13 (GR-11 × IET-14726) in 2009, which is resistant to major rice diseases and grown in large parts of Gujarat (Anonymous 2023). Recurrent selection is employed to accumulate beneficial alleles through intermating of selected lines while maintaining genetic variability. This method relies on environment-dependent phenotypic selection, thereby extending each selection cycle to 2–3 crop seasons. Disease resistance in progenies is generally evaluated through artificial inoculation with the pathogen. Overall, conventional breeding requires lower input costs compared to molecular techniques, needs minimal infrastructure, and can be easily conducted under the supervision of breeders or scientists (Thorat *et al.*, 2024).

### Need for Molecular techniques:

Molecular techniques are increasingly required in crop improvement because phenotypic evaluation alone is often time-consuming, influenced by environmental factors, and ineffective for traits showing linkage drag or recessive inheritance. DNA markers closely linked to target loci provide an additional and reliable option to support phenotypic screening. The use of molecular tools facilitates the fast and economical stacking of resistance genes, especially when multiple genes need to be combined in a single genotype. These techniques reduce the requirement for large field areas and lower the costs associated with maintaining germplasm and agronomic inputs during field trials. Moreover, molecular approaches help ensure that resistance incorporated into host plants is stable and durable, thereby strengthening long-term disease management strategies.

**2. Molecular techniques:** In recent times, crop breeding has undergone significant advancements, and the introduction of modern molecular tools has made it possible to accomplish precision breeding in the shortest possible duration. This technique utilizes simultaneous gene pyramiding which includes introducing simultaneously inserting several genes into a single plant. Innovative molecular breeding technologies, particularly marker-assisted selection (MAS), and gene transformation, are utilized for transferring desirable genes

**A) Marker assisted selection:** An additional option to support phenotypic screening is to use DNA markers that are closely related to the target locus. Marker assisted selection shows great potential in achieving durable resistance against major diseases. For example, blast resistant genes (Pi2 and Pi9) were added to the elite rice variety “Improved Tapaswini” (Das *et al.*, 2018).

**B) Marker assisted Backcrossing (MABC):** The utilization of marker assisted backcrossing involves improving the desired trait in a recipient parent by transferring one or more desired genes from a donor parent through multiple rounds of backcrossing. By employing marker-assisted backcross breeding (MABB) in rice, the blast-resistant genes Pi46, and Pita were effectively introduced from the donor parent into HH179, resulting in the development of three near isogenic lines (NILs) R1791, R1792, and R1793 (Xiao *et al.*, 2016). The effectiveness of MABC for gene pyramiding depends upon:

- ✓ Distance between the closest markers and the target gene
- ✓ Number of target genes to be transferred

- ✓ Genetic base of the trait
- ✓ Number of individuals that can be analyzed
- ✓ Genetic background in which the target gene has to be transferred
- ✓ Type of molecular marker used (Malav *et al.*, 2016)

Gene pyramiding using marker-assisted backcrossing can be achieved through three different strategies:

- 1) **Stepwise gene transfer-** In this approach, the recurrent parent (RP1) is crossed with a donor parent (DP1) to generate an F<sub>1</sub> hybrid, which is subsequently backcrossed up to the third backcross generation (BC<sub>3</sub>) to obtain an improved recurrent parent (IRP1). This improved recurrent parent is then crossed with another donor parent (DP2) to pyramid additional genes. Although this strategy is less preferred because it is time-consuming, it allows highly precise gene pyramiding, as genes are transferred one at a time (Fig 2).
- 2) **Simultaneous gene transfer-** In this strategy, the recurrent parent (RP1) is crossed with multiple donor parents (DP1, DP2, etc.) to produce F<sub>1</sub> hybrids, which are then inter-crossed to generate an improved F<sub>1</sub> (IF<sub>1</sub>). The improved F<sub>1</sub> is subsequently backcrossed with the recurrent parent to obtain the improved recurrent parent (IRP). Here, gene pyramiding occurs during the pedigree stage itself. The main advantage of this strategy is that it is faster; however, when donor parents differ greatly, there is a higher risk of losing pyramided genes during the process (Fig 2).
- 3) **Stepwise and simultaneous gene transfer-** This strategy combines features of both stepwise and simultaneous gene transfer methods. It involves simultaneous crossing of the recurrent parent (RP1) with multiple donor parents, followed by backcrossing up to the BC<sub>3</sub> generation. The backcross populations carrying individual genes are then intercrossed to develop pyramided lines. This method is considered the most acceptable, as it reduces the overall time required and ensures effective fixation of the desired genes (Fig 2).

**Table 1: Examples of durable resistance through MABC gene pyramiding**

Crop	Genotype	Trait	Resistant genes	Reference
Rice	Swarna-Sub1	Blast	<i>Pi1 + Pi54</i> (Swarna LT) <i>Pi2</i> (Swarna-A51)	Patroti <i>et al.</i> , 2019
Wheat	HD2833	Stem rust, leaf rust and powdery mildew	<i>Sr2/Lr27/Yr30</i> , <i>Sr24/Lr24</i> and <i>Sr36/Pm6</i> (Cook)	Aravindh <i>et al.</i> , 2020
Rice	ASD 16 & ADT 43	Bacterial blight, Blast & Sheath blight	<i>xa5</i> , <i>xa13 + Xa21</i> (IRBB60), <i>Pi54</i> and <i>qSBR7-1</i> , <i>qSBR11-1</i> , <i>qSBR11-2</i> (Tetep)	Ramalingam <i>et al.</i> , 2020
Cauliflower	Pusa Meghna	Black rot & Downy mildew	<i>Xcalbo</i> (BR-161) and <i>Ppa3</i> (BR-2)	Saha <i>et al.</i> , 2021
Wheat	Improved PBW 343	Rust	<i>Lr37</i> , <i>Lr24</i> , <i>Lr28</i> , <i>Sr38</i> , <i>Yr17</i> (Thatcher), <i>Yr5</i> , <i>Yr10</i> , <i>Yr15</i> (Avocet) and <i>Yr70</i> , <i>Lr76</i> (WL711)	Sharma <i>et al.</i> , 2021
Tomato	VRT-20-4, VRT-20-9, VRT-20-17	Tomato leaf curl and late blight	<i>Ty-2 + Ty-3</i> (VRT4-20-18), <i>Ty-3</i> and large fruit size (VRT-78-2), <i>Ph-3</i> (LA4286), <i>Ph-2 + Ph-3</i> (LA3152)	Yerasu <i>et al.</i> , 2025

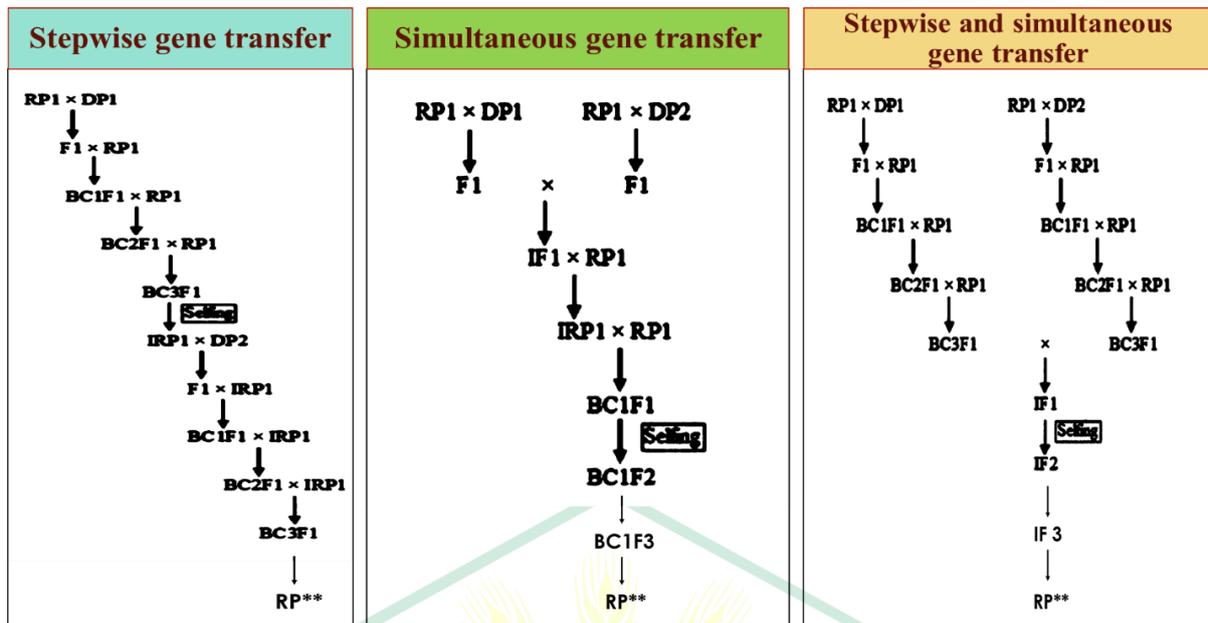


Figure 7: Strategies for gene transfer through Marker-assisted Backcrossing

#### References:

- Adugna, A. (2004). Alternate approaches in deploying genes for disease resistance in crop plants. *Asian J. Plant Sci*, 3, 618-623.
- Anonymous (2023). Annual research report year 2022–23. Main Rice Research Station, Anand Agricultural University, Nawagam, Kheda, Gujarat, India, 23–27.
- Das, G., Rao, G. J., Varier, M., Prakash, A., & Prasad, D. (2018). Improved Tapaswini having four BB resistance genes pyramided with six genes/QTLs, resistance/tolerance to biotic and abiotic stresses in rice. *Scientific reports*, 8(1), 2413.
- Xiao, W. M., Luo, L. X., Wang, H., Guo, T., Liu, Y. Z., Zhou, J. Y., Zhu, X. Y., Yang, Q. Y., & Chen, Z. Q. (2016). Pyramiding of Pi46 and Pita to improve blast resistance and to evaluate the resistance effect of the two R genes. *Journal of Integrative Agriculture*, 15(10), 2290–2298.
- Gnanamanickam, S. S., Priyadarisini, V. B., Narayanan, N. N., Vasudevan, P., & Kavitha, S. (1999). An overview of bacterial blight disease of rice and strategies for its management. *Current Science*, 1435-1444.
- Parlevliet, J. E. (1983). Models explaining the specificity and durability of host resistance derived from the observations on the barley-Puccinia hordei system. In *Durable resistance in crops*. Boston, MA: Springer New York, 57-80.
- Gould, F. (1983). Genetics of plant–herbivore systems: Interactions between applied and basic study. *Variable plants and herbivores in natural and managed systems*, 599-653.
- Thorat, S., Gangwar, R. K., & Sisodiya, D. (2024). Gene pyramiding an advanced approach for disease management in rice: A review. *Innovations in Agriculture*, 7, 1-12.
- Tomar, S. M. S., Singh, S. K., & Sivasamy, M. (2014). Wheat rusts in India: resistance breeding and gene deployment-a review. *The Indian Journal of Genetics and Plant Breeding*, 74(2).
- Reddy, M. S. S., & Rao, M. V. (1981). Resistance genes and their deployment for control of leaf rust of wheat.
- Malav, A. K., Indu, Chandrawat, K. S. (2016). Gene Pyramiding: An Overview. *International Journal of Current Research in Biosciences and Plant Biology*. 3. 22-28.
- Aravindh, R., Sivasamy, M., Ganesamurthy, K., Jayaprakash, P., Gopalakrishnan, C., Geetha, M., ... & Vikas, V. K. (2020). Marker assisted stacking/pyramiding of stem rust, leaf rust and powdery mildew disease resistance genes (Sr2/Lr27/Yr30, Sr24/Lr24 and Sr36/Pm6) for durable resistance in wheat (*Triticum aestivum* L.). *Electronic Journal of Plant Breeding*, 11(03), 907-915.

Saha, P., Ghoshal, C., Saha, N. D., Verma, A., Srivastava, M., Kalia, P., & Tomar, B. S. (2021). Marker-assisted pyramiding of downy mildew-resistant gene Ppa3 and black rot-resistant gene Xca1bo in popular early cauliflower variety pusa meghna. *Frontiers in Plant Science*, 12, 603600.

Patroti, P., Vishalakshi, B., Umakanth, B., Suresh, J., Senguttuvel, P., & Madhav, M. S. (2019). Marker-assisted pyramiding of major blast resistance genes in Swarna-Sub1, an elite rice variety (*Oryza sativa* L.). *Euphytica*, 215(11), 179.

Ramalingam, J., Raveendra, C., Savitha, P., Vidya, V., Chaithra, T. L., Velprabakaran, S., ... & Vanniarajan, C. (2020). Gene pyramiding for achieving enhanced resistance to bacterial blight, blast, and sheath blight diseases in rice. *Frontiers in plant science*, 11, 591457.

Sharma, A., Srivastava, P., Mavi, G. S., Kaur, S., Kaur, J., Bala, R., ... & Singh, G. P. (2021). Resurrection of wheat cultivar PBW343 using marker-assisted gene pyramiding for rust resistance. *Frontiers in plant science*, 12, 570408.

Yerasu, S. R., Prasanna, H. C., Krishnan, N., Maurya, S., Panwar, H. S., Reddy, S. K., ... & Behera, T. K. (2025). Marker assisted pyramiding of major resistance genes of tomato leaf curl and late blight diseases for stabilising tomato production. *Physiology and Molecular Biology of Plants*, 31(1), 105-118.



## Black Soldier Fly, *Hermetia illucens*: Nature's Recycling Powerhouse



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*Hermetia illucens*, known colloquially as the black soldier fly, is a widespread fly of the family [Stratiomyidae](#). In recent years, *H. illucens* has increasingly been gaining attention because of its hyperaccumulation of protein and fats via consumption of renewable substrates.

### Description

The adults of *H. illucens* measure about 16 millimetres long. These medium-sized flies have a predominantly black body, with metallic reflections ranging from blue to green on the thorax and sometimes with a reddish end of the abdomen. The second abdominal [tergite](#) has translucent areas, from which the Latin specific epithet derives. The head is wide, with very developed eyes. The antennae are about twice the length of the head. The legs are black with whitish tarsi. The wings are membranous; at rest, they are folded horizontally on the abdomen and overlapped. *H. illucens* is a mimic fly, very close in size, color, and appearance to the organ pipe mud dauber wasp and its relatives. The mimicry of this particular kind of wasp is especially enhanced by the fly's elongated and wasp-like antennae, pale hind tarsi, and the presence of two small, transparent "windows" in the basal abdominal segments that make the fly appear to have a narrow "wasp waist". Black soldier fly larvae can be differentiated from blowfly or housefly larvae by a thin gray-black stripe on their posterior ends.

### Lifecycle

An adult female lays approximately 200 to 600 eggs at a time. These eggs are typically deposited in crevices or on surfaces above or adjacent to decaying matter such as manure or compost and hatch in about 4 days. Freshly emerged larvae are 1.0 millimetre long, being able to reach a length of 25 millimetres and weight of 0.10 to 0.22 grams by the end of larval stage. The larvae are able to feed on a wide variety of organic matter, adapting to diets with different nutrient content. The larval stage lasts from 18 to 36 days, depending on the food substrate provided to the larvae, of which the post-feeding stage lasts around 7 days. The larval stage can be prolonged by months due to low temperature or lack of food. The pupal stage lasts from 1 to 2 weeks. Adults can live typically 47 to 73 days when provided with water and food, such as sugar in captivity or nectar in the wild or survive for about 8 to 10 days on fat reserves gathered during larval stage when water is provided.

### Human relevance and use

Neither larvae nor adults are considered to be agricultural pests or disease vectors. Black soldier fly larvae play a role similar to that of [redworms](#) as essential decomposers in breaking down organic substrates and returning nutrients to the soil. The larvae have voracious appetites and can be used for composting household food scraps and agricultural waste products. Additionally, black soldier fly larvae are an alternative source of protein for aquaculture, animal feed, and pet food. The larvae are produced and processed in industrial-scale insect factories globally by biotechnology companies such as LIVIN farms.

### As decomposers/in composting

Black soldier fly larvae (BSFL) are used to compost waste or convert the waste into animal feed. Waste streams include fresh manure and food wastes of both animal and vegetable origin. Fly larvae are among the most efficient animals at converting biomass into feed. When the larvae have completed their larval development through six instars, they enter a stage called the "prepupa" wherein they cease to eat, and tend to migrate toward cool, dark, and dry substrates to pupate. This prepupal migration instinct is used by grub composting bins to self-harvest the mature larvae. These containers have ramps or holes on the sides to allow the prepupae to climb out of the composter and drop into a collection area.

### **Black soldier fly larvae are beneficial for use as composters in the following ways:**

Their large size relative to houseflies and blowflies allows BSFL to prevent houseflies and blowflies from laying eggs in decaying matter by consuming larvae of other species. This means compost systems inhabited by BSFL may be a more human-friendly way to handle food waste when compared to those inhabited by houseflies and blowflies which typically produce a much worse smell. They are not a pest to humans. Unlike houseflies, adult black soldier flies have greatly reduced sponging mouthparts, meaning they can only consume liquids such as flower nectar, although they typically do not eat at all. Unlike houseflies, which regurgitate food along with digestive enzymes, adult black soldier flies therefore do not spread pathogens or diseases. They are not attracted to human habitation or foods. As a detritivore and coprovores, the egg-bearing females are only attracted to rotting food or manure.

Black soldier flies do not fly around as much as houseflies. They have less expendable energy due to their limited ability to consume food as adults. They are very easy to catch and relocate when they get inside a house, as they do not avoid being picked up, they are sanitary, and they neither bite nor sting. Their only defense seems to be hiding. When using a wet grub bin that collects or kills all the pupae, the black soldier fly population is easy to reduce by killing the pupae/prepupae in the collection container, before they become adult flies. They may be killed by freezing, drying, manually feeding to domestic animals, putting the collection container in a chicken coop for automatic feeding, or feeding to wild birds with a mouse/pest-proof feeder. and *Salmonella enterica* were measured in hen manure after larvae were added to the manure. They quickly reclaim would-be pollutants: Nine organic chemicals were greatly reduced or eliminated from manure in 24 hours, making them a potential tool for bioremediation. They quickly reduce the volume and weight of waste: larval colonies break apart their food, churn it, and create heat, increasing compost evaporation. Significant amounts of waste are also converted to carbon dioxide respired by the grubs and symbiotic/ mutualistic microorganisms. The use of BSFL in a compost system typically reduces the volume of compost by around 50%. Aside from protein production, fly larvae also produce frass. Fly larval frass is a granulated and odorless residue that can be used as organic fertilizer directly or through conversion by earthworms.

#### **As feed**

Black soldier fly larvae are used as feed for pets and livestock animals. The harvested pupae and prepupae are eaten by poultry, fish, pigs, lizards, turtles, and even dogs. The insect is one of the few insect species approved to be used as feed in aquaculture in the EU. At the pupal stage, black soldier flies are at their nutritional peak. They can be stored at room temperature for several weeks, and their longest shelf life is achieved at 10 to 16 °C (50 to 60 °F). The sector faces financial challenges. In January 2025, Agronutris entered a safeguard procedure to restructure its debts. Recent analyses indicate that the majority of investment in insect farming has been directed towards companies farming black soldier fly larvae (59% of disclosed investments). However, a significant proportion of these investments (around 36%) have gone to firms that have ceased operations or entered court-supervised restructuring. While investment growth was rapid prior to 2021, recent trends show a 65% decline between 2022 and 2024, reflecting a challenging investment environment.

#### **As human food**

Insect-breeding farm in which people can produce edible fly larvae at home. It is a multi-chambered plastic machine that looks like a kitchen appliance and can produce 500 grams of larvae or two meals in a week. The taste of the larvae is said to be very distinctive. According to Unger, "when you cook them, they smell a bit like cooked potatoes. The consistency is a bit harder on the outside and like soft meat on the inside. The taste is nutty and a bit meaty.

#### **For producing grease**

BSFL can be used to produce grease, which is usable in the pharmaceutical industry (e.g. in cosmetics, surfactants for shower gel), thereby replacing vegetable oils such as palm oil. It can also be used in fodder.

#### **For producing chitin**

BSFL can be used to produce chitin. Chitin is used in shipping as an agent against biofouling. It is also used in water purification. Chitin also has potential as a soil amendment, to improve soil fertility and plant resilience.

### For producing organic plant fertilizer

Material left over after the larval waste decomposition process consists of larval faeces, shed larval exoskeletons, and undigested material. Frass is one of the main products from commercial black soldier fly rearing. The chemical profile of the frass varies with the substrate on which the larvae feed, but in general, it is considered a versatile organic plant fertilizer due to a favorable ratio of three major plant nutrients: nitrogen, phosphorus, and potassium. BSFL frass is commonly applied by direct mixing with soil and considered a long-term fertilizer with slow nutrient release. Plant trials have also found short-term fertilizing effects comparable to fast-acting, synthetic fertilizers. In addition to its nutrient contribution, BSFL frass can carry further components that are beneficial for soil fertility and soil health, such as chitin from the shed exoskeletons of the larvae. Finally, the use of BSFL frass as a fertilizer can effectively alter the soil microbial community composition, which plays a crucial role for soil fertility.

### In bioremediation

Recent research in the field of entomoremediation shows the potential of this insect for purification of biomass contaminated with heavy metals. Larvae of *H. illucens* were used in a bioremediation experiment, in which they consumed up to 49% of dry weight corn leaves polluted with cadmium or zinc, for 36 days. Artificially polluted corn leaves were used as a model plant material comparable to plant biomass polluted as a result of phytoextraction. The 49% loss of polluted dry weight material is a better result than in the case of composting alone, which is one of the standard proposed pretreatments for biomass polluted after phytoextraction. The type of heavy metal did not affect the degree of consumption in this experiment. Cadmium mostly accumulates in the puparium, while zinc accumulates in the adult fly.

### References

- Biteau, Corentin; Bry-Chevalier, Tom; Crummett, Dustin; Ryba, Ren; Jules, Michael St. "[Insect-based livestock feeds are unlikely to become economically viable in the near future](#)". *Food and Humanity*. 3 100383. ISSN 2949-8244.
- Bijvoet, Jop. [Creating the Triple Bottom Line in the Insect Rearing Industry: Current and Future Perspective](#).
- Lymbery, Philip. "[Insect Farming Isn't Going to Save the Planet](#)". *Time*. Retrieved 2024-06-07.
- Capinera, John L. (2004). *Encyclopedia of Entomology*. [Kluwer Academic Publishers](#). ISBN 978-0-7923-8670-4.
- Yi, Liya; Lakemond, Catriona M.M.; Sagis, Leonard M.C.; Eisner-Schadler, Verena; Van Huis, Arnold; Van Boekel, Martinus A.J.S. (2013). Extraction and characterisation of protein fractions from five insect species". *Food Chemistry*. 141 (4): 3341–3348.

## “Optimizing Litchi (*Litchi chinensis* Sonn.) Growth, Yield, and Quality through Plant Growth Regulators”



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### Abstract

Litchi (*Litchi chinensis* Sonn.) productivity is often limited by irregular flowering, heavy fruit drop, fruit cracking, and alternate bearing. Plant growth regulators (PGRs) such as auxins, gibberellins, cytokinins, and growth retardants play a pivotal role in regulating vegetative growth, enhancing floral induction, improving fruit retention, increasing fruit size, and extending shelf life. When integrated with proper orchard management, the use of PGRs offers a sustainable strategy to enhance yield, fruit quality, and profitability in litchi cultivation under changing climatic conditions.

### 1. Introduction

Litchi is a high-value subtropical fruit prized for its attractive red pericarp, juicy aril, pleasant flavor, and rich nutritional content. India ranks as the second-largest producer of litchi, with major cultivation concentrated in Bihar, Uttar Pradesh, West Bengal, Jharkhand, Uttarakhand, and the North-Eastern states. Despite its economic importance, litchi productivity is often constrained by irregular flowering, heavy fruit drop, alternate bearing, fruit cracking, small fruit size, and short shelf life (Kumar *et al.*, 2020; Singh & Nath, 2021). Recent studies highlight that plant growth regulators can overcome these limitations by optimizing vegetative growth, flowering, fruit set, and fruit development. Auxins, gibberellins, cytokinins, and growth retardants have been shown to significantly enhance yield, improve fruit retention, and elevate fruit quality, making them indispensable tools in sustainable litchi production (Ghosh *et al.*, 2019; Sharma *et al.*, 2022; Yadav *et al.*, 2023).

### 2. Plant Growth Regulators and their Significance

PGRs are organic compounds, either natural or synthetic, that regulate essential physiological processes, including cell division, elongation, flowering, fruit development, and senescence. In litchi, these regulators maintain a balance between vegetative and reproductive growth, overcoming physiological disorders such as irregular flowering, excessive fruit drop, and poor fruit quality. Auxins (NAA, 2,4-D) help reduce fruit drop, gibberellins (GA<sub>3</sub>) enhance fruit set and size, cytokinins (CPPU, BA) promote cell division and aril development, and growth retardants such as paclobutrazol and CCC control excessive vegetative growth while improving flowering intensity. Ethylene regulators like ethephon regulate flushing and flowering behavior, making PGRs highly effective for improving orchard performance (Sharma *et al.*, 2021; Patel *et al.*, 2022; Meena *et al.*, 2023; Tripathi & Singh, 2024).



Figure 1. Plant Growth Regulators and Their Significance

### 3. Regulating Vegetative Growth

Vegetative growth is a key factor influencing flowering, as flowers develop on mature shoots. Excessive vegetative growth during floral induction can suppress flower bud differentiation, reducing fruit yield. Growth retardants like paclobutrazol and CCC inhibit gibberellin biosynthesis, suppressing shoot elongation, leading to a compact canopy and increased carbohydrate accumulation, which favors floral induction (Singh *et al.*, 2023; Reddy & Sharma, 2024).

### 4. Paclobutrazol for Shoot Management

Paclobutrazol (PBZ) is widely used to control vegetative vigor in litchi. Soil application at 3-5 g a.i. per tree manages excessive shoot growth, promotes a compact canopy structure, improves light penetration, and enhances flowering intensity. These effects are particularly beneficial in high-density orchards. PBZ helps maintain an optimal balance between vegetative and reproductive growth, thereby improving flowering and overall productivity (Choudhary *et al.*, 2021; Mishra & Yadav, 2022; Saxena *et al.*, 2023; Das *et al.*, 2024).

### 5. Enhancing Floral Induction

Flowering in litchi is influenced by temperature, shoot maturity, and hormonal balance. Excessive vegetative growth during floral induction suppresses flower bud differentiation. The use of PGRs, integrated with pruning and irrigation, significantly improves flowering uniformity and intensity. Paclobutrazol indirectly promotes flowering by increasing the carbon-to-nitrogen ratio and carbohydrate accumulation, while ethephon suppresses late vegetative flushes, redirecting assimilates toward reproductive development (Kumari *et al.*, 2022; Ranjan & Singh, 2023).

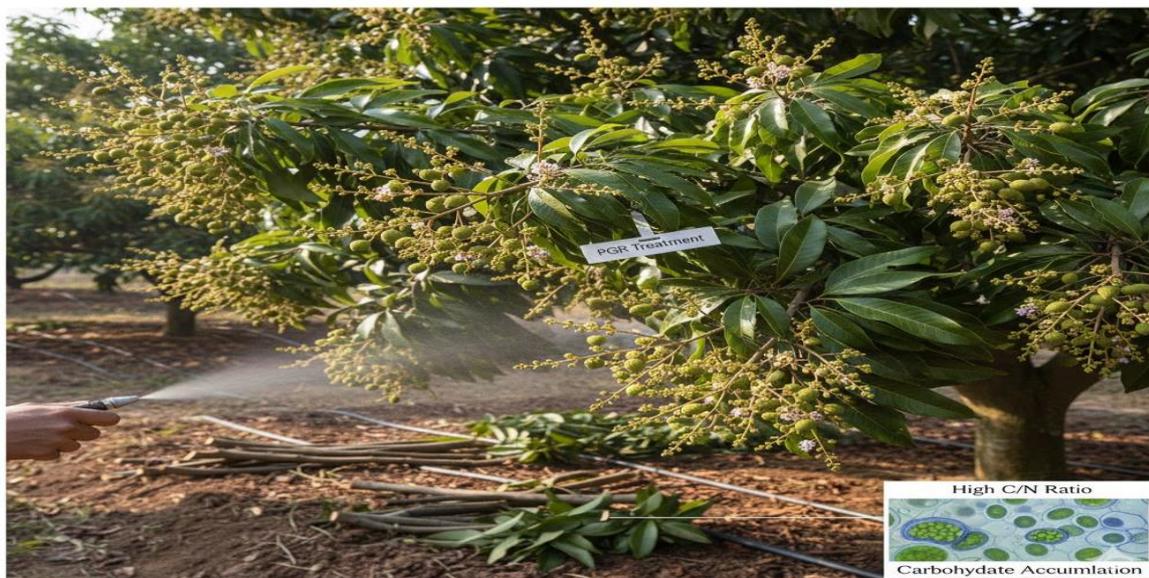


Figure 2. Enhancing Floral Induction

### 6. Reducing Fruit Drop and Improving Fruit Set

Heavy fruit drop, occurring from post-pollination to early fruit development, is often caused by hormonal imbalance and nutrient competition. The combined application of auxins and gibberellins provides a synergistic effect that enhances fruit retention and yield. NAA (20-40 ppm) strengthens the abscission zone, improving retention, while GA<sub>3</sub> (20-30 ppm) enhances fruit set, reduces embryo abortion, and promotes uniform fruit development (Kumar *et al.*, 2022; Patel & Singh, 2023).

### 7. Increasing Fruit Size and Yield

Small fruits are a common concern under stress conditions. Application of PGRs optimizes assimilate allocation, resulting in uniform fruits, a higher harvest index, and improved marketable quality. Cytokinins (CPPU 5-10 ppm) stimulate cell division, increasing both fruit and aril size, while GA<sub>3</sub> further contributes to fruit enlargement and retention (Sharma *et al.*, 2021; Meena *et al.*, 2023).

## 8. Controlling Fruit Cracking

Fruit cracking reduces both market value and shelf life, often due to temperature fluctuations and irregular soil moisture. GA<sub>3</sub> (20-40 ppm) strengthens pericarp elasticity, NAA maintains hormonal balance, and cytokinins improve pericarp thickness and aril development. When combined with proper irrigation and mulching, these regulators effectively reduce fruit cracking incidents (Verma & Ranjan, 2022; Choudhary et al., 2023).

## 9. Improving Fruit Quality and Shelf Life

Marketable traits such as fruit size, color, sweetness, and shelf life are enhanced by PGRs. GA<sub>3</sub> increases total soluble solids, improves aril recovery, and delays senescence, while cytokinins enhance firmness and reduce post-harvest weight loss. Pre-harvest application of PGRs slows pericarp browning, maintaining fruit quality for both domestic and export markets (Tripathi & Singh, 2022; Yadav et al., 2023).

## 10. Mitigating Alternate Bearing

Alternate bearing limits orchard productivity. Paclobutrazol helps control vegetative growth during “off” years, while GA<sub>3</sub> and NAA improve fruit retention in “on” years. Balanced PGR application stabilizes flowering and yield across seasons, mitigating alternate bearing and improving orchard profitability (Rao & Kumar, 2021; Mehta & Sharma, 2023).

## 11. Practical Guidelines for Farmers

Farmers should adhere to recommended doses, timing, and application methods to avoid phytotoxicity. Uniform canopy sprays ensure maximum coverage. Combining PGR use with pruning, irrigation, and fertilization practices produces optimal results. Unverified combinations of growth regulators should be avoided.

**Table 1: Key PGRs for Litchi Cultivation**

PGR	Dose	Application Stage	Effect on Litchi
NAA	20-40 ppm	Pea stage	Reduces fruit drop, improves retention
GA <sub>3</sub>	20-30 ppm	Early fruiting	Increases fruit set, size, and retention
CPPU	5-10 ppm	Early fruit development	Enhances aril growth and fruit size
Paclobutrazol	3-5 g a.i./tree	Pre-flowering	Controls vegetative growth, promotes flowering
Ethephon	200-400 ppm	Pre-flowering	Suppresses late vegetative flushes, enhances floral induction

## 12. Future Prospects and Research Needs

Future research should focus on developing region-specific PGR recommendations, integrating PGRs with organic or bio-regulators to reduce chemical load, and improving export-quality traits such as fruit size, color, and shelf life. Judicious use of PGRs can substantially improve productivity, fruit quality, and sustainable orchard management (Kumar et al., 2023; Ranjan & Singh, 2024).

### Conclusion

Plant growth regulators are essential for enhancing litchi growth, flowering, fruit set, yield, and quality. Integration of auxins, gibberellins, cytokinins, and growth retardants with proper orchard management ensures balanced vegetative and reproductive growth, stabilizes yield, mitigates alternate bearing, and enhances marketability. Science-based, judicious use of PGRs offers a sustainable and profitable strategy for litchi cultivation under changing climatic conditions.

### References

- Chandra, A. & Nath, P. (2021). Influence of vegetative growth on flowering performance in *Litchi chinensis*. *Journal of Subtropical Horticulture*, 18(2), 45-52.
- Choudhary, R., Verma, L., & Gupta, S. (2021). Effect of paclobutrazol on vegetative vigor and flowering in litchi orchards. *Indian Journal of Horticultural Research*, 26(1), 12-19.
- Das, M., Singh, R., & Kumar, V. (2024). Growth retardants for improved orchard performance in subtropical fruit crops. *Horticulture Science Today*, 12(1), 78-85.
- Ghosh, D., Roy, S., & Banerjee, M. (2019). Plant growth regulators in tropical and subtropical fruit crops: A review. *Fruit Grower Journal*, 11(4), 112-128.

5. Jha, S., Mehta, P., & Singh, D. (2022). Physiological effects of paclobutrazol on shoot development and carbohydrate partitioning in litchi. *Journal of Horticulture and Forestry*, 14(6), 55-62.
6. Kumari, R., Singh, A., & Pandey, P. (2022). Role of ethephon and growth regulators in floral induction of litchi. *Advances in Fruit Science*, 8(3), 33-40.
7. Kumar, N., Singh, H., & Joshi, R. (2020). Production constraints and management strategies for litchi cultivation in India. *International Journal of Fruit Sciences*, 20(5), 257-270.
8. Kumar, P., Tiwari, S., & Yadav, L. (2023). Prospects of plant growth regulator use in subtropical horticulture. *Horticultural Advances*, 5(2), 101-110.
9. Meena, K., Rao, A., & Singh, T. (2023). Cytokinin and gibberellin effects on fruit development and quality in litchi. *Journal of Plant Growth Regulation*, 42(1), 122-131.
10. Mishra, R. & Yadav, S. (2022). Responses of litchi trees to paclobutrazol application under semi-arid conditions. *Fruit Research Journal*, 30(2), 65-72.
11. Patel, V. & Singh, K. (2023). Auxin and gibberellin interactions for fruit retention in litchi. *Horticulture Practice*, 15(4), 88-95.
12. Ranjan, S. & Singh, P. (2023). Integrated regulation of flowering and reproductive growth in litchi using growth regulators. *International Journal of Horticultural Science*, 29(3), 47-55.
13. Rao, S. & Kumar, D. (2021). Managing alternate bearing in litchi through growth regulators. *Journal of Fruit Production*, 17(1), 29-36.
14. Reddy, M. & Sharma, N. (2024). Vegetative suppression and flowering enhancement in litchi with growth retardants. *Horticultural Review*, 9(1), 14-22.
15. Saxena, L., Gupta, A., & Mehta, H. (2023). Growth retardants for shoot regulation in high-density litchi orchards. *Journal of Tropical Fruit Crops*, 13(2), 99-107.
16. Sharma, R., Singh, A., & Kumar, S. (2021). Role of plant growth regulators in fruit set and quality improvement in subtropical fruits. *Fruit Science and Technology*, 19(4), 155-164.
17. Sharma, S., Yadav, B., & Roy, D. (2022). Growth regulators and crop productivity in litchi: An overview. *Journal of Horticultural Research*, 28(2), 203-215.
18. Singh, J. & Nath, V. (2021). Horticultural status and production challenges of litchi in India. *Indian Journal of Agricultural Sciences*, 91(6), 789-797.
19. Singh, M., Raut, P., & Das, B. (2022). Practical guidelines for use of plant growth regulators in fruit crops. *Extension Horticulture*, 7(3), 60-68.
20. Singh, R., Verma, A., & Kumar, P. (2023). Effect of vegetative management on flowering and yield in litchi. *Journal of Subtropical Horticultural Systems*, 15(1), 21-30.
21. Tripathi, V. & Singh, U. (2022). Use of gibberellins for quality enhancement in litchi fruits. *Fruit Quality International*, 8(2), 44-50.
22. Verma, H. & Chauhan, S. (2023). Integrated orchard practices for optimizing plant growth regulator efficiency in fruit crops. *Horticultural Extension Review*, 11(1), 12-20.
23. Verma, N. & Ranjan, K. (2022). Growth regulator application and fruit cracking control in litchi. *Journal of Fruit Disorders*, 6(2), 70-78.
24. Yadav, T., Mehta, V., & Singh, R. (2023). Recent advances in litchi quality improvement using plant growth regulators. *Journal of Horticultural Improvement*, 21(3), 88-99.

## Atmanirbharata in Pulses: Towards Strengthening India's Food and Nutritional Security



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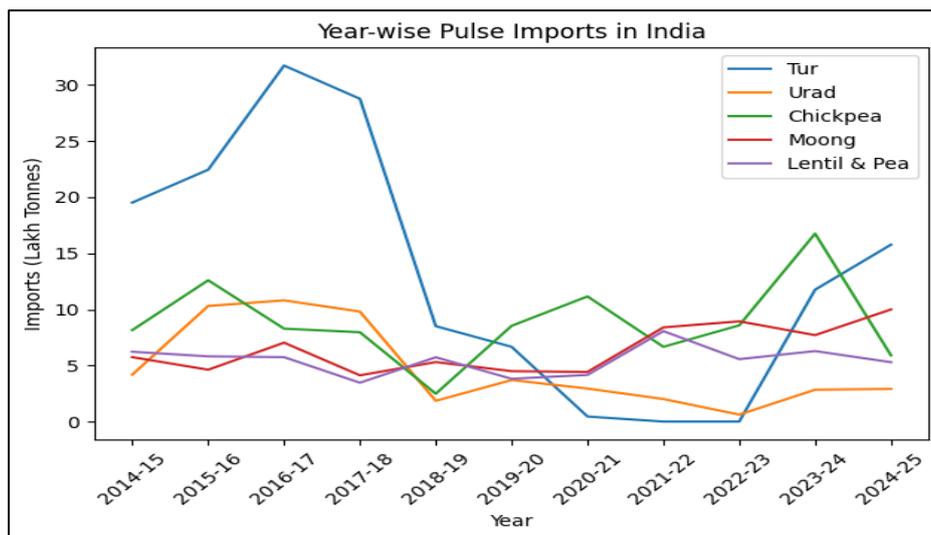
### Introduction:

Pulses are a keystone of India's nutritional security, soil health and rural livelihoods. They are often referred to as the "poor man's meat" because of their high protein content and affordability. In addition to proteins, pulses provide essential minerals, vitamins and dietary fiber, making them a vital component of the vegetarian diet. Pulses play a pivotal role in maintaining soil health and the sustainability of farming systems. Agronomically, they enrich the soil by fixing atmospheric nitrogen and are well suited for crop rotation and intercropping systems.

India, with its vast agro-climatic diversity, grows a wide range of pulse crops such as chickpea, pigeon pea, greengram, blackgram, lentil, field pea, cowpea and horse gram. Pulse cultivation generates rural employment and entrepreneurial opportunities, particularly for women and youth, while their wide genetic diversity supports the development of climate-resilient varieties. Integration of pulses into agroforestry systems improves food security and farmers' income, and their crop residues serve as nutritious livestock feed. Additionally, pulses have a low carbon footprint and minimal water requirement, making them an environmentally sustainable source of protein.

### Status of Pulse Production in India and its economic implications

India is the largest producer and consumer of pulses in the world. Pulses are cultivated across different seasons *kharif*, *rabi* and summer under diverse production systems. Most pulse crops are grown under rainfed conditions, often on marginal and sub-marginal lands with limited inputs. They are commonly intercropped with cereals such as sorghum, pearl millet, maize, cotton and oilseeds, thereby enhancing overall farm productivity. India's annual pulse production is around 290–300 lakh tonnes, which places the country at the top globally. Over the years, concerted efforts by researchers, extension agencies and farmers have helped increase productivity, particularly in crops like chickpea and mungbean. However, production remains unstable due to climatic variability, pest and disease pressure and price fluctuations. Although India produces large quantities of pulses, domestic demand often exceeds supply. As a result, the country continues to depend on imports, especially for pigeon pea, blackgram and lentil. During 2022–23, pulse imports declined sharply to about 24 lakh tonnes, mainly due to improved domestic production. However, unfavourable weather conditions in subsequent seasons led to reduced output, resulting in a sharp rise in imports during 2023–24, which reached 47.38 lakh tonnes. Between April and November 2024 alone, pulse imports were valued at approximately 3.28 billion US dollars. In the current agricultural year (2024–25), imports have already crossed 40 lakh tonnes, with pigeon pea accounting for nearly 10 lakh tonnes. If this trend continues, India's pulse import bill may reach 5.9 billion US dollars, compared to 4.24 billion US dollars in 2016–17. Such high levels of imports lead to increased foreign exchange outflow, widening of the trade deficit and vulnerability to global market fluctuations. Dependence on imports also poses a risk to food security during international supply disruptions.



Source: Department of Commerce

India's continued reliance on pulse imports is driven by multiple factors, including erratic rainfall and climate change that adversely affect pulse yields, price instability that discourages farmers from expanding pulse cultivation and liberal import policies that depress domestic market prices. In addition, farmers often prefer more profitable commercial crops over pulses, while India remains dependent on major exporting countries such as Mozambique, Tanzania, Myanmar, Canada, Australia and Turkey to bridge the demand–supply gap.

#### Mission on *Atmanirbharata* in Pulses

With the aim of achieving self-reliance in pulses, increasing production, reducing import dependency and enhancing farmers' income, the Government of India introduced a six-year Mission on *Atmanirbharata* in Pulses in the FY 2025–26 Budget with an outlay of 11,440 crores.



Source: Ministry of Agriculture and farmers welfare

Prime Minister Shri Narendra Modi has set the ambitious goal of making India fully self-reliant in pulses by December 2027, with particular focus on Tur (Arhar), Urad (Blackgram) and Masoor (Lentil). The new mission strengthens this vision by aiming to meet India's future pulses demand entirely through domestic production. The Mission is aligned with Vision 2047, emphasizing sustainable growth, diversified cropping patterns and the empowerment of farmers through assured income, adoption of advanced technologies and climate-resilient agricultural practices. The Mission plans to expand the area under pulses cultivation by an additional 35 lakh hectares, targeting rice fallows and other suitable lands, while promoting intercropping and crop diversification. A key focus will be the development and dissemination of high-yielding, pest-resistant and climate-resilient pulses varieties, supported by a robust seed system. This includes the production and distribution of 126 lakh quintals of certified seeds and the free provision of 88 lakh seed kits to farmers.

#### Operational Strategy

- ✓ States will prepare rolling five-year seed production plans, with breeder seed production monitored by ICAR and seed quality ensured through the SATHI portal (seedtrace.gov.in).

- ✓ The Mission follows a holistic approach, integrating soil health management, mechanization, balanced fertilizer use, plant protection, and large-scale field demonstrations.
- ✓ ICAR institutes, Krishi Vigyan Kendras (KVKs) and State Agricultural Departments will play a key role in technology dissemination and farmer capacity building.
- ✓ To strengthen the post-harvest value chain, the mission proposes establishing 1,000 processing and packaging units, supported by subsidies up to ₹25 lakh per unit.
- ✓ These interventions aim to reduce post-harvest losses, enhance value addition, and generate rural employment, particularly in pulse-growing regions.
- ✓ A cluster-based approach, as recommended by NITI Aayog, will be adopted to ensure efficient resource utilization and geographic diversification of pulse cultivation.
- ✓ By 2030–31, the mission targets expanding pulse cultivation to 310 lakh hectares, increasing production to 350 lakh tonnes and raising productivity to 1,130 kg per hectare.
- ✓ The Mission also seeks to reduce import dependence, conserve foreign exchange and promote climate-resilient and soil-friendly farming practices.

#### **Budget Allocation and Implementation Strategy**

An allocation of ₹1000 crore has been earmarked for the mission over a six-year period. National agencies such as:

- National Agricultural Cooperative Marketing Federation of India (NAFED)
- National Cooperative Consumers' Federation of India (NCCF)

have been entrusted with MSP-based procurement and market intervention. These agencies will ensure fair prices for farmers and steady availability of pulses to consumers.

#### **Expected Benefits of the Mission**

The *Atmanirbharata* in Pulses Mission is expected to:

- Benefit nearly 1.7 crore farmers directly
- Promote adoption of improved varieties and technologies
- Strengthen research and seed production systems
- Expand pulse cultivation into non-traditional areas
- Enhance farmer income and livelihood security

#### **Conclusion**

The Mission on *Atmanirbharta* in Pulses marks a major milestone in India's pursuit of nutritional and economic security. By emphasizing self-reliance, the Mission empowers farmers through access to quality seeds, modern technologies, assured procurement and capacity building, while encouraging sustainable and climate-resilient farming practices. The integration of scientific innovation, cluster-based interventions and strengthened post harvest and value-chain infrastructure is expected to enhance productivity, stabilize prices, reduce import dependence and significantly improve farmers' income. Beyond boosting production, the mission has far-reaching impacts on nutrition, soil health and rural livelihoods. By promoting pulses in nutrition programs, improving processing and packaging infrastructure and generating employment opportunities, it supports inclusive rural development and environmental sustainability. Overall, the Mission lays a strong foundation for a self-reliant, resilient and productive pulses sector, contributing to farmer prosperity, consumer well-being, and the broader vision of a *Viksit Bharat*.

#### **References:**

- Sitharaman, N. (2025). Budget Speech 2025–26, Government of India.
- NITI Aayog. (2025). Strategies and pathways for accelerating growth in pulses towards the goal of *Atmanirbharta*, Government of India.
- Press Information Bureau. (2025). India's Mission for *Aatmanirbharta* in Pulses, Government of India.

## “Nano Urea: A Sustainable Approach for Enhancing Nitrogen Use Efficiency in Agriculture”



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### Abstract

Excessive use of conventional urea reduces nitrogen use efficiency and degrades soil health. Nano urea, a nano-technology-based liquid fertilizer, offers higher nitrogen use efficiency (80–90%) with minimal losses through foliar application. Combined use of nano urea with recommended fertilizer doses improves yield, nutrient uptake and profitability of crops. By minimizing fertilizer input and environmental losses, nano urea contributes to long-term agricultural sustainability.

### Introduction

The excessive use of chemical fertilizer increases agriculture production cost while also degrading soil health. With increased fertilizer consumption, yield does not enhance, resulting in the decreased nutrient utilization efficiency (NUE) and food grain production.

Nano technology has made a real revolution in the agriculture. The use of nano-fertilizers has led to the increased productivity, reduced production costs and also has led to the increased production stability due to reduction of biotic and abiotic stresses. Nano urea (water soluble) use by farmers will boost balanced nutrition program by reducing the excess use of urea application in the soil and will make the crops stronger, healthier and protect them from lodging effect.

### What is Nitrogen Use Efficiency?

- ❖ The output of any crop per unit of nitrogen applied under particular soil and climate conditions is known as N utilization efficiency.
- ❖ NUE can be calculated by dividing the total amount of nutrients accessible to the crop by the grain yield.
- ❖ It is a practical indicator for monitoring and evaluating appropriate fertilizer application.

### Challenges facing Indian agriculture:

- ✓ Inappropriate use of fertilizer.
- ✓ Soil health degradation
- ✓ Poor growth in food grain productivity.
- ✓ Emerging multi-nutrient deficiencies.

### Nano fertilizers:

Nano fertilizers have a large surface area and have the ability to retain an abundant amount of nutrients and release them slowly and stably for a relatively longer time so as to facilitate the nutrient absorption that corresponds to the crop requirement without any shortcomings associated with specialized fertilizer inputs (Chinnappa *et al.*, 2023).



Parameters	Conventional Urea	Nano Urea
Size	9,000-30,000 nm	20 – 50 nm
Form	Granules/Prills	Liquid
N use efficiency	25 – 50 %	80 – 90 %
Application	Soil application	Foliar spray
N losses	High	Low
Impact	Environmental pollution risk	Sustainable, Reduced agro-chemical use
Requirement of product	Large	80-100 times less than that of chemical fertilizer
Stress tolerant	No effect	Ten times more stress tolerant than the chemical fertilizer
Cost	Subsidized by the government	No subsidy from the government, still 2-4 times less costly than the chemical fertilizer
Soil health	No improvement or adverse impact	Sustain the soil health with the recommended dose of Nano-fertilizer

### Conclusions:

Nano Urea is a nanotechnology based revolutionized Agri input which provides nitrogen to the plants that reduces the burden on usage of conventional chemical fertilizers which are the major causes of deteriorating the soil health. In maize, under 100% RDN + 4000 ppm (4 ml/L) spray of nano urea recorded highest kernel yield. In rice, 100% N (Urea) + 2 foliar sprays of nano urea @ 4 ml/L resulted in the highest N uptake by grain and straw. In maize, higher B:C ratio obtained with application of 50% N, 100% PK + 2 sprays of IFFCO nano urea @ 4 ml/L mixed with IFFCO Sagarika @ 2 ml/L.

### References:

- Ajithkumar, K.; Kumar, Y.; Savitha, A. S.; Ajayakumar, M. Y.; Narayanaswamy, C.; Ramesh, R.; Krupashankar, M. R. and Bhat, S. N. (2021). Effect of IFFCO nanofertilizer on growth, grain yield and managing Turcicum leaf blight disease in maize. *International Journal of Plant and Soil Sciences*, **33**(16):19-28.
- Chinnappa, S. A.; Krishnamurthy, D.; Ajayakumar, M. Y.; Ramesha, Y. M., and Ravi, S. (2023). Effect of nano fertilizers on growth, yield, nutrient uptake and soil microbiology of kharif sorghum. *International Journal of Environment and Climate Change*, **13**(10): 2339-2348.
- Namasharma, S.; Pahari, A.; Banik, A.; Pal, S.; Sana, M.; Pal, S. and Banerjee, H. (2023). Impact of foliar applied nano-urea on growth, productivity and profitability of hybrid rice (*Oryza sativa* L.). *An International Journal of Rice*, **60**(3): 464-472.
- Srivastava, A.; Singh, R.; Choudhary, D.; Pradhan, A.; Roy, S.; Pandey, S. and Anand, S. (2023). Effect of nitrogen rates and foliar spray of urea application and nano urea on yield and economics of rabi maize (*Zea mays* L.). *International Journal of Environment and Climate Change*, **13**(10): 555-561.

## Advance Foliar Nutrition Strategies for Maximizing Crop Productivity



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### 1. Introduction

The entire world has been faced with the twin need to increase food supply by a projected seventy percent before the year 2050 to meet the demands of an ever-growing population, and in the same breath to reduce the environmental impact of the intensive farming methods. Traditionally, crop nutrition has been relying on the application of macronutrient soils; however, the effectiveness of soil-liquid fertilisers has been less than ideal. Use efficiency of nitrogen can seldom exceed half its level, and that of phosphorus, and micronutrients is often severely limited by extreme pH of soil, moisture, and adverse interactions between ions.

A better-targeted remedy to these inefficiencies is foliar fertilization. Evading the soil matrix the nutrients deposited to the phyllosphere are easily recaptured and transported to metabolically active sites. Foliar nutrition was initially considered as a rescue therapy of the observable deficiency symptoms, but today it is a key aspect of the Integrated Nutrient Management (INM).

The high technologies in this field are beyond application of mere spraying of simple fertilizer salts. These involve a subtle interpretation of physiology of leaf surfaces, manipulating the formulation chemistry to increase a surface penetration, and timing of application to occur during times of maximum physiological need, like reproductive initiation or grain filling, when the uptake kinetics in the soil cannot match the fast provocation of the growth rate of crops.

### 2. Physiological Mechanisms of Foliar Nutrient Uptake

In order to maximize foliar nutrition, the barriers to entry must first be known. The major challenge is the leaf cuticle a hydrophobic layer of waxy material developed to stop water loss, which intrinsically blocks uptake of hydrophilic nutrient solutions.

Uptake occurs through two primary pathways:

- a) **Cuticular Penetration (Passive):** The most common way. The nutrients pass through the waxy cuticle by a concentration gradient. The lipophilicity of the molecule, the thickness of cuticle and the humidity in the environment modify the rate by hydrating the cuticular pores.
- b) **Stomatal Uptake (Active/Passive):** Stomata are capable of solute uptake though primarily they serve a role of exchanging gases, this becomes possible when surfactants reduce the surface tension of the spray solution, and then the surface solution enters the stomatal pore. In addition, preferential sites of absorption are composed of ectodesmata (or aqueous pores) that are adjacent to guard cells.

The nutrients have to be actively carried into the cellular mass across the cell membrane into the symplast where they can be metabolically consumed or loaded into the phloem to be transported to other parts of the plant, such as developing fruits or tubers (Figure 1).

### 3. Innovations in Formulation Technology

The effectiveness of foliar spray is not as much determined by the concentration of the raw nutrient in it but it is determined by the formulation. The advanced ones are based on the chemistry that helps the nutrient to penetrate the cuticular barrier.

#### 3.1. Advanced Adjuvants and Surfactants

Water has a high degree of surface tension, which means that the droplets will bead on the leaves with a layer of waxy plant matter, and thus reduce the amount of contact. The tension is reduced by surfactants (surface-active

agents) which causes droplets to spread and adsorb and enhances the absorption interface. Another vital group of adjuvants is humectants, which draw moisture into the air and keep the nutrient deposit in the hydrated dissolved state on the leaf surface to a more extended period and therefore expand the absorption window.

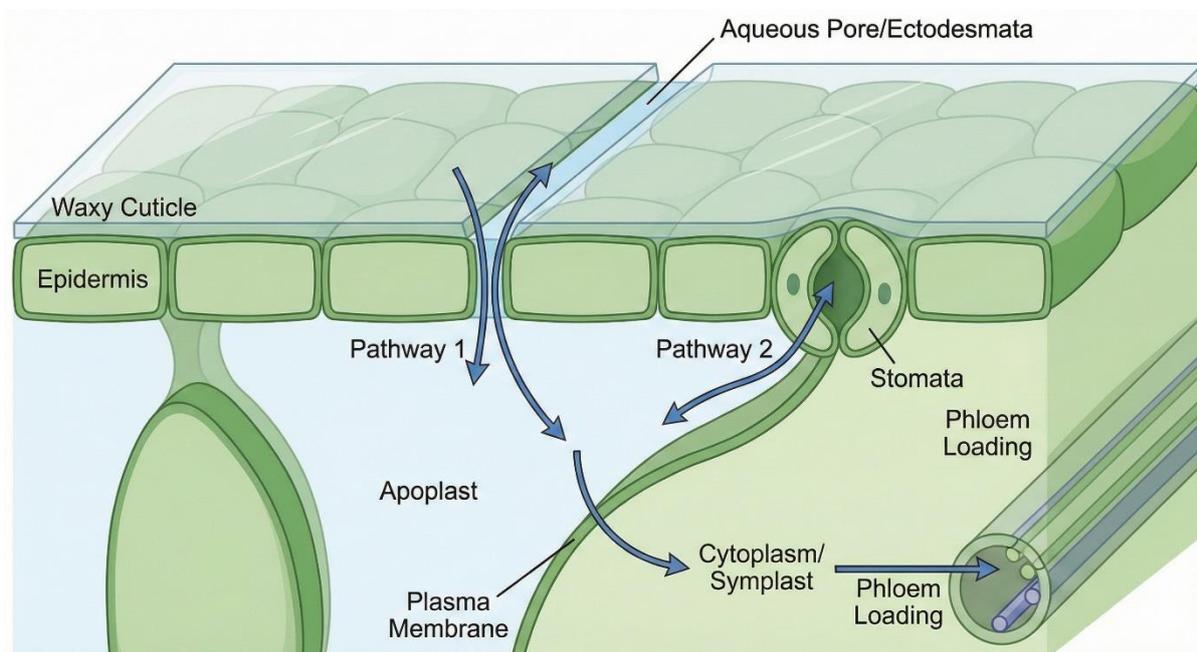


Figure 1. Cross-Section of Leaf Nutrient Uptake Pathways (Pathway 1: Epiplast, Pathway 2: Symplast)

### 3.2. Chelation and Complexation

Inorganic salts (e.g., zinc sulphate) are often inefficient when used in the foliar applications because of their charge and their tendency to cause leaf phytotoxicity (burning). Chelation involves the association of metal ions (Zn, Fe, Mn, Cu) with organic ligands like EDTA, DTPA or amino acids.

- Neutralizing Charge:** The chelate wraps the positively charged metal cation forming something that is neutral and more easily penetrates the negatively charged cuticular pores.
- Prevention of Lock-up:** Chelates prevent reactions of the metal-ions on the leaf surface or in the spray tank to form insoluble precipitates.

One of the developments is the amino acid complexes. The active transport of amino acids by the plants also enables an easy recognition of these complexes, which is why transmembrane transport is fast, a process generally known as trojan horse uptake.

Table 1. Comparative Efficacy of Micronutrient Formulations in Foliar Application

Formulation Type	Mechanism of Action	Advantages	Disadvantages
<b>Inorganic Salts (e.g., Sulfates, Nitrates)</b>	Passive diffusion of dissociated ions.	Low cost; readily available.	High risk of phytotoxicity; low absorption efficiency; easily washed off by rain.
<b>Synthetic Chelates (e.g., EDTA, DTPA)</b>	Charge neutralization; protects nutrient from precipitation.	High stability in tank mixes; improved cuticular penetration.	Higher cost; EDTA molecules are not metabolized by the plant.
<b>Amino Acid/Peptide Complexes</b>	Trojan Horse mechanism; utilizes active transport channels.	Rapid uptake and translocation; highly biocompatible; provides additional organic nitrogen/energy.	Premium pricing; lower stability in very high/low pH tank mixes compared to EDTA.
<b>Sugar/Organic Complexes (e.g., Glucoheptonates)</b>	Complexation with carbohydrates.	Good biocompatibility; moderate cost.	Less stable than synthetic chelates in soil, but effective foliarly.

### 3.3. Nanotechnology in Foliar Nutrition

The new frontier in formulation looks into the nano-fertilizer. Their surface-area-volume ratio increases exponentially by a reduction of nutrient particles to the nanoscale (1100nm). Nanoparticles are capable of penetrating through cuticular pores that are too small to allow large solutes to penetrate. Further, nano-encapsulation can provide the controlled release of nutrients with time, which reduces the multiplicity of applications and phytotoxicity.

### 4. Synergistic Strategies: Biostimulants and Nutrient Interactions

The modern paradigm of progressive foliar nutrition is not an individual application of nutrients but the combination of approaches. The integration between the nutrients of minerals and biostimulants creates synergistic effects that increase the overall plant physiological performance.

Biostimulants, such as seaweed extracts (phytohormones, e.g., cytokinins and auxins), humic/fulvic acids, and protein hydrolysates do not provide much nutrition as such, but rather regulate plant metabolic activities. They are applied foliarly with nutrients and:

When applied foliarly with nutrients:

1. **Upregulation of Transporters:** Some biostimulants are perceived by the plant to boost the activity of membrane transporter protein to hasten the transfer of co-applied mineral nutrients between the apoplast and symplast.
2. **Stress Mitigation:** Abiotic stress (drought, heat) promotes stomatal closure and cuticle thickening which inhibits foliar uptake. Glycine betaine (an osmolyte) is a biostimulant that is useful in the maintenance of cell turgor and metabolic activity during stress, thus maintaining active nutrient absorption pathways.

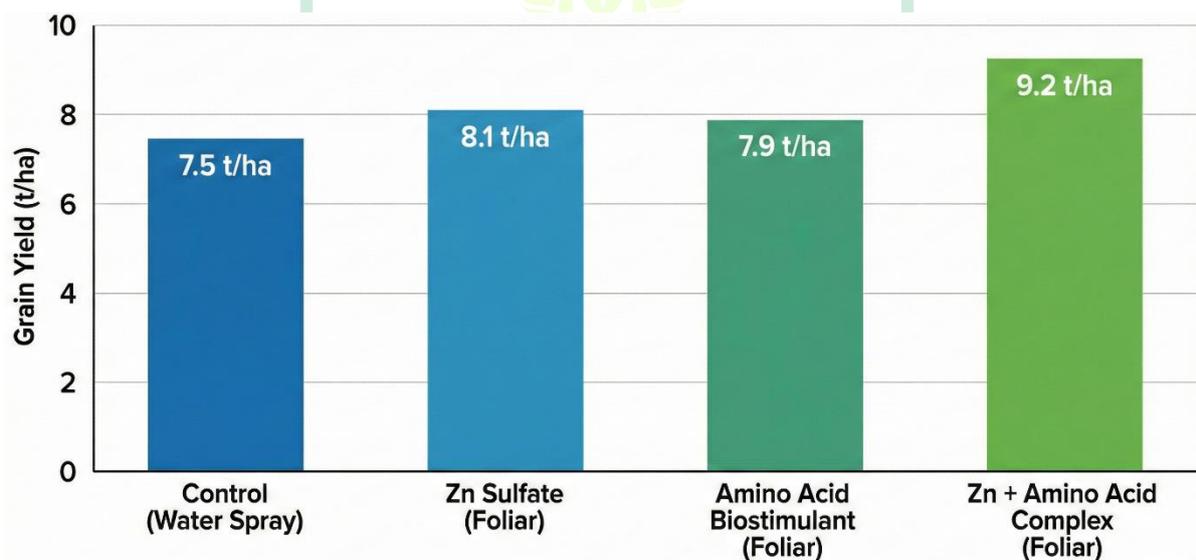


Figure 2. Hypothetical Synergistic Effect of Zinc and Amino Acid Biostimulant on Wheat Yield

Figure 2 shows that whereas zinc only, biostimulants only, or both have an incremental effect, the incremental effect of the combination is often greater than the additive effect of each individual on metabolism and grain filling, indicating synergistic effect.

### 5. Strategic Timing and Phenological Windows

The when is as critical as the what. Advanced foliar nutrition is predicated on applying nutrients during transient periods of high demand that the soil supply cannot meet.

#### Critical Phenological Stages:

- a) **Early Vegetative Stage (Establishment):** Foliar phosphorus and zinc can compensate the deficit in root systems; root development is stimulated, especially in cold and wet soils where the soil P is unavailable.
- b) **Reproductive Transition (Flowering/Anthesis):** This stage is usually the stage of maximum nutrient requirement. Nutrient translocation by the leaves of developing seeds initiated in grain crops. Boron

(required to promote pollen -tube growth and fruit set), and calcium (important to promote cell -wall integrity in developing fruit) foliar applications are of utmost importance. Ca and B uptake by the soil is transpiration-related, thus, when there is cloudiness or humidity, foliar sprays are significantly more effective.

- c) **Grain/Fruit Filling:** The photosynthetic engine (flag leaf in cereals) has to be preserved. Foliar sprays in late season (nitrogen and potassium) have the potential to extend grain-filling (delay senescence) and enhance grain protein content and seed weight.

## 6. Integration with Precision Agriculture Technologies

The future of foliar nutrition lies in moving from blanket applications to variable-rate, need-based applications.

Remote Sensing and Spectral Analysis:

Modern agriculture utilizes drone or satellite imagery equipped with multispectral cameras. These capture light reflectance in non-visible spectrums (like Near-Infrared). Indices such as NDVI (Normalized Difference Vegetation Index) or NDRE (Normalized Difference Red Edge) correlate strongly with plant biomass and nitrogen status.

By mapping a field's nutritional variability, farmers can generate prescription maps. A high-clearance sprayer equipped with individual nozzle control and GPS can then apply foliar nutrients only where needed, and at different rates. This Variable Rate Application (VRA) maximizes ROI by reducing fertilizer waste in high-fertility zones and targeting deficiencies in low-performing zones.

### Real-time Sensors:

Emerging technologies include tractor-mounted sensors that read crop fluorescence in real-time as the sprayer moves, adjusting the foliar application rate instantaneously based on the immediate crop canopy health readings.

## 7. Economic and Environmental Considerations

While foliar nutrition is generally more expensive per unit of nutrient than soil application due to formulation costs and application equipment requirements, its economic viability must be viewed through the lens of NUE and ROI.

Because foliar utilization rates are very high (often >90% for well-formulated products), far less total active ingredient is introduced into the environment compared to soil fertilization. This significantly reduces the risk of nutrient leaching into groundwater (common with soil nitrates) or runoff into surface bodies of water (common with phosphates). Therefore, advanced foliar strategies align with sustainable intensification goals, allowing for higher yields with a reduced total nutrient footprint on the landscape.

## 8. Conclusion

Maximizing crop productivity in the current agricultural climate requires a sophisticated approach to crop nutrition that transcends traditional soil fertilization. Advanced foliar nutrition strategies provide a powerful toolkit for bypassing soil constraints, capitalizing on synergistic interactions between nutrients and biostimulants, and targeting specific physiological windows of demand.

The successful implementation of these strategies relies on a deep understanding of leaf physiology, the selection of appropriate high-performance formulations like amino-acid chelates or nanomaterials, and integration with precision agriculture technologies. By shifting from reactive treatments to proactive, integrated nutritional strategies, producers can achieve significant gains in both yield and quality while improving the overall environmental sustainability of their operations. Future research must focus on refining nano-delivery systems and developing real-time, ion-specific leaf sensors to further automate and optimize the foliar feeding process.

### References

- Bindraban, P. S., Dimkpa, C., Nagarajan, L., Roy, A., & Rabbinge, R. (2015). Revisiting fertilisers and fertilisation strategies for improved nutrient use efficiency by crops. *Biology and Fertility of Soils*, 51(4), 489–511. <https://doi.org/10.1007/s00374-015-1039-7>
- Eichert, T., & Fernández, V. (2012). Uptake and release of elements by leaves and other aerial plant parts. In P. Marschner (Ed.), *Marschner's mineral nutrition of higher plants* (3rd ed., pp. 71–84). Academic Press.

- Fernández, V., & Eichert, T. (2009). Uptake of hydrophilic solutes through plant leaves: Current state of knowledge and perspectives of foliar fertilization. *Critical Reviews in Plant Sciences*, 28(1–2), 36–68. <https://doi.org/10.1080/07352680902743069>
- Kah, M., Beulke, S., Tiede, K., & Hofmann, T. (2013). Nanopesticides: State of knowledge, environmental fate, and exposure modeling. *Critical Reviews in Environmental Science and Technology*, 43(17), 1823–1867. <https://doi.org/10.1080/10643389.2012.671750>
- Shukla, A. K., Behera, S. K., Pattanayak, A., & Chaudhary, S. K. (2018). Foliar fertilization of micronutrients in field crops. *Indian Journal of Agronomy*, 63(1), 1–12.
- Yakhin, O. I., Lubyantsev, A. A., Yakhin, I. A., & Brown, P. H. (2017). Biostimulants in plant science: A global perspective. *Frontiers in Plant Science*, 7, Article 2049. <https://doi.org/10.3389/fpls.2016.02049>



## Advances in Micropropagation and Tissue Culture Techniques in Horticulture



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### 1. Introduction

Horticulture has been facing a challenge: there is a high demand for high-quality planting materials in the world, and there is a limited supply of resources (land, labour and environmental factors) to meet the demands. A possible solution is the plant tissue culture, which means the sterile cultivation of cells, tissues, organs, or complete plants under a stringent nutritional and environmental regimen in the long term. Micropropagation facilitates the mass-culture of homogenous, true-to-type, phytosanitary certified plants which can be grown regardless of the seasonal constraints, and allows the exploitation of the totipotency of the cellular parts.

Despite the fact that the principles that were set out by early scientists like Murashige and Skoog are still active, traditional micropropagation is usually highly labour-intensive, expensive and susceptible to physiological problems like hyperhydricity. Recent theoretical and practice studies are focused on overcoming these shortcomings. The new age of tissue culture can be characterized by a shift in values from simple culture maintenance to the exact replication of the in-vitro ecosystem, along with the incorporation of the latest biotechnological equipment and automation, which makes the process commercially feasible. The discussion below outlines the major technological breakthroughs currently transforming the process of horticultural propagation.

### 2. Environmental and Nutritional Optimization

In prior practice, the heterotrophic conditions were widely used in which explants needed an external source of carbohydrate in the media in the form of sucrose, because of the compromised in-vitro photosynthetic functioning. Not only did this dependence increase the cost of using agar gelling agents, but it has also increased the chances of contamination.

#### 2.1 Photoautotrophic Micropropagation (PAM)

Another important thing is the introduction of photoautotrophic micropropagation. During PAM, the growth media are designed in a manner that they are able to produce their own carbon through photosynthesis, thus a close replication of ex-vitro conditions.

This is achieved by:

- a) **Removing or drastically reducing sucrose** in the medium.
- b) **Enriching the culture vessel atmosphere with CO<sub>2</sub>** (typically 1000–3000  $\mu\text{mol mol}^{-1}$ ), requiring gas-permeable vessels or forced ventilation.
- c) **Increasing light intensity (PPFD)** to levels sufficient for net photosynthesis.

PAM has the capacity to reduce the cost of the media, lessen the effects of contamination, and create strong plantlets, which have well-developed cuticles and stomatal functioning, thus enhancing the survival chances during the severe acclimatization period.

#### 2.2 Spectral Control via LEDs

The use of Light-Emitting Diodes (LEDs) in place of the traditional fluorescent lamps has transformed in-vitro environmental control. LEDs allow one to design wavelengths or spectra, which have desired physiologic effects.

- a) **Red Light (660 nm):** Generally, promotes stem elongation and carbohydrate accumulation.
- b) **Blue Light (450 nm):** Often regulates stomatal opening, reduces stem elongation (resulting in sturdier plants), and promotes chlorophyll production.

Propagators can also adjust morphology without using chemical growth regulators by adjusting the red: blue ratio. An example is that too much stretching in densely populated cultures can be avoided by adding bluer to the mixture.

**Table 1. Comparison of Traditional vs. Advanced Environmental Conditions in Tissue Culture**

Parameter	Traditional Heterotrophic System	Advanced Photoautotrophic/Mixotrophic System
<b>Carbon Source</b>	Exogenous Sucrose (2-4%)	Atmospheric CO <sub>2</sub> (enriched); minimal/zero sucrose
<b>Gelling Agent</b>	Agar or Gellan Gum (Solid media)	Often Liquid media (Bioreactors) or porous substrates
<b>Gas Exchange</b>	Restricted (to prevent contamination)	Enhanced (forced ventilation or permeable membranes)
<b>Lighting Source</b>	Fluorescent lamps (broad spectrum, high heat)	LEDs (specific red/blue ratios, low heat)
<b>Light Intensity</b>	Low (40–80 $\mu\text{mol m}^{-2} \text{s}^{-1}$ )	Moderate to High (100–250 $\mu\text{mol m}^{-2} \text{s}^{-1}$ )
<b>Primary Benefit</b>	Simplicity; established protocols.	Faster growth; reduced contamination; better acclimatization.

### 3. Liquid Systems and Bioreactor Technology

The use of small vessels and agar media is also a significant cost driver because of the manual labour involved in the preparation of media and sub-culturing. Liquid culture systems provide an avenue to automation and scale, but continuous submersion may result in hyperhydricity (vitrification) and oxygen deprivation.

#### 3.1 Temporary Immersion Systems (TIS)

Temporary Immersion Systems (TIS) are applied to a permanent cooling system in times of peak demand to substitute the system.

To overcome the constraints of the standing liquid cultures, temporary Immersion Systems are used. TIS are divided into portable, semi-portable and mobile systems. The procedure entails periodic immersion of plant tissues with liquid nutrients, after which the tissues are drained, thereby permitting a minimal aerial exposure.

#### Mechanism of Action:

- I. **Nutrient Phase:** Liquid medium is forced into a reservoir chamber into the culture chamber by compressed air, immersing the explants.
- II. **Aeration Phase:** No longer aerated, the medium will sink back into the reservoir, the explants are covered by a thin layer of nutrient and are directly exposed to gases in the headspace.

TIS bring together the benefits of liquid media, which is a high uptake of nutrients and dilution of toxic exudates, and aeration required in aerobic respiration. This duality has a huge impact on increasing multiplication rates and biomass development as opposed to semi-solid media.

### 4. Somatic Embryogenesis and Synthetic Seeds

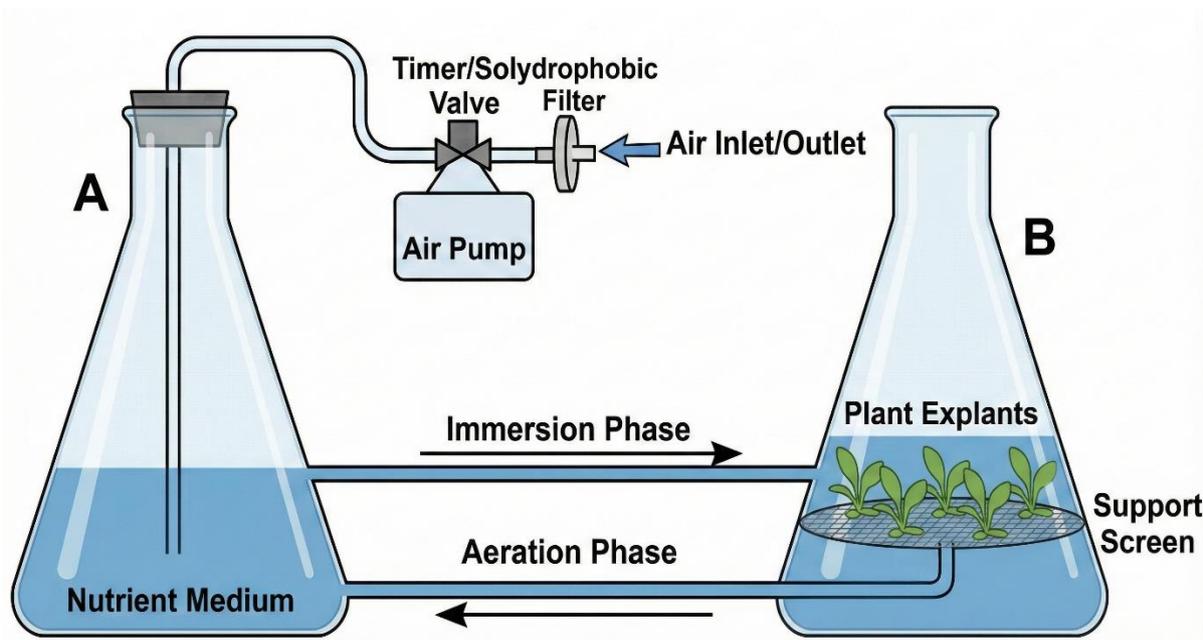
Though organogenesis (bud induction into shoots) has been a common method, somatic embryogenesis (SE) has better propagation potential especially in mass production because embryos may be grown in liquid suspension cultures that can be grown in bioreactors.

#### 4.1 Synthetic Seed Technology

A significant breakthrough that has been associated with SE is the creation of artificial seeds, or synseeds. This is done by wrapping somatic embryos in a protective, biodegradable gel, and, most commonly, calcium alginate gel.

A notable development that goes along with SE is the development of artificial seeds, or synseeds. These are created by encasing somatic embryos in a biodegradable gel, most of which are calcium alginate. The embryo is fragile and thus encapsulation ensures that the embryo is not damaged when handling, transporting, and planting. Other nutrients, fungicides or useful microorganisms (bio-priming) may be included in the alginate bead. The synseeds offer an avenue to:

- a) **Germplasm Conservation:** Long-term storage via cryopreservation.
- b) **Direct Planting:** Potential for direct sowing in greenhouse trays, bypassing complex acclimatization steps.
- c) **Exchange:** Facilitating the international exchange of sterile germplasm without bulky glassware.



**Figure 1. Conceptual Schema of a Temporary Immersion System**

## 5. Tissue Culture as an Enabler of New Breeding Technologies (NBTs)

New Breeding Technologies are based on the use of plant tissue culture. Contemporary agricultural breeding is becoming more and more based on an accurate genetic engineering, and tissue culture provides the very necessary background to the application of these technologies.

### 5.1 CRISPR/Cas9 and Regeneration

CRISPR/Cas9 gene editing requires the introduction of the editing apparatus into a plant cell. However, it is pointless to edit one cell unless it will be possible to regenerate it into a full-fledged fertile plant.

Advanced tissue culture protocols are required to:

1. Develop highly regenerable callus tissues or protoplasts receptive to transformation (via *Agrobacterium* or biolistics).
2. Apply precise selection pressure (e.g., antibiotics) to kill non-edited cells while allowing edited cells to proliferate.
3. Induce shoot and root regeneration from the transformed micro-calli.

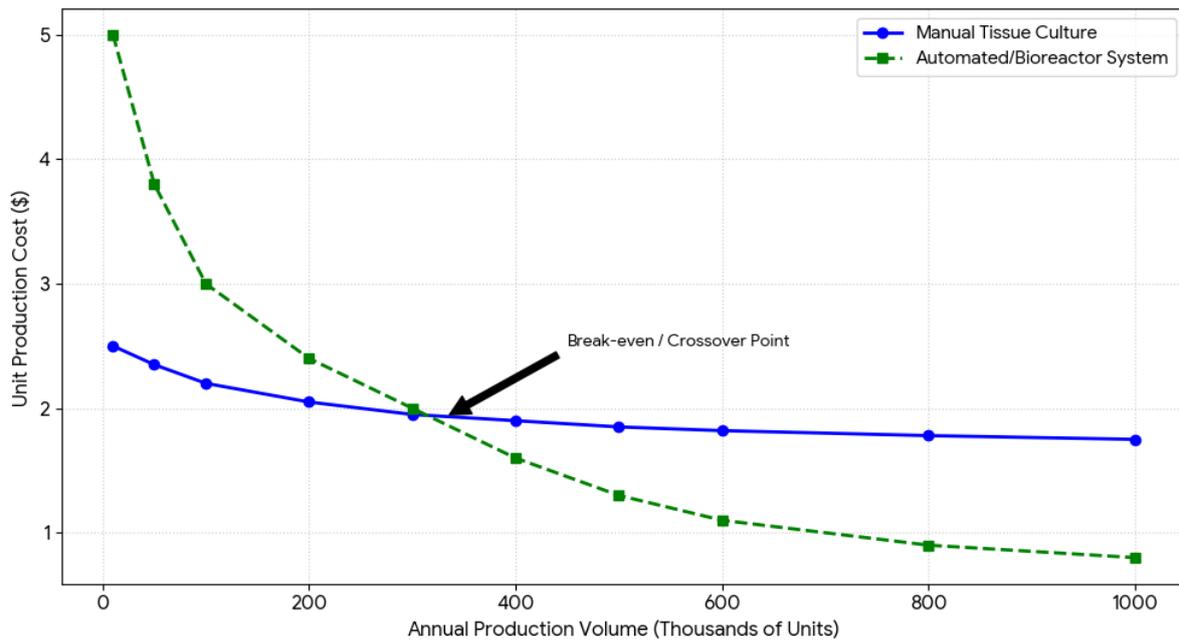
The principle of regeneration recalcitrance has remained a significant obstacle to the application of CRISPR in most woody horticultural crops. The new studies are currently looking at the morphogenic regulators (e.g. WUSCHEL or BABY Boom genes) which can be temporarily activated to boost the regeneration effectiveness in recalcitrant crops.

## 6. The Frontier: Automation and Robotics

In commercial micropropagation, labour forms 6070% of the costs of production, despite the advancement in biology. Therefore, the future of the field will be determined by the ability to minimize human intervention by technological innovation.

Current developments in automation include:

- a) **Automated Media Dispensing:** High-throughput filling of vessels.
- b) **Robotic Explant Transfer:** Using machine vision and robotic arms to identify nodal sections, cut them precisely, and transfer them to fresh media. This is challenging due to the variable shapes of plants.
- c) **Intelligent Growth Chambers:** integrated sensors monitoring pH, dissolved oxygen, and biomass non-invasively, adjusting conditions in real-time.



**Figure 2. Projected Cost vs. Volume Relationship in Automated vs. Manual Micropropagation**

## 7. Conclusion and Future Outlook

The field of horticultural tissue culture is transitioning from an artisanal, labor-intensive practice toward a high-technology, industrial process. The integration of physiological understanding (photoautotrophy), engineering principles (TIS bioreactors, LEDs), and biotechnology (CRISPR, synseeds) is addressing the historical limitations of cost and scalability.

Future developments will likely focus on refining protocols for recalcitrant species, particularly woody perennials and threatened medicinal plants. Furthermore, the convergence of synthetic biology and artificial intelligence to optimize culture media formulations without extensive empirical trial-and-error promises to accelerate the development of new protocols. For the modern horticulturalist, understanding and adopting these advanced micropropagation techniques will be essential for maintaining competitiveness in a market demanding sustainable, high-volume, and genetically superior planting materials.

## References

- De Carlo, A., Tarraf, W., Lambardi, M., & Benelli, C. (2021). Temporary immersion system for production of biomass and bioactive compounds from medicinal plants. *Agronomy*, *11*(12), 2414. <https://doi.org/10.3390/agronomy11122414>
- Gago, D., Sánchez, C., Aldrey, A., Christie, C. B., Bernal, M. Á., & Vidal, N. (2022). Micropropagation of plum (*Prunus domestica* L.) in bioreactors using photomixotrophic and photoautotrophic conditions. *Horticulturae*, *8*(4), 286. <https://doi.org/10.3390/horticulturae8040286>
- Kozai, T., Afreen, F., & Zobayed, S. M. A. (Eds.). (2005). *Photoautotrophic (sugar-free medium) micropropagation as a new propagation and transplant production system*. Springer.
- Loyola-Vargas, V. M., & Ochoa-Alejo, N. (Eds.). (2018). *Plant cell culture protocols* (4th ed.). Humana Press. <https://doi.org/10.1007/978-1-4939-8594-4>

## Agricultural Nano technology for enhancing Soil-Plant-Microbes Interactions Under Climate Stress



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### 1. Introduction

The need to nourish a growing population of the world is running headlong into the reality of a changing climate. The abiotic stresses like drought, salinity level, and extreme temperatures are increasing in frequency and severity, thus forming the major bottlenecks to the agricultural output. These stresses do not occur in isolation on the plant but in a severe way on the physicochemical environment and the intricate community of microorganisms living around the roots of plants, the microbiome.

The rhizosphere is the dynamic interface that constructs the interaction between plant roots, soil components, and microorganisms in complex biochemical signalling and nutrient exchange. In ideal scenarios, the interaction of the three parts enables mobilization of nutrients, suppression of diseases, and promotion of growth. Stress caused by climate destabilizes this system however. Indicatively, drought has a serious limitation in nutrient diffusion at the soil matrix, whereas salinity causes osmotic stress and ion toxicity on plant roots and other useful microorganisms.

To solve these issues, interventions that go beyond traditional bulk fertilizers and agrochemicals that often have low use efficiency and environmental losses are required. Agricultural nanotechnology-engineering of functional systems on the molecular scale-, provides new tools to be able to bring the rhizosphere under precise control. Due to their large surface area to volume ratio, controllable pore size and distinctive surface reactivities, nanomaterials (NMs) can enter biological barriers and react with cellular systems in a manner not achievable with bulk materials. This is possible, enabling the desired improvement of soil health, plant physiological behaviours, and the functionality of microorganisms under stress.

### 2. Fundamentals of Agro-Nanotechnology Under Stress

Nanotechnology in agriculture is not simply the issue of particle size reduction, but it involves taking advantage of the new characteristics that arise at nanoscale to address certain biological and environmental issues. When applied to climate stress, NMs are designed to execute three major functions:

- Smart Delivery Systems:** Nano-fertilizers and nano-pesticides are activated by environmental factors like a change in the pH or moisture content of the soil or over a prolonged interval, and this helps in minimizing losses as a result of leaching or volatilisation.
- Stress Alleviators:** There are also nanoparticles that have inherent catalytic abilities, such as the ability to mimic antioxidant enzymes, and can help plants to remove reactive oxygen species (ROS) produced under stress.
- Rhizosphere Modifiers:** Hydrogel nanocomposites are capable of enhancing the retention of soil water whereas other NMs are capable of altering the structure of the microbial communities.

**Table 1. Common Nanomaterials utilized in stress-resilient agriculture**

Nanomaterial Class	Examples	Primary Function in Stress Mitigation
<b>Metal/Metal Oxide NPs</b>	Zinc Oxide (ZnO), Titanium Dioxide (TiO <sub>2</sub> ), Cerium Oxide (CeO <sub>2</sub> )	Micronutrient supply; ROS scavenging (enzyme mimicry); photosynthetic enhancement.
<b>Metalloid NPs</b>	Silicon Dioxide (SiO <sub>2</sub> ), Selenium (Se)	Fortification of cell walls (physical barrier); alleviation of heavy metal and salinity stress.
<b>Carbon-based NMs</b>	Carbon Nanotubes (CNTs), Graphene Oxide (GO)	Seed germination enhancement; water channel regulation; slow-release carriers.
<b>Polymer/Biocomposites</b>	Chitosan NPs, Nano-hydrogels	Smart delivery carriers; superabsorbent polymers for drought tolerance; stimulation of defense compounds.

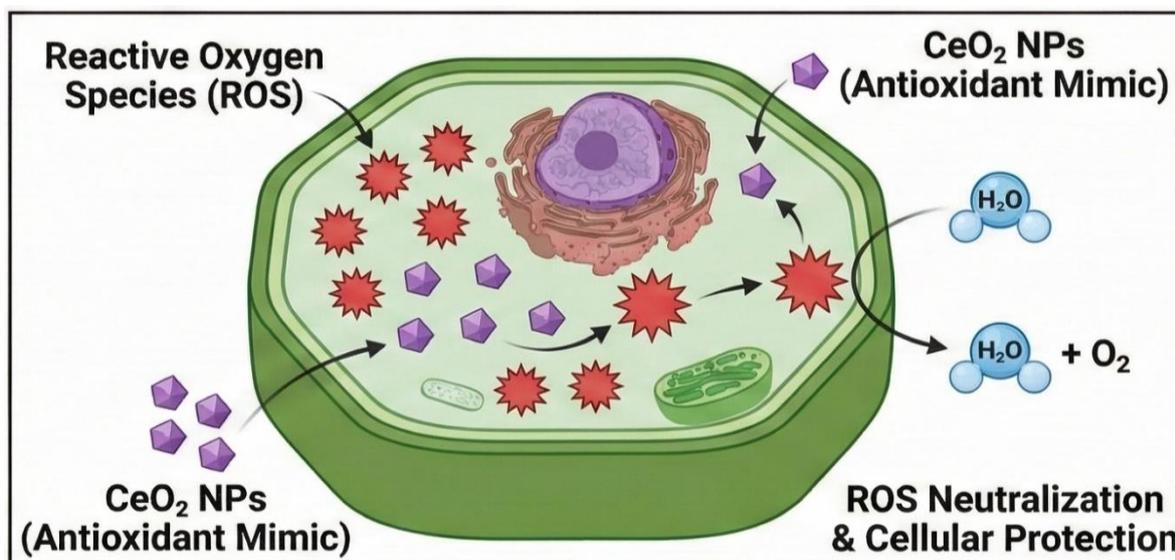


Figure 1. Nanoparticle-Mediated ROS Scavenging in Plant Cell

### 3. Mechanisms of Enhanced Soil-Plant Interactions

Climate stress has its very basis where the dynamics of water and availability of nutrients in the soil is completely altered. Nanotechnology can overcome these limitations in a number of direct ways which influence the soil matrix and the plant root system.

#### 3.1. Optimizing Soil Physicochemistry and Water Retention

Drought stress is mainly due to the inability of the soil supply of moisture to respond to the need of plants to transpire. The absorption of huge amounts of water by the soil can be achieved with superabsorbent nano-hydrogels introduced to the soil, which release the water gradually as the soil dries out, and the time taken before permanent wilting point. Besides, the nanoparticles, e.g. nano-silica, or nano-zeolites, boost the aggregation and porosity of the soil and, therefore, the infiltration of water and root penetration in compacted soils commonly aggravated by dry conditions.

Sodium ions in saline soils have high concentration thus rival the nutrients like potassium and calcium. Certain nanoparticles, especially nano-gypsum or man-made metal oxides act as ion exchangers in the soil complex, replacing sodium and making the vital cations more accessible to root up-take, thereby alleviating ionic toxicity.

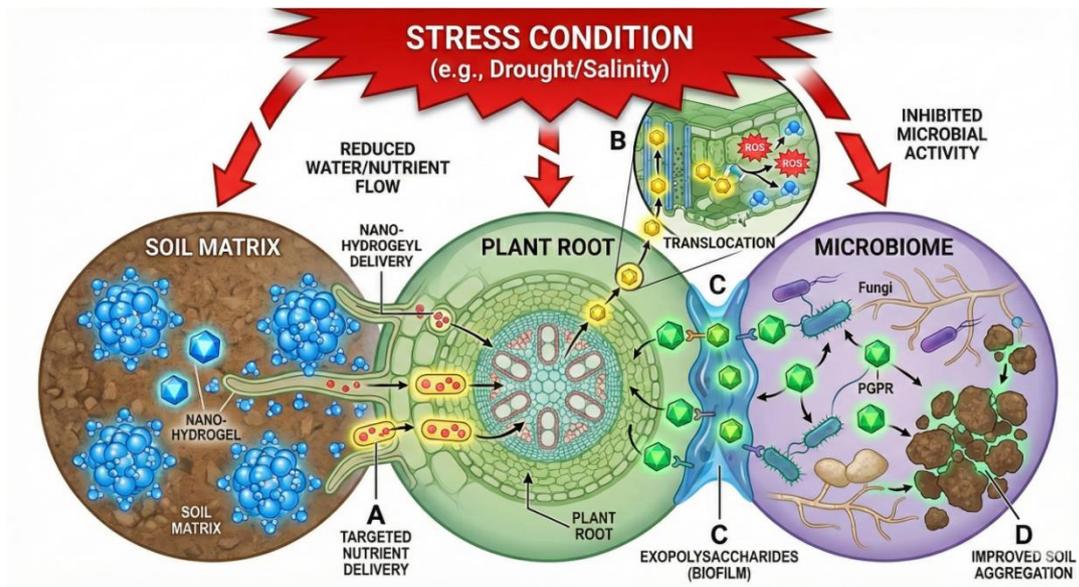
#### 3.2. Modulating Plant Physiological Responses

In situations where plants are stressed, they produce more ROS and cause the oxidative damage of lipids, proteins, and DNA. One of the most important solutions to this is nanotechnology in which an intrinsic approach to antioxidants exists, in the form of nanoparticles. The nanoparticles of cerium oxide (CeO<sub>2</sub> NPs), such as ROS scavengers, imitate the action of such enzymes as superoxide dismutases (SOD) and catalases (CAT). These NPs prevent oxidative stress and membrane damage by entering the root and translocation to shoot tissues in heat or drought stress.

In addition, nanomaterials affect the plant hormonal signalling. The above discussion has shown that foliar or root application of particular NPs can alter the production of abscisic acid (ABA), the major stress hormone that governs stomatal closure, and thus enhances plant water-use efficiency without significantly affecting photosynthesis.

### 4. The Crucial Link: Nanotechnology and the Microbiome

Plant microbiome, especially Plant Growth-Promoting Rhizobacteria (PGPR), and Arbuscular Mycorrhizal Fungi (AMF) is an essential ally in abiotic stress resistance. These organisms help to solubilise nutrients, generate phytohormones like indole -acetic acid and exopolysaccharides (EPS) enhance soil structure and keep soil moisture adjacent to roots.



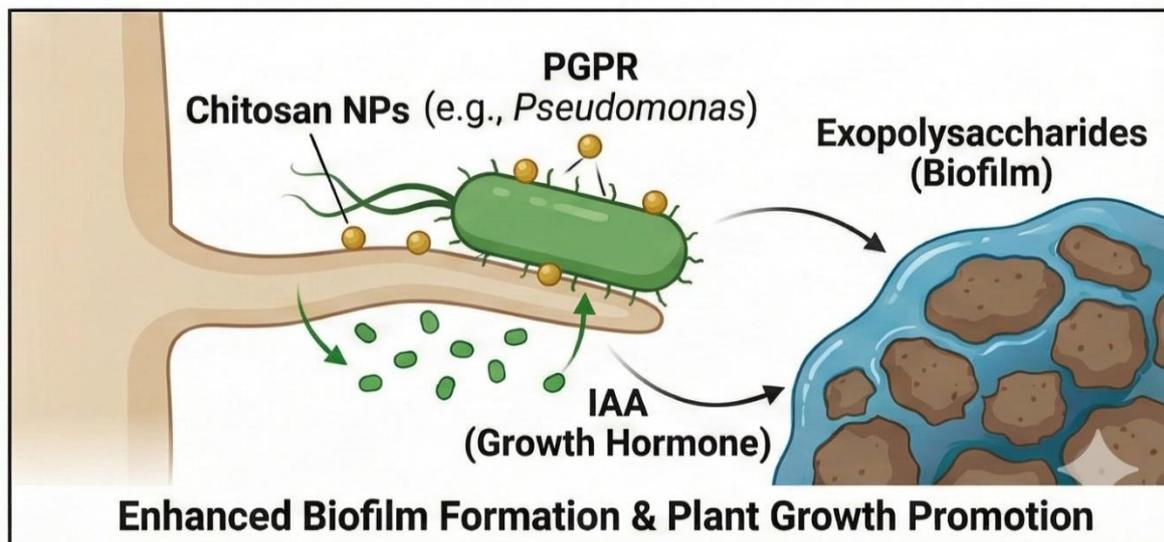
**Figure 2. Conceptual Model of Conceptual Model of Nano-Interactions in the Rhizosphere Under Stress**

Climate stress depresses the activity of these beneficial microbes. Nanotechnology can intervene in two primary ways:

#### 4.1. Supporting Beneficial Microbial Activity

An example of this type of nanoparticles is chitosan nanoparticles that can be used as sources of carbon or signalling molecules that selectively stimulate the growth of PGPR. In drought stress conditions, it has been demonstrated that the use of certain nano-nutrients (e.g. nano-iron or nano-molybdenum) improves the nitrogen-fixation capacity of rhizobia, the phosphate-solubilising effect of other bacteria, which are normally inhibited by water deficits.

Besides, nanoparticles have the potential to strengthen the symbiotic interaction between plant roots and AMF. SiO<sub>2</sub> NPs used under saline conditions have been found to increase the percentages of mycorrhizal colonisation. Silicon-enriched fungi enhance the absorption surface area of the root that absorbs water and excludes toxic ions.



#### 4.2. The Antimicrobial Duality

The interactions between NPs and microbes are a two-sided problem that should be taken seriously. Several metal-oxide NPs (e.g., silver, zinc oxide, copper oxide) have inbuilt antimicrobial capacity at specific concentrations. Although it can be utilized to suppress soil-borne pathogens, its unrestrained use would destroy useful microbial populations eventually damaging the health of the soil.

Therefore, nanotech strategies for climate stress are shifting toward:

- Biogenic Synthesis:** Using plant extracts or microbes to synthesize NPs, often resulting in higher biocompatibility.
- Precise Dosage:** Locating the hormetic window at low doses, which will stimulate advantageous microbes, and the more significant doses will be lethal.
- Encapsulation:** Using biological shells to prevent direct contact between a reactive metallic core and sensitive microbes until delivery is required.

**Table 2: Impacts of Specific Nanoparticles on Beneficial Soil Microbes Under Stress Conditions.**

Nanoparticle Type	Targeted Stress	Observed Interaction with Beneficial Microbiome	Physiological Outcome for Plant
Chitosan NPs (Biopolymer)	Drought	Stimulation of PGPR (e.g., <i>Pseudomonas</i> spp.) to produce ACC deaminase.	Lowered ethylene levels in plants, reducing drought-induced senescence.
Nano-Silicon (SiO <sub>2</sub> )	Salinity	Enhanced colonization of Arbuscular Mycorrhizal Fungi (AMF).	Improved water uptake and exclusion of Na <sup>+</sup> ions via fungal hyphae network.
Nano-Zinc Oxide (ZnO) (Low Dose)	High Temp / General	Stimulation of IAA (auxin) production by rhizobacteria.	Improved root architecture and deeper soil penetration to access water.
Nano-Iron (Fe <sub>2</sub> O <sub>3</sub> )	Nutrient Deficiency (induced by pH)	Increased activity of siderophore-producing bacteria.	Enhanced iron acquisition by the plant under alkaline soil conditions.

#### 5. Challenges and Future Perspectives

While the potential of agricultural nanotechnology to ameliorate climate stress is significant, the transition from laboratory proof-of-concept to large-scale field application faces substantial hurdles.

**Ecotoxicology and Risk Assessment:** The long-term fate of nanomaterials in soil is not fully understood. There are legitimate concerns regarding the bioaccumulation of non-biodegradable metal oxide NPs in the food chain and their potential toxicity to non-target organisms, including earthworms and essential soil fungi. A robust regulatory framework requiring comprehensive lifecycle assessments (LCA) of agro-nanomaterials is essential before widespread adoption.

**Economic Viability and Scalability:** The synthesis of engineered nanomaterials is currently expensive relative to bulk fertilizers. Developing cost-effective, green synthesis methods utilizing agricultural waste streams or microbial bio-factories is necessary to make these technologies accessible to farmers, particularly in developing regions hardest hit by climate change.

**Complexity of Field Conditions:** Most current research is conducted in controlled environments. The heterogeneity of field soils varying in pH, organic matter, and clay content drastically affects the behaviour, mobility, and bioavailability of nanoparticles. Future research must prioritize multi-year field trials to validate stress-mitigation efficacy under real-world conditions.

#### 6. Conclusion

Climate stress presents a multifaceted challenge to global agriculture that demands multifaceted solutions. Agricultural nanotechnology offers a powerful toolkit for engineering the rhizosphere, moving beyond mere chemical supplementation to the precise modulation of biological and physical processes. By enhancing water use efficiency, scavenging reactive oxygen species, and supporting beneficial microbial alliances, nanomaterials can significantly increase crop resilience to drought, salinity, and temperature extremes. However, the path forward must be navigated with caution. Responsible innovation, anchored by rigorous ecotoxicological assessment and a focus on biocompatible materials, will determine whether nanotechnology becomes a

cornerstone of climate-smart agriculture or introduces new environmental liabilities. The integration of nanotech with existing best management practices holds the greatest promise for securing future food systems.

#### References

- El-Saadony, M. T., Saad, A. M., Soliman, S. M., Salem, H. M., Desoky, E. M., Babalghith, A. O., El-Tahan, A. M., Ibrahim, O. M., Ebrahim, A. A. M., Abd El-Mageed, T. A., Elrys, A. S., Elbadawi, A. A., El-Tarabily, K. A., & AbuQamar, S. F. (2022). Role of nanoparticles in enhancing crop tolerance to abiotic stress: A comprehensive review. *Frontiers in Plant Science*, 13. <https://doi.org/10.3389/fpls.2022.946717>
- Giraldo, J. P., Wu, H., Newkirk, G. M., & Kruss, S. (2019). Nanobiotechnology approaches for engineering smart plant sensors. *Nature Nanotechnology*, 14(6), 541–553. <https://doi.org/10.1038/s41565-019-0470-6>
- Lowry, G. V., Avellan, A., & Gilbertson, L. M. (2019). Opportunities and challenges for nanotechnology in the agri-tech revolution. *Nature Nanotechnology*, 14(6), 517–522. <https://doi.org/10.1038/s41565-019-0461-7>
- Mittler, R. (2017). ROS are good. *Trends in Plant Science*, 22(1), 11–19. <https://doi.org/10.1016/j.tplants.2016.08.002>
- Rashid, M. M., Forte Tavčer, P., & Tomšič, B. (2021). Influence of titanium dioxide nanoparticles on human health and the environment. *Nanomaterials*, 11(9), 2354. <https://doi.org/10.3390/nano11092354>
- Sodhi, G. K., Wijesekara, T., Kumawat, K. C., Adhikari, P., Joshi, K., Singh, S., Farda, B., Djebaili, R., Sabbi, E., Ramila, F., Sillu, D., Santoyo, G., de los Santos-Villalobos, S., Kumar, A., Pellegrini, M., & Mitra, D. (2025). Nanomaterials–plants–microbes interaction: Plant growth promotion and stress mitigation. *Frontiers in Microbiology*, 15. <https://doi.org/10.3389/fmicb.2024.1516794>



## Agronomic Interventions for Increasing Oilseed Productivity



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### 1. Introduction

The world oil demand in all its forms vegetable oil, culinary, industrial and bio fuel is escalating at an unprecedented rate. The demand is based on the major oilseed's species: soybean, rapeseed-mustard, groundnut, sunflower, and palm. In addition, the by-product oilcake forms a major source of livestock and poultry food due to its high protein content in the food. However, in various parts of the world, particularly in developing countries, the production of oilseeds is below the average production in the world hence an indicator of a severe disparity in productivity.

The major limitation to oilseed production is the large-scale production of rainfed crops in energy-deficient and marginalized lands. These systems are conventionally pushed to low-fertile soils and given little agronomic inputs that makes them very vulnerable to biotic and abiotic stresses. As a result, this impediment is not merely genetic but strongly agronomic. It requires a paradigm shift to precision agronomy to bridge the yield gap, the gap between yields that can be obtained under optimal research conditions and the yields obtained on commercial farms.

### 2. Genetic Enhancement and Quality Seed Material

The cornerstone of agronomic achievement lies on the genetic potential within the seed. Despite the fact that the breeding of plants represents a separate field, it is agronomy that defines the effective application of genetic resources.

#### 2.1 Varietal Selection and Seed Replacement Rate (SRR)

Farmers should abandon the use of farm-saved seeds of old varieties of plants to certified seeds of high-yielding varieties (HYVs) and hybrids. Modern varieties are not only chosen on the basis of yield but a combination of other agronomically pertinent characteristics such as:

- Short duration maturity:** To escape terminal drought or fit into intensive cropping sequences.
- Stress tolerance:** Specific resistance to salinity, waterlogging, or prevalent pests/diseases.
- High oil content:** Increasing the economic value per unit of biomass.

The most crucial thing is to increase the Seed Replacement Rate (SRR) i.e. the percentage of the acreage under certified seed planted. A lowered SRR has a direct proportional relationship to reduced germination, low vigour and increased disease.

#### 2.2 Seed Priming and Treatment

Before sowing, agronomic intervention begins with seed treatment.

- Bio-priming:** Seed priming with useful microorganisms like *Trichoderma viride* or *Pseudomonas fluorescens* gives seedlings greater vigour and early resistance to pathogenic microbes in the soil;
- Rhizobium Inoculation:** In leguminous oilseeds (soybean, groundnut), crop-specific *Rhizobium* strains are essential to achieve optimum biological fixation of nitrogen (BNF) to minimise the use of synthetic nitrogen.

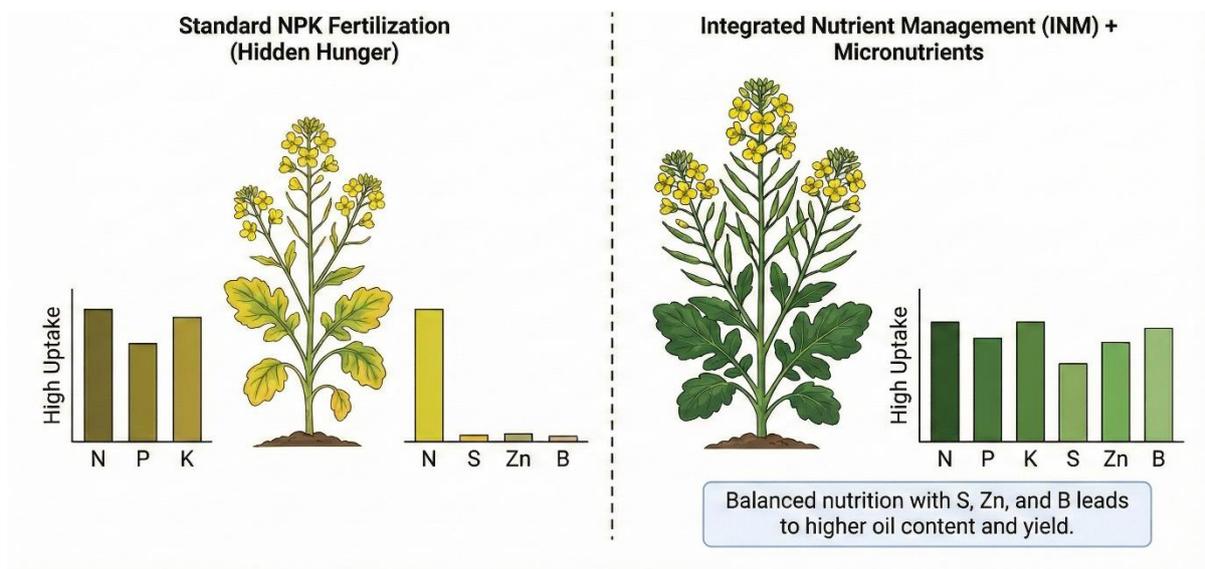
### 3. Optimized Nutrient Management Strategies

Oilseeds are a nutrient-demanding crop by nature and therefore have a high demand of nutrients. Trusting in the macronutrients nitrogen, phosphorus, and potassium (NPK) is not sufficient and, probably, can even threaten the health of the soil in the long term.

### 3.1 The Critical Role of Sulphur

The fourth nutrient, oilseeds are often referred to as sulphur (S). It is a part of essential amino acids, cysteine and methionine and is directly involved in the production of oil. Lack of sulphur causes lack of flowering, lack of pod formation, and significantly low content of oil.

**Recommendation:** The use of sources of sulphur like gypsum, single-super phosphate (SSP), or elemental sulphur is very important, especially in soils that have a light texture and are deficient in sulphur.



**Figure 1. Impact of micronutrient and sulphur deficiencies on oilseed growth and yield**

### 3.2 Micronutrient Deficiencies: The Hidden Hunger

Intensive cropping without micronutrient replenishment has led to widespread deficiencies, most notably in Zinc (Zn) and Boron (B).

- a) **Boron:** Critical for pollen tube growth, fertilization, and seed setting. Deficiency leads to hollow heart in groundnut and poor pod filling in mustard.
- b) **Zinc:** Essential for enzymatic activity and auxin synthesis.

**Table 1. Typical Nutrient Uptake by Major Oilseed Crops (per ton of economic yield)**

Crop	Nitrogen (N) kg	Phosphorus (P <sub>2</sub> O <sub>5</sub> ) kg	Potassium (K <sub>2</sub> O) kg	Sulphur (S) kg	Critical Micronutrients
Soybean	70-80*	15-20	30-40	6-8	Zn, Mo, B
Groundnut	50-60*	10-15	20-25	5-7	B, Ca, Zn
Rapeseed-Mustard	25-30	10-12	20-25	10-12	S, B, Zn
Sunflower	30-35	12-15	30-35	4-6	B

(Source: Adapted from Indian Institute of Soil Science data.)

### 3.3 Integrated Nutrient Management (INM)

INM advocates an integrative approach to the use of chemical fertilizers, organic manures such as farmyard manure (FYM) and compost with biofertilizers. Organic amendments optimise the soil physical structure, increase its capacity to retain water and activate microbial growth, thus increasing the efficiency with which organic fertilizers are used.

### 4. Water Use Efficiency and Irrigation Management

In rainfed areas, water is often the most restricting factor to the productivity of oilseeds. The agricultural practices should be aimed at increasing yields per unit of water.

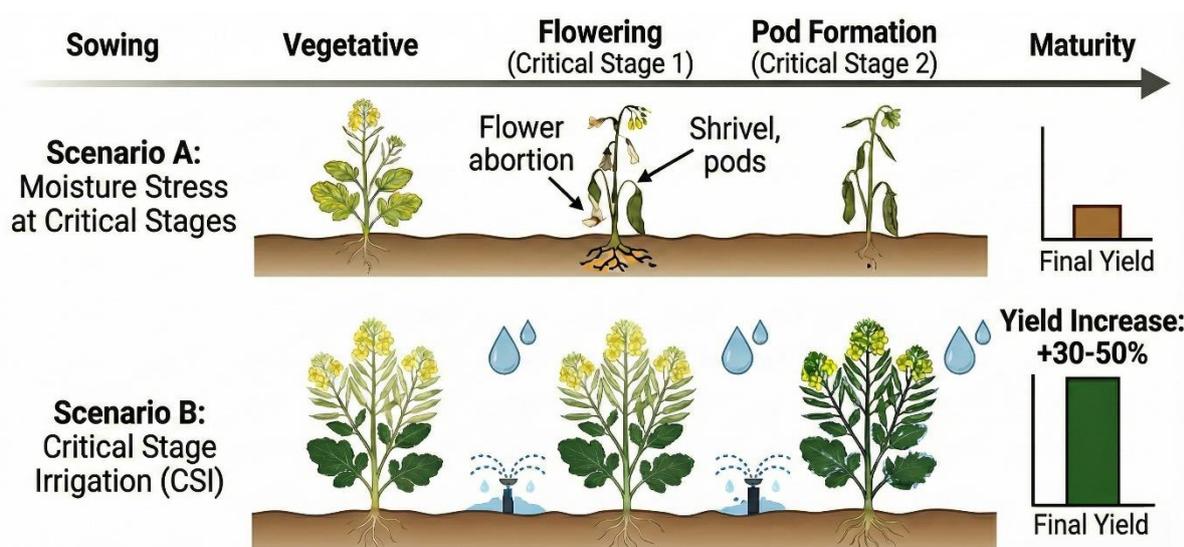


Figure 2. Influence of irrigation at critical physiological stages on oilseed yield potential

#### 4.1 *In-situ* Moisture Conservation

Conservation of soil moisture in rainfed systems is critical:

- Land Configuration:** broad bed and furrow (BBF) or ridge and furrow planting methods mitigate the effect of heavy rainfall in terms of drainage and of dry weather in terms of moisture retention in furrows
- Mulching:** The surface mulch cover of crop residues lowers the evaporation losses and also regulates soil temperatures.

#### 4.2 Critical Growth Stages for Irrigation

Irrigation water where it is available should be applied at specific time periods when it is known that the moisture is sensitive to physiological stages. The stress due to moisture in these seasons causes permanent loss of yield.

Table 2. Critical Physiological Stages for Irrigation in Oilseed Crops

Crop	Primary Critical Stage	Secondary Critical Stage	Impact of Water Stress
Rapeseed-Mustard	Flowering/Stem Elongation	Siliqua (Pod) formation	Flower drop, poor seed filling
Groundnut	Flowering & Pegging	Pod development	Poor peg penetration, shrivelled kernels
Soybean	Flowering	Pod filling	Flower abortion, reduced seed size
Sunflower	Button stage/Flowering	Seed filling	Poor head size, chaffy seeds

#### 4.3 Micro-Irrigation

Adoption of drip or sprinkler irrigation systems can improve water use efficiency by 30-50% over flood irrigation, while also allowing for fertigation (applying nutrients through water).

### 5. Integrated Biotic Stress Management

Oilseeds are highly susceptible to competition from weeds and attack by pests and diseases.

#### 5.1 Integrated Weed Management (IWM)

In the early stages of growth, weeds are very competitive in terms of nutrients, water and light. Weed competition normally occurs during the first 30-45 days following sowing.

- Cultural:** Proper spacing, crop rotation, and stale seedbed techniques.
- Chemical:** Pre-emergence herbicides (e.g., Pendimethalin) followed by need-based post-emergence application.

- c) **Mechanical:** Inter-cultivation using hoeing, which simultaneously aids in soil aeration and moisture conservation.

## 5.2 Integrated Pest Management (IPM)

Indiscriminate pesticide uses leads to resistance and residue issues. IPM promotes a balanced approach:

- a) **Biological control:** Encouraging natural predators like *Trichogramma* or *Chrysoperla*.
- b) **Cultural control:** Trap crops (e.g., planting castor around groundnut to trap *Spodoptera*), deep summer ploughing to destroy pupae.
- c) **Chemical control:** Using economic threshold levels (ETL) to decide timing of pesticide application, prioritizing safer, target-specific chemicals.

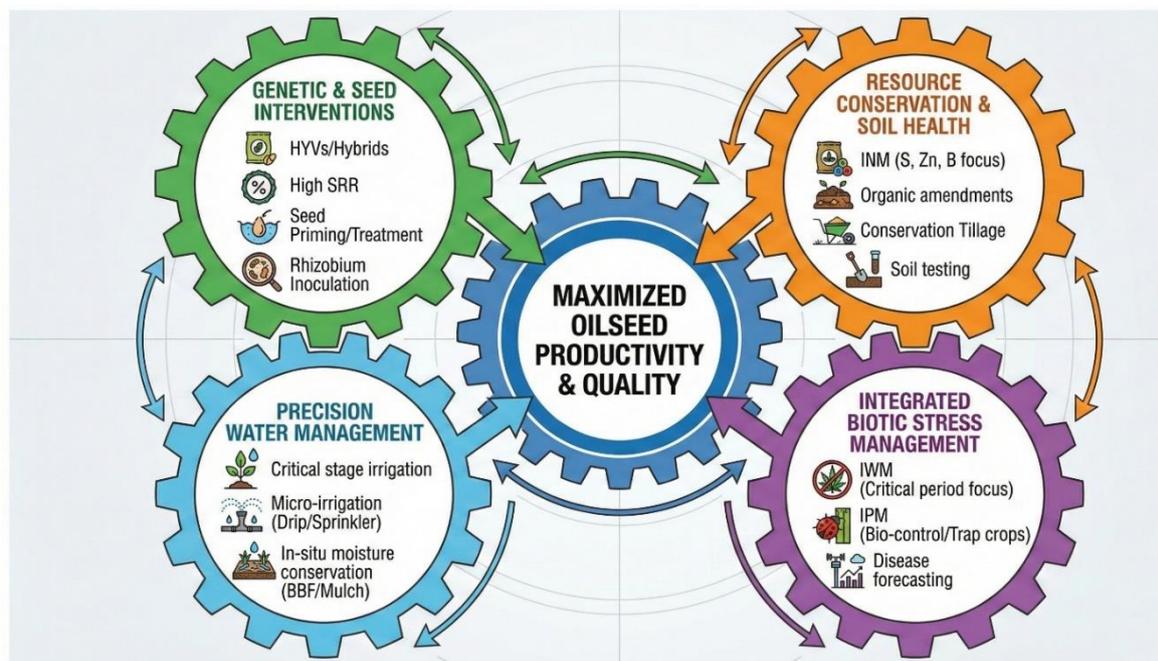


Figure 3. The Conceptual Framework of Integrated Agronomic Interventions

## 6. Cropping Systems and Planting Geometry

Optimizing the spatial and temporal arrangement of crops is vital for resource maximization.

### 6.1 Planting Geometry and Plant Population

Achieving optimum plant population is the first step toward high yields. Both sub-optimal and supra-optimal populations reduce yield.

- a) Line sowing using seed drills ensures uniform depth and spacing, compared to broadcasting.
- b) Adjusting spacing based on variety type (spreading vs. bunch type in groundnut) and soil fertility is crucial.

### 6.2 Intercropping Systems

Oilseeds are excellent component crops in intercropping systems due to their varying canopy structures and root depths.

- a) **Cereal-Oilseed systems:** Examples include Maize + Soybean or Sorghum + Groundnut. This offers insurance against total crop failure in rainfed areas and improves land equivalent ratio (LER).
- b) **Legume effect:** Leguminous oilseeds improve soil nitrogen status for the companion or succeeding non-legume crop.

## 7. Conclusion and Future Prospects

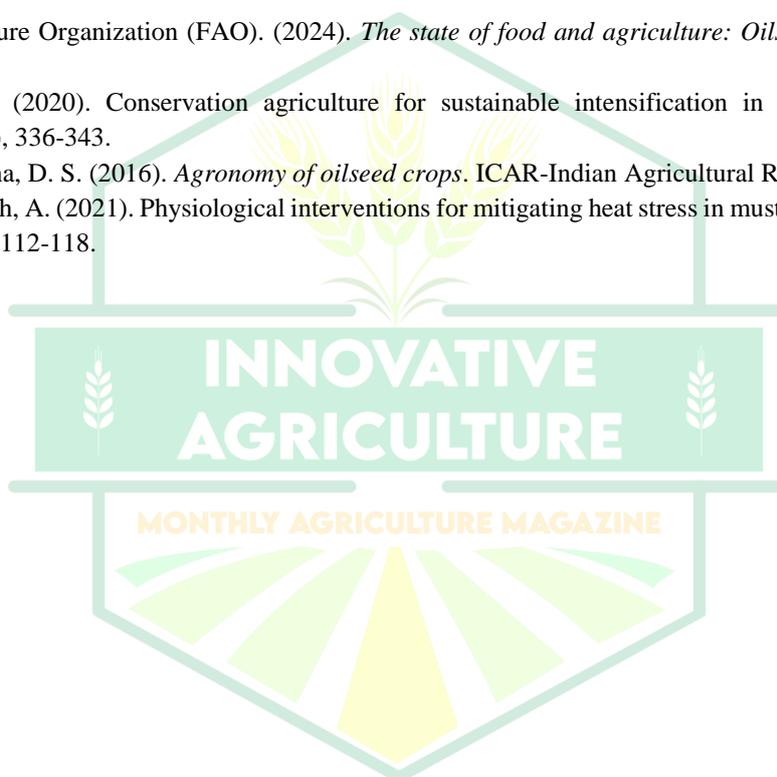
Increasing oilseed productivity is not merely a technical challenge but an imperative for economic stability and nutritional security. The yield stagnation currently witnessed is largely attributable to sub-optimal agronomic management rather than genetic limitations alone.

The path forward lies in the adoption of knowledge-intensive agriculture over input-intensive agriculture. A holistic approach that integrates improved genetics with site-specific nutrient management (especially Sulphur and micronutrients), precision water application, and integrated stress management is required.

Future agronomic research must focus on climate-resilient technologies, such as agronomic fortification to enhance oil quality, conservation agriculture to sequester carbon in oilseed-based systems, and the use of digital tools (drones, sensors) for precision monitoring of crop health. By bridging the agronomic knowledge gap at the farm level, substantial improvements in national average yields of oilseed crops are attainable.

#### References

- Bamaniya, B. R., et al. (2022). Influence of sulphur and zinc on yield, quality and nutrient uptake of mustard (*Brassica juncea* L.). *The Pharma Innovation Journal*, 11(2), 233-236.
- Choudhary, G. L., & Yadav, L. R. (2018). *Textbook of oilseed production technology*. New India Publishing Agency.
- Directorate of Rapeseed-Mustard Research (DRMR). (2023). *Vision 2050*. Indian Council of Agricultural Research.
- Food and Agriculture Organization (FAO). (2024). *The state of food and agriculture: Oilseeds market review*. FAO.
- Jat, M. L., et al. (2020). Conservation agriculture for sustainable intensification in South Asia. *Nature Sustainability*, 3(4), 336-343.
- Rana, K. S., & Rana, D. S. (2016). *Agronomy of oilseed crops*. ICAR-Indian Agricultural Research Institute.
- Sharma, P., & Singh, A. (2021). Physiological interventions for mitigating heat stress in mustard. *Journal of Plant Physiology*, 18(4), 112-118.



## Antimicrobial Resistance in Veterinary Practice: Challenges and Control Strategies



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### 1. Introduction

The emergence and extensive use of antimicrobials have radically changed the field of veterinary medicine, as it has revolutionized the treatment of infectious diseases in food-producing and companion animals. These are the agents that are still essential in maintaining health, welfare and productivity in animals. However, currently, the therapeutic armament is being depleted at an extremely high rate because of the selective pressure created by the use of antimicrobials that promotes the development and spread of antimicrobial resistance (AMR). AMR is not only a veterinary issue but also an archetypal One Health crisis. The difficult-to-treat bacteria and their genetic determinants can easily migrate between any animal, human and environmental reservoirs and represent serious dangers to the health of both the population and animals. Uncontrolled AMR is also causing the failure of treatment, increased mortality in animals, reduced efficiency in production, and the risk of zoonotic spread of multi-drug resistant (MDR) pathogens to humans in veterinary practice.

The solution to this multifaceted situation requires a paradigm shift that defines the use of antimicrobials as secondary management effects to the use of a comprehensive approach in which prevention, accurate diagnosis, and wise exploitation are the key elements. The given article aims to offer a systematic discussion of the existing challenges that face veterinary practitioners and producers in the framework of AMR, and present effective and scientifically proven control and mitigation strategies.

### 2. Mechanisms and Anthropogenic Drivers of Resistance

Although resistance is an inherent evolutionary process, the acceleration of resistance at present is too anthropogenic. It is important to understand these drivers to come up with effective interventions.

#### 2.1 The Biological Basis

The bacteria develop resistance by genetic mutation or, more popular in the situation of such rapid spread by horizontal gene transfer by the use of plasmids, transposons and integrons. These mobile genetic components facilitate resistance characteristics to cross-species boundaries. The selective forces exerted by the existence of antibiotics favour the persistence and increase of the resistant strains, whereas the populations that are vulnerable are eliminated in effect.

#### 2.2 Veterinary Drivers of Selection Pressure

In veterinary contexts, several practices historically contributed to high selection pressure:

- a) **Growth Promotion:** The administration of sub-therapeutic quantities of antimicrobials of medical significance in feed to increase the conversion rates was a significant force. Despite being prohibited in the European Union and being phased out in the United States and other parts of the world regarding medically important drugs, the practice remains widespread in most parts of the developing world.
- b) **Metaphylaxis and Prophylaxis:** Mass medication of animal populations (e.g., poultry flocks, feedlot cattle) to treat diseased individuals and prevent disease in at-risk animals (metaphylaxis), or antenatal dose-giving of drugs because of high-risk states (prophylaxis) subjects large populations to the best selection of resistance.
- c) **Empirical Therapy:** It is common practice in veterinary medicine because of the inherent constraints of diagnostic methods that the practitioner must commence treatment before the culture and susceptibility data. When the selected drug fails to act on the target pathogen but alters commensal flora, it will cause resistance without a clinical effect.

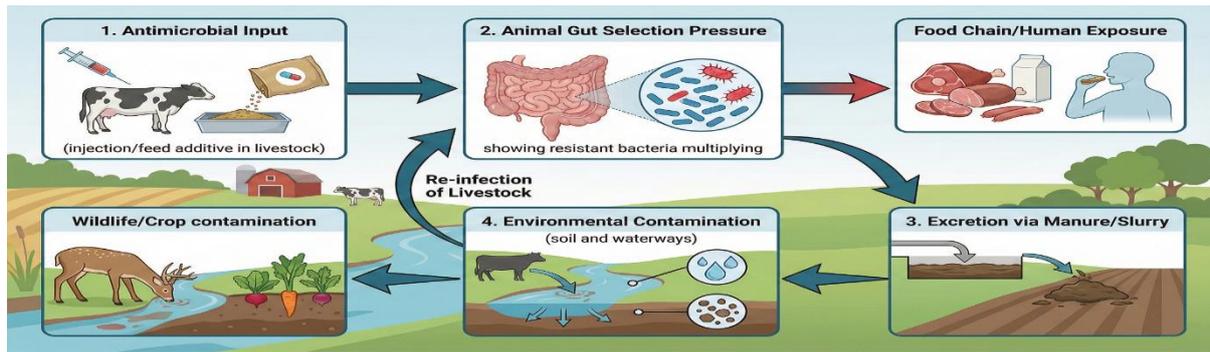


Figure 1. the flow of Antimicrobial Resistance (AMR) in an agricultural setting

### 3. Key Challenges in Contemporary Veterinary Practice

Although most people accept the fact that AMR crisis has taken place, there is a lot of challenge in the adoption of effective control measure in the field.

#### 3.1 Diagnostic Limitations and Latency

Culture and antimicrobial susceptibility testing (AST) is the standard of prudent prescribing. Nevertheless, in most of the agricultural environments, especially remote ones or resource-constrained, there is limited access to the veterinary diagnostic laboratories. Conventional microbiological methods take an average of 48-72 hours to give results. In acute clinical cases, e.g. bovine respiratory disease or neonatal diarrhoea, the veterinarian does not have this time to waste and must use empirical treatment, perhaps using historical farm records or clinical experience.

#### 3.2 Economic Pressures on Producers

Agriculture is a low margin business. Antibiotics in most production systems are viewed as a cheap insurance policy against disease outbreak caused by intensive husbandry environment (e.g. excessive stocking densities or inappropriate ventilation). Other options like better biosecurity facilities, vaccination, or probiotic feed supplements have high initial capital investment requirements or increased operating costs and producers often cannot absorb this cost without a subsidy or regulatory obligation.

#### 3.3 Regulatory and Surveillance Gaps

Though advanced countries have developed surveillance systems (e.g., NARMS in USA, CIPARS in Canada, EFSA networks in Europe), the data on the whole world is dispersed. In most places, the veterinary antimicrobials are sold over the counter without the supervision of professional personnel hence their unregulated and in most cases inappropriate use. Moreover, the regulatory channels of granting approvals to alternatives to antibiotics like phage therapy or new immunomodulators are often complicated and time-consuming.

Table 1. Major Barriers to Antimicrobial Reduction in Veterinary Medicine

Challenge Category	Specific Obstacle	Impact on AMR Mitigation
<b>Diagnostic</b>	Long turnaround time for Culture & Susceptibility (C&S).	Forces reliance on empirical, broad-spectrum therapy rather than targeted, narrow-spectrum treatment.
	Cost of diagnostic testing relative to the value of individual animals (e.g., poultry, small ruminants).	Discourages testing; encourages mass medication based on flock/herd symptoms.
<b>Economic/Management</b>	Perceived low cost of antibiotics vs. high cost of structural biosecurity improvements.	Maintains reliance on chemical management of disease rather than environmental management.
	Intensive farming practices (high stocking density).	Increases disease transmission rates, necessitating frequent metaphylactic interventions.
<b>Knowledge/Behavioral</b>	Lack of veterinary oversight in some jurisdictions (OTC sales).	Leads to incorrect dosing, inappropriate drug selection, and failure to observe withdrawal periods.
	Client pressure for "quick fix" solutions.	Veterinarians may prescribe antimicrobials to satisfy client expectations even when viral etiology is suspected.

#### 4. Control Strategies

The fight against AMR would be a multifaceted one that is focused on Antimicrobial Stewardship (AMS). Veterinary medicine AMS is the conglomeration of activities that would assist in the responsible utilization of antimicrobials to maintain their effectiveness and guarantee animal well-being and health.

##### 4.1 Implementing Antimicrobial Stewardship Programs (ASPs)

An effective ASP shifts the focus from treating disease to managing health. Key tenets include:

- Commitment to the 5 R's:** Responsibility, Reduction, Refinement, Replacement, and Review.
- Evidence-Based Prescribing:** Evidence-Based Prescribing (Use Narrow-spectrum antimicrobials) - References: VICH (International Cooperation on Harmonisation of Technical Requirements for registration of Veterinary Medicinal Products) guidelines and national formularies should be used, and narrow-spectrum antimicrobials should be prioritised whenever possible, based on the results of AST.
- Categorization of Critically Important Antimicrobials (CIAs):** Categorisation of Critically Important Antimicrobials (CIAs) - Compliance with the lists provided by World Health Organization (WHO) and World Organisation for Animal Health (WOAH) lists according to which antimicrobials are categorised into the most important ones in terms of human medicine. CIAs with highest priority (such as fluoroquinolones, 3rd/4th generation cephalosporins, colistin) should be saved as the last-resort therapy in veterinary medicine and only used when diagnostic tests rule out other alternative treatment.

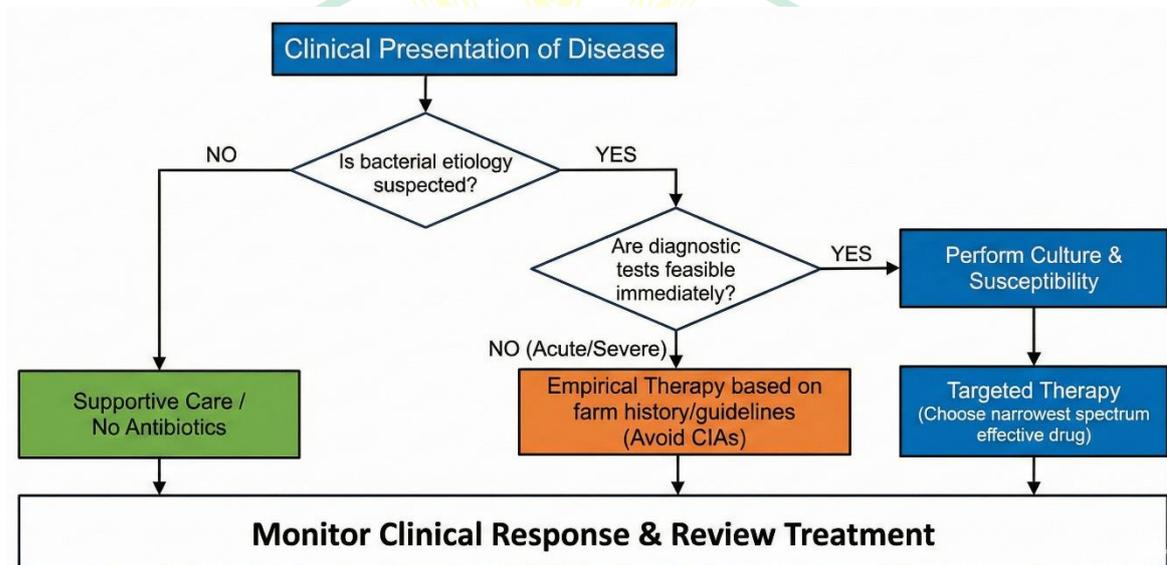


Figure 2. Decision Tree for Antimicrobial Use

##### 4.2 Infection Prevention and Control (IPC) and Biosecurity

Prevention of the diseases that require antimicrobial use is the best way of reducing antimicrobial use. The core of IPC is healthy biosecurity.

- External Biosecurity:** The process of preventing the entry of pathogens to the farm (e.g., quarantine measures of new animals, disinfection of vehicles, controlled access of visitors).
- Internal Biosecurity:** Inclusion of pathogen spread in a farm (e.g. all-in/all-out production systems, age separation, strict clean and disinfection measures between batches).
- Vaccination:** The secondary bacterial infections which commonly need antimicrobial therapy (e.g., bacterial pneumonia in cattle is reduced by vaccination against viral respiratory pathogens) are hugely reduced through maximization of the utilization of existing vaccines against viral and bacterial pathogens.

##### 4.3 Nutritional and Husbandry Alternatives

Optimizing animal resilience reduces susceptibility to infection. This involves:

- a) **Gut Health Management:** The use of prebiotics, probiotics, organic acids, and enzymes to maintain a healthy gut microbiome, which acts as a barrier to pathogen colonization.
- b) **Environmental Management:** Improving ventilation to reduce respiratory challenges, managing litter quality to prevent pododermatitis in poultry, and reducing stocking densities to lower stress and pathogen loads.

**Table 2: Practical Implementation of Stewardship Principles at the Farm Level**

Principle	Actionable Steps for Veterinarians and Producers
<b>Prevention First</b>	Develop comprehensive herd/flock health plans focusing on vaccination and biosecurity audits.
<b>Diagnosis-Driven Therapy</b>	Invest in rapid, on-farm diagnostic tools where available. Mandate C&S testing for treatment failures or recurrent cases.
<b>Prudent Selection</b>	Utilize veterinary formularies that categorize drugs by importance. Avoid using Highest Priority CIAs for routine therapy.
<b>Dosage Optimization</b>	Ensure dosing is based on accurate body weight estimates. Adhere strictly to recommended treatment durations; do not under-dose or end treatment prematurely.
<b>Record Keeping</b>	Maintain detailed records of all antimicrobial treatments (drug, dose, duration, indication, animals treated) to identify trends and areas for improvement.

## 5. The One Health Imperative and Future Outlook

Veterinary medicine does not exist in a vacuum. The resistance traits selected for in animal agricultural environments have direct routes to human populations.

- a) **Direct Contact:** Farmers, veterinarians, and abattoir workers are at higher risk of colonization by resistant zoonotic bacteria (e.g., MRSA, resistant *E. coli*).
- b) **Foodborne Transmission:** Resistant bacteria can contaminate meat and milk products during processing.
- c) **Environmental Pathways:** Land application of animal manure containing drug residues and resistant bacteria contaminates soil and groundwater, impacting wildlife and potentially entering human water sources.

The future of AMR control relies on strengthening this One Health collaboration. This includes integrated surveillance systems that track resistance patterns simultaneously across human, animal, and environmental samples. It also requires continued investment in research for novel non-antibiotic therapies, such as bacteriophage therapy, CRISPR-Cas antimicrobial systems, and virulence inhibitors that disarm bacteria rather than killing them, thereby reducing selection pressure.

## 6. Conclusion

Antimicrobial resistance is a defining challenge for modern veterinary practice, threatening the sustainability of animal agriculture and public health security.<sup>24</sup> The era of unbridled antimicrobial use is over. While significant challenges exist regarding diagnostics, economics, and behavioral change, the transition to a stewardship-based model is not optional; it is essential. By prioritizing biosecurity, embracing diagnostic-driven therapy, and strictly adhering to guidelines for limiting critically important antimicrobials, the veterinary profession can safeguard animal health while fulfilling its crucial duty within the "One Health" framework to preserve the efficacy of these life-saving drugs for future generations.

## References

- Caneschi, A., Bardhi, A., Barbarossa, A., & Zaghini, A. (2023). The use of antibiotics and antimicrobial resistance in veterinary medicine, a complex phenomenon: A narrative review. *Antibiotics*, 12(3), 487. <https://doi.org/10.3390/antibiotics12030487>
- Cazer, C. L., Frye, A., Lawless, J. W., Gonzalez, L., Cobo-Angel, C., & Safi, A. G. (2023). Pathways to sustainable antimicrobial use in cats. *Journal of the American Veterinary Medical Association*, 261(12), 1769–1780. <https://doi.org/10.2460/javma.23.08.0481>
- Cheng, G., Hao, H., Xie, S., Wang, X., Dai, M., Huang, L., & Yuan, Z. (2014). Antibiotic alternatives: The substitution of antibiotics in animal husbandry? *Frontiers in Microbiology*, 5, 217. <https://doi.org/10.3389/fmicb.2014.00217>

Enshaie, E., Nigam, S., Patel, S., & Rai, V. (2024). Livestock antibiotics use and antimicrobial resistance. *International Journal of Molecular Sciences*, 25(21), 12891. <https://doi.org/10.3390/ijms252112891>

Frey, E., Costin, M., Granick, J., Kornya, M., & Weese, J. S. (2022). 2022 AAEP/AAHA antimicrobial stewardship guidelines. *Journal of the American Animal Hospital Association*, 58(4), 1–5. <https://doi.org/10.5326/1547-3317-58.4.1>

Horvat, O., & Kovačević, Z. (2025). Human and veterinary medicine collaboration: Synergistic approach to address antimicrobial resistance through the lens of planetary health. *Antibiotics*, 14(1), 38. <https://doi.org/10.3390/antibiotics14010038>



## Application of Artificial Intelligence and Machine Learning Techniques for Soil Fertility Evaluation



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### 1. Introduction

Since soil is a complex medium, it is heterogeneous. The chemical and physical characteristics of it change considerably in the short distances, i.e. a phenomenon called spatial variability. Conventional soil testing is based on composite sampling and then extraction, titration or colorimetry, which presumes that the soil is homogenous in the field, that is, hectares of land are regarded as a homogenous unit. However, the imperfection of this assumption is revealed by the yield monitors and satellite imagery regularly. The different levels of soil fertility spread the so-called average fertilizer dilemma: a universal rate based on an average soil test value causes under-fertilization of soil in the areas that are nutrient poor and over-fertilization of the soils in the nutrient-rich areas, thus wasting the resources. This variability requires the use of high-density sampling to control this variability, yet the cost of obtaining an analysis on hundreds of samples per hectare using wet chemistry is prohibitive, thus becoming a bottleneck. This problem has led to the development of Digital Soil Mapping (DSM) and Pedometrics- areas that have used mathematical and statistical models to estimate soil properties by using environmental covariates and sensor measurements. The recent advantage of the computational power has made these areas move past the simple geostatistics (kriging) to advanced AI and ML methods. These methods do not consider soil analysis a purely chemical problem but a data pattern recognition problem by utilizing spectral signatures to predict non-destructively and quickly non-destructively fertility parameters.

### 2. The Technological Backbone

The input data of AI models needs to be strong. The data of this information is mostly obtained by three methods namely Proximate Sensing, Remote Sensing and Environmental Covariates in the contemporary soil fertility assessment process.

#### 2.1 Proximate Soil Sensing (PSS)

PSS involves sensors placed in direct contact with or very close to the soil.

- a) **Vis-NIR Spectroscopy (350–2500 nm):** Vis-NIR Spectroscopy (350–2500 nm): This is the most commonly adopted analysis. The soil constituents that have C-H, N-H, and O-H bonds absorb light at the respective frequencies because of the molecular vibrations- overtones and combinations bands. Although basic vibrations take place in the Mid-Infrared (MIR) they have their overtones in the Near-Infrared (NIR) and are very useful in estimating Soil Organic Carbon (SOC), moisture, and clay content.
- b) **X-Ray Fluorescence (pXRF):** Portable XRF devices excite the soil using high-energy X-rays, which make the elements emit secondary fluorescent X-rays. This technique is the gold standard of quick heavy-metal and total elemental analysis of micronutrients like Iron (Fe), Manganese (Mn), Zinc (Zn) and Copper (Cu).
- c) **Electromagnetic Induction (EMI):** These types of sensors measure the Apparent Electrical Conductivity (ECa), which has a close relationship with salinity of soil, soil texture and moisture-holding capacity.

#### 2.2 Remote Sensing (RS)

Satellite and aerial platforms provide the spatial continuum.

- a) **Multispectral Imagery:** Satellites such as Sentinel -2 and Landsat -9 are reflectance satellites that measure data in separate bands. Bare-soil composite images and soil indices allow mapping of SOC and surface variability of large areas.
- b) **Hyperspectral Imaging:** Hyperspectral instruments capture hundreds of narrow adjacent bands in contrast with multispectral sensors, thus allowing subtle absorption features (which can be attributed to a particular mineral) to be observed (e.g. clay mineralogy) that cannot be seen with a broader sensor.

### 2.3 Environmental Covariates

Based on the SCORPAN model (Soil = f(Soil, Climate, Organisms, Relief, Parent Material, Age, Nature)), AI models often incorporate non-spectral data:

- a) **Digital Elevation Models (DEM):** attributes like slope, aspect, and Topographic Wetness Index (TWI) drive nutrient leaching and accumulation.
- b) **Climatic Data:** Precipitation and temperature gradients influence weathering rates and organic matter decomposition.

### 3. Machine Learning Architectures in Pedometrics

The correlation between the spectral signature of a soil and its chemical concentration is not often linear. Noise and complicated interference patterns are introduced by soil moisture, particle size and mineralogy. AI/ML algorithms are good at separating these complex signals.

#### 3.1 Chemometrics: Partial Least Squares Regression (PLSR)

While arguably a statistical method rather than pure AI, PLSR is the benchmark algorithm in soil spectroscopy. It addresses the issue of multicollinearity (where adjacent spectral bands are highly correlated) by projecting the data into a lower-dimensional space of latent variables.

- **Pros:** Computationally fast, interpretable coefficients.
- **Cons:** Assumes linear relationships; often underperforms in predicting complex nutrients like extractable Phosphorus (P).

#### 3.2 Machine Learning (Non-Linear)

To capture non-linear dependencies, advanced ML algorithms are employed.

- a) **Random Forest (RF):** RF is an ensemble-learning method, which uses many decision trees in its training process. In case of regression, it generates an average prediction of all trees.
  - **Mechanism:** RF is a highly robust model against over-fitting and noisy spectral data, and it achieves this by bagging (bootstrap aggregating) and random feature selection. It also provides a measure called Variable Importance that aids the researcher to know the wavelengths that have the greatest impact on a particular nutrient.
- b) **Support Vector Machines (SVM):** SVM maps input vectors to a high-dimensional feature space using a kernel function (e.g. Radial Basis Function). It tries to fit the hyperplane which fits the data in a  $\epsilon$ -insensitive tube in the best way possible. SVMs do well with small and high dimensional data.
- c) **Cubist:** A model in the extension of the M5 model tree. It produces a set of rules of the form of if-then; each terminal node of the rule gets a special linear regression model. This combination technique is frequent to produce better outcomes on the soil properties that differ significantly among the landscape positions.

#### 3.3 Deep Learning (DL)

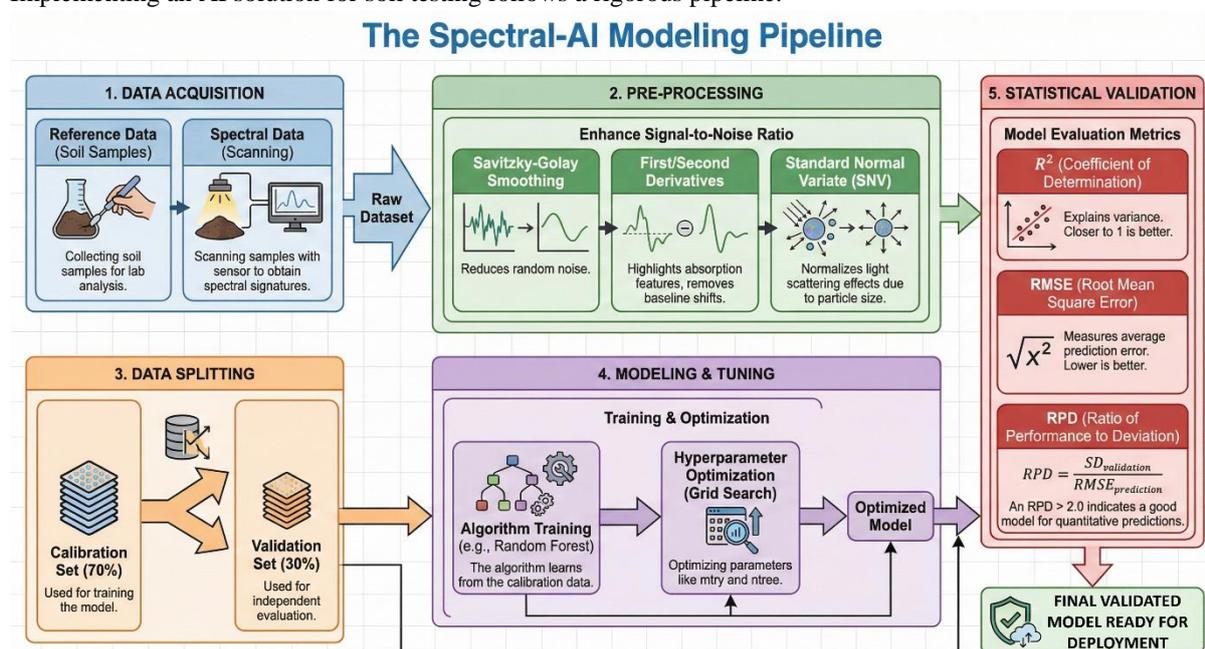
Deep Learning and, specifically, Convolutional Neural Networks (CNNs) are the forerunners of soil AI. First, CNNs were created to work with 1-D spectral data after they were originally created to work with image recognition. CNNs do not need preprocessing (smoothing, derivatives) regularly, unlike RF or PLSR, but learn representations of features of spectral data directly when the data are presented as raw spectra, preserving local patterns and shapes in the spectral curve that are not recognized by traditional techniques.

**Table 1: Comparative Analysis of Algorithms for Soil Fertility Evaluation**

Algorithm	Type	Complexity	Best Suited For	Key Limitation
PLSR	Linear / Chemometric	Low	SOC, Total N, Calibration baselines	Fails to capture non-linear spectral interference.
Random Forest	Ensemble / Non-linear	Medium	Regional mapping, noisy data, feature selection	Can overlook linear trends; predictions are bounded by the training range.
SVM	Kernel-based	High	Small datasets, specific micronutrients	Computational cost rises with dataset size; Black Box nature.
Cubist	Rule-based	Medium	SOC, Clay, pH	Sensitive to tuning parameters; complex to interpret.
CNN (Deep Learning)	Neural Network	Very High	Large spectral libraries, Hyperspectral imagery	Requires massive training data; computationally expensive (GPU).

#### 4. Methodology: The AI-Soil Workflow

Implementing an AI solution for soil testing follows a rigorous pipeline.



**Figure 1. The Spectral-AI Modelling Pipeline**

#### Application Focus: Predicting Specific Nutrients

##### 4.1 Soil Organic Carbon (SOC)

Vis-NIR spectroscopy with ML has the highest predictability of SOC. The whole organic matter has direct spectral responses in the NIR region - primarily at 1400, 1900 and 2200 nm.

- *Current Status:* AI models regularly achieve  $R^2 > 0.85$  for SOC.
- *Application:* Rapid calculation of Carbon Credits and monitoring soil health.

##### 4.2 Macronutrients (N, P, K)

- **Nitrogen (N):** Total N correlates highly with SOC (C:N ratio), making it relatively easy to predict. However, nitrate ( $NO_3^-$ ), the plant-available form, is mobile and difficult to detect spectrally.
- **Phosphorus (P) and Potassium (K):** These minerals do not have strong, direct spectral features in the Vis-NIR range. Prediction relies on covariation mechanisms where the AI model detects minerals (like Iron oxides or Clay) that hold P and K, and infers the nutrient level.
- **ML Performance:** Variable. Deep Learning and Hybrid approaches (Vis-NIR + XRF) are showing promise in improving P and K prediction ( $R^2$  typically 0.60 – 0.75).

##### 4.3 Micronutrients (Zn, Fe, Mn, Cu)

Predicting DTPA-extractable micronutrients is a frontier research area.

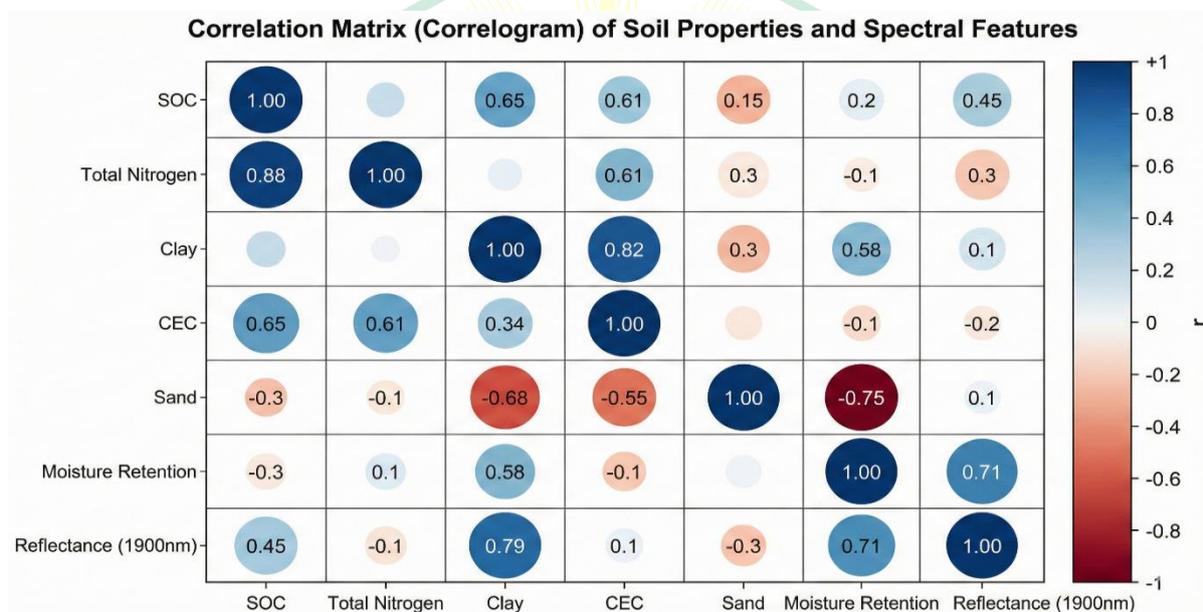
- **Iron (Fe):** Highly predictable due to strong colour and spectral influence in the visible range (hematite/goethite peaks).
- **Zinc (Zn) and Copper (Cu):** These exist in trace amounts (ppm). While difficult for Vis-NIR alone, the integration of **pXRF** (which directly measures total elemental composition) with ML regressions allows for accurate conversion of total metal to available metal, which is crucial for agronomic recommendations.

**5. Case Study Simulation: Vis-NIR Prediction Results**

To illustrate the efficacy of these methods, consider a simulated dataset of 500 soil samples processed using a Gradient Boosting Machine (GBM) model.

**Table 2: Performance Metrics of ML Model for Various Properties**

Soil Property	Band Usage	R <sup>2</sup> (Validation)	RMSE	RPD	Interpretation
<b>Organic Carbon (%)</b>	Vis-NIR (Full)	0.88	0.12	2.65	<b>Excellent</b>
<b>Clay Content (%)</b>	Vis-NIR (SWIR)	0.82	3.50	2.10	<b>Good</b>
<b>Available N (kg/ha)</b>	Vis-NIR	0.71	15.2	1.85	<b>Moderate</b>
<b>Available P (kg/ha)</b>	Vis-NIR + pH	0.64	5.10	1.55	<b>Fair (Screening only)</b>
<b>Exch. K (mg/kg)</b>	Vis-NIR + EC	0.69	22.5	1.70	<b>Fair</b>
<b>Iron (Fe) (ppm)</b>	Vis-NIR (Vis)	0.85	1.80	2.30	<b>Good</b>



**Figure 2. The Correlation Matrix (Correlogram) of Soil Properties and Spectral Features**

A correlation plot (typically generated using R libraries like corrplot) reveals the inter-dependencies utilized by the ML model.

- Strong Positive Correlation:** Visible between SOC and Total Nitrogen (dark blue circles), and between Clay and Cation Exchange Capacity (CEC).
- Negative Correlation:** Often observed between Sand content and Moisture retention.
- Spectral Correlation:** High correlation exists between reflectance at 1900nm (water band) and Clay content, explaining why the model predicts texture well.

**6. Challenges and Future Directions**

While the potential is immense, the transition from Research to Farm faces hurdles.

**6.1 The Transferability Crisis**

A recurring issue in Soil Spectroscopy is that a model trained in one region (e.g., the black soils of Central India) often fails when applied to another (e.g., the alluvial soils of the Indo-Gangetic plains). This is due to differences in parent material and mineralogy.

- **Solution:** Spiking and Transfer Learning. This involves taking a global spectral library (like the USGS or ICRAF libraries) and spiking it with a few local samples to recalibrate the AI model for the new site.

## 6.2 Interpretability vs. Accuracy

As models become more complex (Deep Learning), they become Black Boxes. An agronomist cannot easily see why a neural network predicted low Zinc. This lack of transparency can hinder trust.

- **Trend:** Explainable AI (XAI) techniques, such as SHAP (SHapley Additive exPlanations), are being introduced to map spectral features back to chemical properties, making the models transparent.

## 6.3 Data Fusion

The future lies in multi-sensor fusion. Combining the spectral resolution of laboratory/proximate sensors with the spatial coverage of satellite imagery allows for the generation of digital soil maps at 10m resolution. Research is currently moving towards On-the-Go sensors mounted on tractors that feed data into edge-computing AI systems, generating real-time variable-rate fertiliser maps during the tillage operation itself.

## 7. Conclusion

The application of Artificial Intelligence and Machine Learning in soil fertility evaluation represents a definitive leap forward in agricultural science. It addresses the critical limitations of wet chemistry cost, speed, and environmental waste transforming soil analysis into a high-throughput, data-driven discipline.

While algorithms like PLSR provided the foundation, the integration of non-linear ML models like Random Forest and Deep Learning has significantly improved prediction accuracies for complex soil parameters. As we refine these models to handle regional variability and integrate them with remote sensing platforms, we move closer to the ultimate goal of Precision Agriculture: the right nutrient, at the right rate, at the right time, and in the right place. The soil lab of the future is not a room full of beakers, but a robust database and a powerful algorithm.

## References

- Chandra, H., Pawar, P. M., Elakkiya, R., Tamizharasan, P. S., Muthalagu, R., & Panthakkan, A. (2023). Explainable AI for soil fertility prediction. *IEEE Access*, *11*, 97866–97878. <https://doi.org/10.1109/ACCESS.2023.3311827>
- Padarian, J., Minasny, B., & McBratney, A. B. (2020). Machine learning and soil sciences: A review aided by machine learning tools. *SOIL*, *6*(1), 35–52. <https://doi.org/10.5194/soil-6-35-2020>
- Sarangi, A., Raula, S. K., Ghoshal, S., Kumar, S., Kumar, C. S., & Padhy, N. (2024). Enhancing process control in agriculture: Leveraging machine learning for soil fertility assessment. *Engineering Proceedings*, *67*(1), 31. <https://doi.org/10.3390/engproc2024067031>
- Viscarra Rossel, R. A., Behrens, T., Ben-Dor, E., Brown, D. J., Demattê, J. A. M., Shepherd, K. D., Shi, Z., Stenberg, B., Stevens, A., Adamchuk, V., et al. (2016). A global spectral library to characterize the world's soil. *Earth-Science Reviews*, *155*, 198–230. <https://doi.org/10.1016/j.earscirev.2016.01.012>
- Wadoux, A. M. J.-C., Minasny, B., & McBratney, A. B. (2020). Machine learning for digital soil mapping: Applications, challenges and suggested solutions. *Earth-Science Reviews*, *210*, 103359. <https://doi.org/10.1016/j.earscirev.2020.103359>
- Zeng, P., Song, X., Yang, H., Wei, N., & Du, L. (2022). Digital soil mapping of soil organic matter with deep learning algorithms. *ISPRS International Journal of Geo-Information*, *11*(5), 299. <https://doi.org/10.3390/ijgi11050299>
- Zhang, Y., Lei, M., Li, K., & Ju, T. (2023). Spatial prediction of soil contamination based on machine learning: A review. *Frontiers of Environmental Science & Engineering*, *17*, Article 114. <https://doi.org/10.1007/s11783-023-1693-1>

# Application of Biochar and Nanomaterials for Enhancing Soil Fertility and Crop Performance



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## 1. Introduction

The need to have sustainable agricultural intensification is beyond doubt. With intensive cultivation, soil erosion, and salinization, soil health, which is the basis of terrestrial ecosystems and agricultural production, is in dire threat. Traditional methods of soil fertility restoration extensively depend on synthetic nitrogen (N), phosphorus (P) and potassium (K). Although they work in the short run, the intensity with which these inputs are inefficient poses a significant problem; usually, less than 50 percent of applied nitrogen is absorbed by the crops, and the remaining parts are lost to leaching, volatilisation, and denitrification, thus leading to eutrophication and atmospheric pollution.

To overcome these systemic inefficiencies, there is a growing tendency in agricultural science towards industry materials that control the soil environment at the basic levels. The two materials that are currently experiencing high momentum are biochar and agricultural nanomaterials. Biochar is an ancient idea rejuvenated by contemporary science; it finds its main application as the carrier of carbon and soil conditioning. Nanotechnology is the next generation in the world of materials science, which involves the atomic and molecular control of matter (1-100nm) to produce fertilizers and pesticides with new characteristics.

## 2. Biochar: Mechanisms of Soil Improvement

Biochar is a porous black solid that is rich in carbon and has been formed through thermochemical conversion (pyrolysis) of organic biomass under an oxygen-restricted environment. Biochar, in contrast to an unprocessed organic matter, is extremely aromatic and recalcitrant and cannot be broken down by microbes, remaining in the soil centuries. The soil matrix is essentially changed with its application.

### 2.1 Impact on Soil Physicochemical Properties

The quality of biochar depends mostly on its feedstock and pyrolysis temperature that defines the surface area and porosity as well as the composition of functional groups.

- a) **Porosity and Water Holding Capacity (WHC):** Biochar has a complicated internal pore structure. When it is added to coarse-textured soils, it dramatically enhances overall porosity and WHC and lowers irrigation needs and makes crops more resilient to drought stress.
- b) **Cation Exchange Capacity (CEC) and pH:** With time, biochar undergoes oxidation on its surface (developing negative charges (carboxylic and phenolic groups). This enhances the CEC of the soil, which has the capacity to hold positively charged nutrient ions ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$ ,  $\text{NH}_4^+$ ) and hence stabilize nutrient leaching. Moreover, a majority of biochars are alkaline and they are liming agents which alleviate soil acidity and release unavailable phosphorus in low-pH soils.

### 2.2 Impact on Soil Microbiology

Biochar forms a special micro-housing. The soil bacteria and mycorrhizal fungi are sheltered by its pores against biotic and abiotic stressors. Biochar adsorbs organic molecules and nutrients by creating hotspots of microbial activity, which improves nutrient-cycling processes including nitrification and solubilisation of phosphorus.

## 3. Nanomaterials in Agriculture: Precision and Efficiency

Nanotechnology in agriculture does not focus on feeding the soil but focuses on feeding the plant, but in a very precise manner. Nanomaterials used in agriculture that are mainly nano-fertilisers and nano-pesticides take advantage of the physicochemical characteristics that become apparent at the nanoscale, including ultra-high surface-volume ratios and reactivity.

### 3.1 Nano-fertilizers

Traditional bulk fertilisers are fast to dissolve and the nutrients are often absorbed faster by the plants than by the conventional fertilisers. Nano-fertilisers deal with this in a number of ways:

- Targeted Delivery:** Nanoparticles can be designed to react to particular stimuli in the environment, e.g. rhizosphere pH, root exudates and to release nutrients only where and when needed.
- Slow/Controlled Release:** Nutrients may be encased in polymeric or inorganic nanomaterials, or as nanoscale particles (e.g. nano-hydroxyapatite phosphorus). This produces a stable crop supply of nutrients throughout the crop cycle, similar to plant uptake curves and reducing losses.
- Enhanced Uptake Efficiency:** Due to their small size, nanoparticles have the potential to penetrate the plant cell walls and cuticles more easily than ionic nutrients, which use other pathways of uptake and are more mobile throughout the system.

### 3.2 Beyond Nutrition: Nano-sensors and Ameliorants

Still other applications of nanomaterials include soil remediation (immobilising heavy metals) and sensing. The soil matrix nano-sensors would provide real-time information as to the moisture and nutrient levels so that irrigation and fertilisation could be done with hyper-precision.

**Table 1. Summary of Biochar Effects on Key Soil Parameters**

Soil Parameter	Primary Effect of Biochar Application	Underlying Mechanism
<b>Soil Organic Carbon (SOC)</b>	Significant, long-term increase.	Biochar is highly recalcitrant to microbial decomposition, sequestering carbon.
<b>Water Holding Capacity</b>	Increased, especially in sandy soils.	High internal porosity and surface area act as a sponge.
<b>Cation Exchange Capacity</b>	Increased retention of cations (K <sup>+</sup> , NH <sub>4</sub> <sup>+</sup> , etc.).	Development of negatively charged functional groups on biochar surfaces over time.
<b>Soil pH</b>	Generally increased (liming effect).	Alkaline nature of most biochar ash residues; carbonates present.
<b>Bulk Density</b>	Decreased.	Biochar is lower density than mineral soil, aiding aeration and root penetration.
<b>Microbial Biomass</b>	Increased abundance and activity.	Provision of habitat (pore space) and substrates (adsorbed organic matter).

## 4. Synergistic Applications: The Biochar-Nanomaterial Nexus

Although biochar and nanomaterials have their own benefits, they have their own limitations. Even though biochar is an excellent soil conditioner, in many cases it is not rich in nutrients that are readily available. Nanomaterials are effective but costly and can be a source of potential ecotoxicological risks, when it moves too freely in the environment.

The resulting product of the combination of these materials is a synergistic biochar based nanocomposite or biochar based nanomaterial (BSN) to cope with the weaknesses of the individual materials.

### 4.1 Mechanisms of Synergy

In this combined strategy, biochar is a stable and high-concentration carbon scaffold/carrier of highly reactive nanomaterials.

- Immobilization and Reduced Runoff:** The large surface area and CEC of biochar can adsorb metal-oxide nanoparticles (nano-ZnO or nano-CuO) strongly or nutrients can be deposited in its pore network. This fixes the nanoparticles in the root zone region so that they cannot be washed away to water bodies and cause any possible toxicity to non-target organisms.
- Enhanced Slow Release:** As the nutrients are loaded into the biochar pores by means of nanomaterial precursors, the rate of nutrient release is additionally suppressed by the physical barrier of the biochar structure, which lengthens the nutrient availability period during the growing season.
- Microbial Stimulation:** Biochar forms the habitat, and nano-fertilisers contribute the necessary micronutrients, which can inhibit microbial enzymes. An example is nano-iron or nano-molybdenum that is loaded on biochar and that induces nitrogen-fixing bacteria.

The combination of these strategies is an effective way to build an intelligent soil amendment, which has enhanced physical structure, but serves as an efficient nutrient reserve, which is slow-releasing.

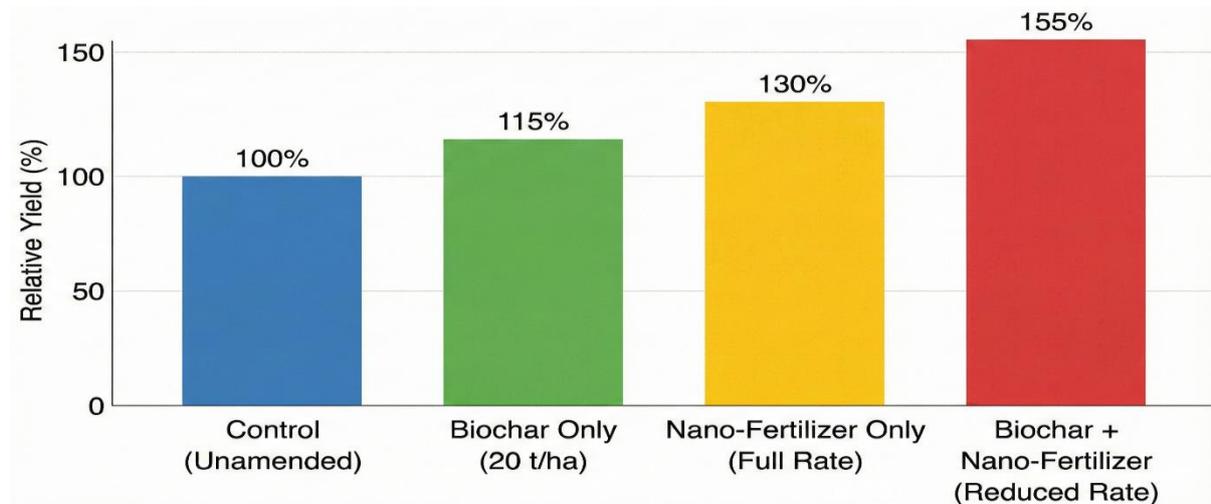


Figure 1. Comparison of Conventional vs. Nano-Fertilizer Dynamics in Soil

## 5. Effects on Crop Performance

Crop performance is the final indicator of any agricultural input and it consists of yield, nutrition quality and ability to endure stress. The process of biochar and nanomaterial integration brings soil enhancement to actual plant gains.

### 5.1 Nutrient Use Efficiency (NUE) and Yield

Massive enhancement of NUE is the key element contributing to higher yields in biochar-nano systems. With a reduced rate of losses and the ability to release nutrients when required by the plant, crops receive the best nutrient supplement at the most crucial periods of their growth (e.g. flowering and grain filling). Surveys have indicated that biochar with a nano-NPK can yield equal or better than conventional fertilisers using 20-30 per cent less total nutrient doses.

### 5.2 Alleviation of Abiotic Stress

Climate change increases the occurrence of the abiotic stresses including drought and salinity.

- **Drought:** Biochar's water retention properties ensure moisture availability during dry spells.
- **Salinity:** Biochar has the ability to adsorb surplus sodium ions. At the same time, some of the nanomaterials (e.g., nano-silicon or nano-selenium) that are implanted through biochar vectors can improve the physiological antioxidant defence of a plant, which alleviates the salt-induced oxidative stress.

## 6. Challenges, Risks, and Future Perspectives

Despite the immense promise, the widespread adoption of biochar-nanomaterial systems faces significant hurdles that require rigorous academic and practical investigation.

### 6.1 Ecotoxicology and Environmental Fate

The behaviour of nanomaterials in the complex soil matrix is not fully understood. There are legitimate concerns regarding the long-term accumulation of engineered nanoparticles in soil. Key questions remain:

- Do nanoparticles adversely affect beneficial soil microbiomes (e.g., mycorrhizae or nitrogen fixers) over prolonged exposure?
- Is there a risk of nanoparticles entering the food chain through plant uptake? While embedding nanoparticles in biochar seems to mitigate movement, long-term degradation studies are necessary.

### 6.2 Regulatory and Standardization Issues

Currently, regulatory frameworks for agricultural nanomaterials are nascent globally. Furthermore, biochar is not a uniform product; its properties vary wildly based on feedstock and production method. Standardizing biochar-nanocomposites to ensure consistent performance and safety is a major challenge for commercialization.

### 6.3 Economic Viability

While biochar can be produced locally, high-quality agricultural nanomaterials are currently expensive to synthesize. Production costs must decrease, or the agronomic returns (yield gains and fertilizer savings) must be substantial enough to justify the investment for average farmers.

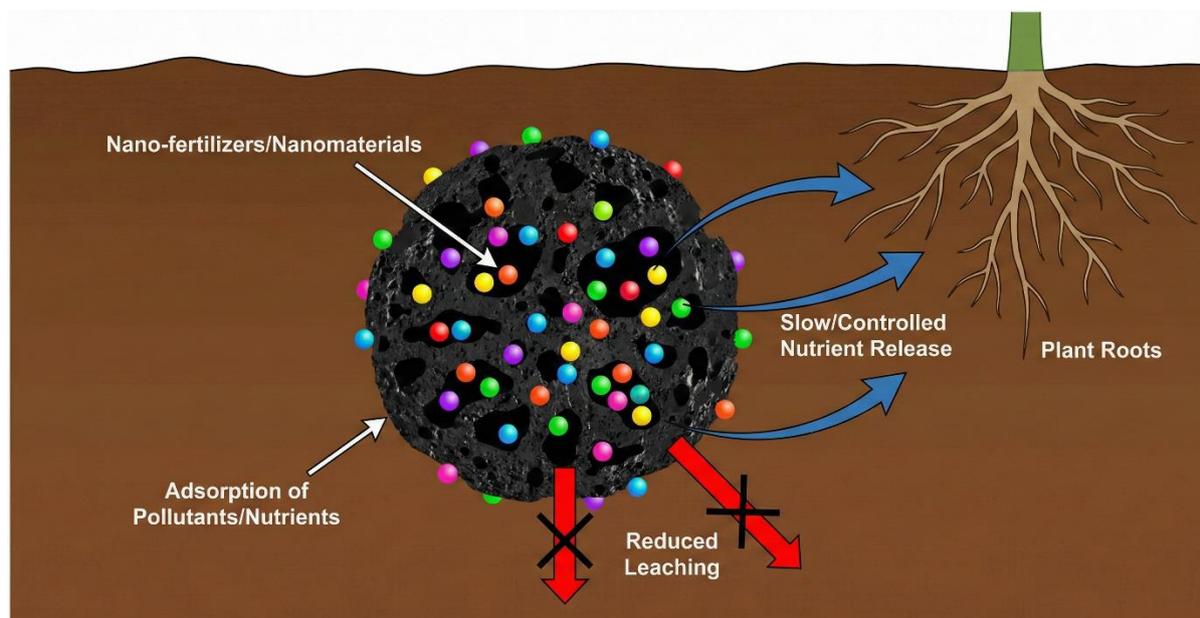


Figure 2. Crop Yield Response to Different Soil Amendment Strategies

### 7. Conclusion

The convergence of biochar technology and nanotechnology offers a transformative approach to sustainable soil management. Biochar provides the necessary reconstruction of degraded soil physical and biological architecture, while nanomaterials offer unprecedented control over chemical fertility and nutrient use efficiency. The synergistic application of these materials using biochar as a stable carrier for reactive nano-agents represents a significant leap forward from conventional agricultural practices.

Moving forward, research must transition from short-term pot trials to long-term field studies to validate the persistence of these benefits and rigorously assess environmental safety. If the challenges of cost, standardization, and safety can be navigated, biochar-nanomaterial composites could become cornerstone tools in the global effort to achieve food security without compromising planetary boundaries.

### References

- Al-Wabel, M. I., Al-Omran, A., El-Naggar, A. H., Nadeem, M., & Usman, A. R. (2013). Pyrolysis temperature induced changes in physical and chemical characteristics of corn stover biochar. *Bioresource Technology*, *131*, 374–379. <https://doi.org/10.1016/j.biortech.2012.12.165>
- El-Ramady, H., Alshaal, T., Abowaly, M., Abd Alla, E., Taha, H. S., Domokos-Szabolcsy, É., Fari, M., & El-Marsafawy, S. (2018). Nanotechnology in sustainable agriculture: Recent trends and future perspective. *Egyptian Journal of Basic and Applied Sciences*, *2*(3), 1–16. <https://doi.org/10.1016/j.ejbas.2018.06.002>
- Gao, M., Yang, L., DeRycke, E. G., & Hussain, M. (2020). Carbon-based nanomaterials: A promising avenue for sustainable agriculture. *Journal of Agricultural and Food Chemistry*, *68*(43), 11679–11693. <https://doi.org/10.1021/acs.jafc.0c03975>
- Hossain, M. Z., Bahar, M. M., Sarkar, B., Donne, S. W., Ok, Y. S., Palansooriya, K. N., Kirkham, M. B., Chowdhury, S., & Bolan, N. (2020). Biochar and its broad impacts in soil quality and fertility, nutrient leaching and crop productivity: A review. *Journal of Environmental Chemical Engineering*, *8*(3), 103746. <https://doi.org/10.1016/j.jece.2020.103746>

- Kah, M., Kookana, R. S., Gogos, A., & Bucheli, T. D. (2018). A critical evaluation of nanopesticides and nanofertilizers against their conventional analogues. *Nature Nanotechnology*, 13(8), 677–684. <https://doi.org/10.1038/s41565-018-0131-1>
- Lehmann, J., & Joseph, S. (Eds.). (2015). *Biochar for environmental management: Science, technology and implementation* (2nd ed.). Routledge.
- Mansour, E., & Desoky, E. M. (2022). Biochar and nanoparticles: A new approach for mitigating abiotic stress in plants. In V. D. Rajput (Ed.), *Nanotechnology and Plant-Microbe Interactions* (pp. 145–168). Elsevier.
- Mittal, D., Kaur, G., Singh, P., Yadav, K., & Ali, S. A. (2020). Nanoparticle-based sustainable agriculture and food science: Recent advances and future outlook. *Frontiers in Nanotechnology*, 2, 579954. <https://doi.org/10.3389/fnano.2020.579954>
- Premarathna, K. S. D., Manishankha, A., Sarkar, B., Vithanage, M., & Ok, Y. S. (2019). Biochar-based engineered composites for sorptive removal of contaminants from water: A critical review. *Bioresource Technology*, 294, 122112. <https://doi.org/10.1016/j.biortech.2019.122112>
- Rajput, V. D., Minkina, T., Ahmed, B., Sushkova, S., Singh, R., Soldatov, M., Laratte, B., Fedorenko, A., & Mandzhieva, S. (2022). Interaction of copper-based nanoparticles to soil, water, and plant systems. *Environmental Geochemistry and Health*, 44, 3671–3693. <https://doi.org/10.1007/s10653-021-01072-4>



## Application of Biotechnology in Horticultural Crop Improvement



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### 1. Introduction

Horticultural crops, high-value fruits, vegetables, tubers, ornamentals, medicinal plants, and spices, are also vital in the health of human beings and supply important vitamins, minerals, and dietary fibre. Horticulture is a huge capital of agricultural GDP in most developing and developed countries. Nevertheless, increasing demands of the growing world population, the shrinking arable land, and the uncertain effects of the climate change put even more strain on the sector as the biotic and abiotic stressors increase.

Horticultural crops are complex to improve compared to staple field crops such as wheat or rice. Most horticultural species are perennial and have long generation cycles (e.g. apples, citrus), and therefore traditional backcrossing programs are prohibitively slow. Moreover, both heterozygosity and complicated levels of ploidy in crops such as potato, strawberry, as well as banana complicate the genetic examination and fixation of traits.

Thought to be the foundations of agriculture conventional breeding is becoming saturated in dealing with these sudden environmental shifts and consumer needs of quality. Biotechnology in agriculture offers superior and supplementary solutions to overcome such limitations. Biotechnology also makes it possible to transfer traits across the species boundary, multiply elite germplasm very fast and to edit endogenous genes precisely with manipulation of cellular and molecular processes. This paper describes the key pillars of biotechnology that underpin contemporary enhancement of horticulture.

### 2. Plant Tissue Culture: The Foundation of Modern Horticulture

The most popular biotechnological tool used in horticulture is the plant tissue culture (PTC). It is based on cellular totipotency, which is that one cell of a plant can be regenerated to become a complete plant in sterile and controlled circumstances.

#### 2.1 Micropropagation

Micropropagation is the high-speed vegetative multiplication of the elite genotype of plants. In crops where seeds or standard vegetative cuttings are hard to propagate, e.g. orchids, bananas, strawberries and most ornamental foliage plants, the use of micropropagation ensures that large volumes of uniform and true-to-type planting material are produced. This method has transformed the floriculture business and it is important in the quick distribution of new cultivars.

#### 2.2 Somatic Embryogenesis and Organogenesis

These routes are capable of regeneration of somatic tissues. In addition to propagation, they are also necessary preconditions to genetic transformation regimes. The limitation that may occur in the implementation of advanced biotech to hard-to-transform horticultural crops, such as some woody perennials, is often the development of efficient regeneration systems.

#### 2.3 Virus Elimination through Meristem Culture

Most horticultural crops, especially those that are vegetatively propagated, such as potato, cassava, and citrus, are susceptible to the accretion of viral pathogens in generations, thereby grossly lowering yield (seed degeneration). Viruses tend to be absent in the apical meristem of a plant because there is no vascular connection, and the cell division is fast. The regeneration of virus-free mother stock by culture of these small meristematic tips has been important in certified seed potato programs and the boycott of citrus orchards with a new surge of life.

### 3. Molecular Breeding: Accelerating the Selection Process

The management of the plant material is applied when using tissue culture, and the management of the genetics is applied when using molecular breeding. Traditional breeding involves the use of phenotypic selection, where

a plant is held to wait till it grows up and the trait is expressed (e.g. fruit colour, disease resistance) and then chosen to be used in the next generation. This is time consuming and is affected by environmental differences.

### 3.1. Marker-Assisted Selection (MAS)

MAS eliminates the field selection and puts it in the laboratory. With the aid of the identification of molecular markers (SNPs or SSRs), which are closely associated with genes that control traits of interest, breeders have the ability to screen seedlings at a very early age.

In case one of the markers exist, then it is likely that the desired trait exists. This would be of great help to:

- Recessive traits:** Determining heterozygous carriers which do not exhibit the phenotype.
- Late-expressing traits:** Screening fruit attributes of tree seedlings many years before the fruit is produced.
- Pyramiding genes:** Piling up of several resistant genes to various strains of pathogens in a single cultivar, which is almost impossible when using phenotypic selection.

MAS has been highly applied in breeding tomatoes with resistance genes stacked against *Verticillium*, *Fusarium* and nematodes.

### 3.2. Quantitative Trait Loci (QTL) Mapping

Yield, flavour complexity and drought tolerance are many economically significant horticultural characteristics which are polygenic (controlled by many genes with small effect). QTL mapping is the statistical technique that is used to correlate phenotypic data and molecular marker data to determine which genomic regions are related to these intricate phenotypes. The QTLs can be selected once they have been identified.

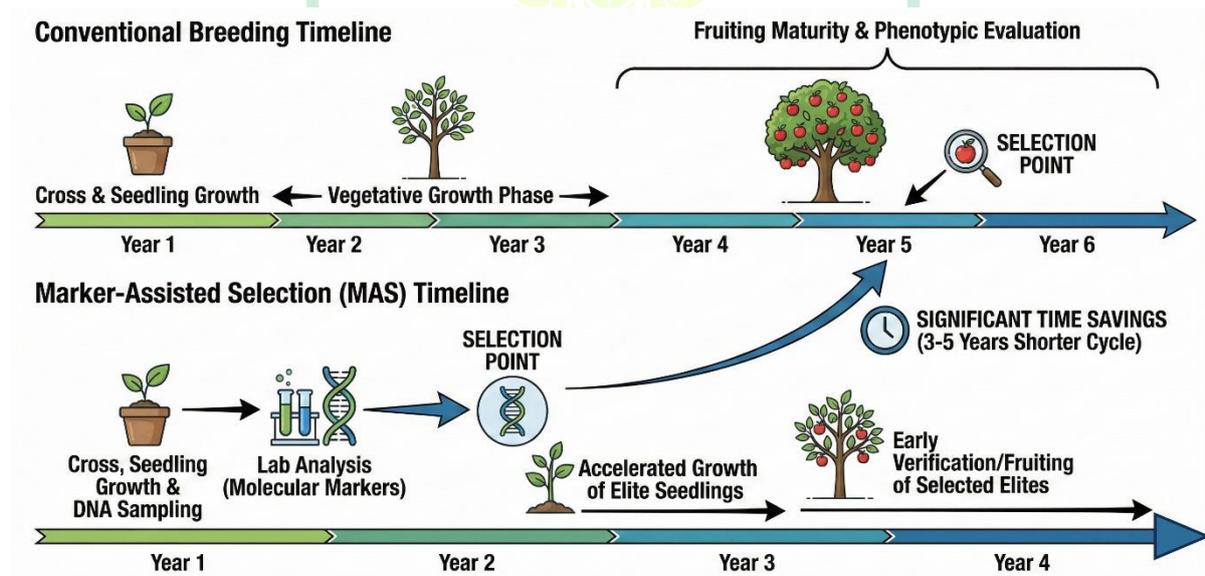


Figure 1. Comparison of Conventional Breeding vs. Marker-Assisted Selection (MAS) timelines in a perennial fruit crop

## 4. Genetic Transformation

With recombinant DNA technology, it is possible to insert genes of any organism (plant, microbe or animal) into the genome of a crop to provide a new characteristic. This avoids sexual compatibility barriers.

### 4.1. Techniques of Transformation

- Agrobacterium-mediated transformation:** It is a natural soil bacterium *Agrobacterium tumefaciens*, that is used as a vector to deliver desired genes into the plant genome. It is extensively applied in horticultural crops that are dicotyledons, such as tomato, potato and brinjal.
- Biolistics (Gene Gun):** Micro-particles that are coated with DNA are physically fired into plant cells. This can be used on monocots and those species that do not succumb to *Agrobacterium* infection.

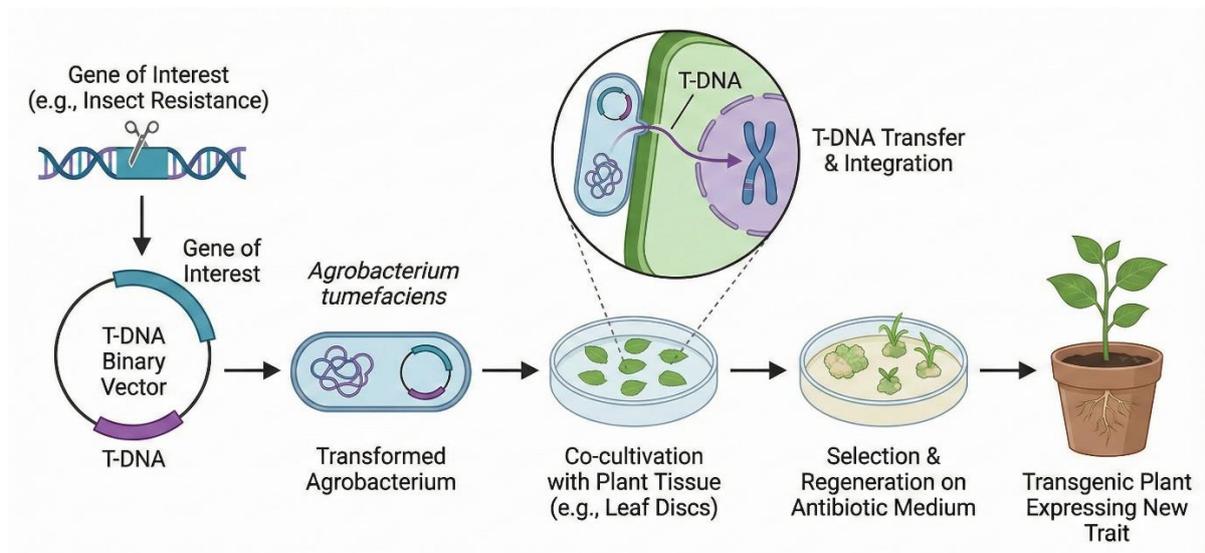


Figure 2. Agrobacterium-mediated genetic transformation process in plants

#### 4.2 Major Success Stories in Horticulture

- Virus Resistance:** The most popular example is Rainbow papaya of Hawaii. It was introduced in the late 1990s and was engineered by the Papaya Ringspot Virus (PRSV) coating protein gene, which provides resistance through RNA interference. This rescued the Hawaiian papaya industry.
- Insect Resistance (Bt Crops):** inclusion of Cry genes in *Bacillus thuringiensis* (Bt) offers protected defence against certain lepidopteran insects. Bt brinjal (eggplant) has demonstrated a lot of minimizations of pesticide application in the countries where it is commercialized, albeit it is regulatory in other countries.
- Herbicide Tolerance:** Enables crops to live against particular broad-spectrum herbicides, making it easy to manage weeds.

These technical achievements notwithstanding, transgenic horticultural crops have a major obstacle to commercial acceptance because of regulatory challenges in different countries and because of their different levels of acceptability by consumers globally.

#### 5. The New Frontier: Genome Editing (CRISPR/Cas)

Genome editing, particularly the CRISPR/Cas9 system, represents a paradigm shift in plant breeding. Unlike transgenics, which involve inserting foreign DNA at random locations, genome editing acts as molecular scissors, allowing for precise modifications, deletions, insertions, or base changes at specific target sites within the plant's own endogenous genome.

##### 5.1. Precision and Regulation

Genome editing and specifically CRISPR/Cas9 system is a paradigm shift in plant breeding. In contrast to transgenics, in which the foreign DNA is inserted randomly, genome editing can be likened to the use of the molecular scissors, which is capable of making a specific change, deletion, insertion, or base alteration in the plant, but in a specific place within its endogenous genome.

##### 5.2. Applications in Horticulture

- Knockout of Susceptibility Genes:** Instead of adding resistance genes, CRISPR can disable plant genes that pathogens hijack to cause disease. For example, editing *MLO* genes has conferred powdery mildew resistance in tomatoes and grapevines.
- Quality Improvement:** CRISPR has been used to develop non-browning mushrooms and potatoes by knocking out polyphenol oxidase (PPO) genes, reducing food waste.
- Domestication of New Species:** Researchers are using CRISPR to rapidly domesticate wild relatives of crops like groundcherry (*Physalis pruinosa*) by editing CRISPR to rapidly domesticate wild relatives of crops like groundcherry (*Physalis pruinosa*) by editing genes related to plant architecture and fruit size, compressing centuries of breeding into a few years.

**Table 1. Comparative Overview of Breeding Technologies in Horticulture**

Feature	Conventional Breeding	Molecular Breeding (MAS)	Genetic Transformation (GMO)	Genome Editing (CRISPR)
<b>Principle</b>	Sexual crossing based on phenotype	Sexual crossing based on genotype markers	Insertion of foreign DNA (transgene)	Precise modification of endogenous DNA
<b>Gene Source</b>	Within sexually compatible species	Within sexually compatible species	Any organism (cross-kingdom)	Usually, within the species genome
<b>Precision</b>	Low (entire genome shuffled)	Medium (targets linked regions)	Medium (random insertion site)	High (target specific sequence)
<b>Regulatory Status</b>	Generally unregulated	Unregulated	Highly regulated globally	Varied depending on technique and country
<b>Timeframe</b>	Slowest (many generations)	Faster (early selection)	Fast development, slow regulation	Fastest development possible

## 6. Targeted Trait Improvement via Biotechnology

The application of these tools is directed toward solving critical challenges in horticultural production.

### 6.1. Abiotic Stress Tolerance

Horticultural crops are highly sensitive to drought, salinity, and temperature extremes. Biotechnology targets transcription factors (master regulators like *DREB* genes) that control the plant's response to stress. Transgenic approaches overexpressing osmoprotectants (like glycine betaine) or enhancing antioxidant systems have shown promise in crops like tomato and potato under saline conditions in controlled environments.

### 6.2. Post-Harvest Quality and Shelf Life

Fruits and vegetables are highly perishable. Controlling ethylene production (the ripening hormone) is a major target. The Flavr Savr tomato (the first commercialized GM food) used antisense technology to suppress polygalacturonase, delaying softening. While commercially unsuccessful due to business factors, it proved the concept. Modern CRISPR approaches targeting ethylene biosynthesis genes (*ACO*, *ACS*) are being developed in tomato, banana, and melon to extend shelf life without sacrificing flavour.

### 6.3. Nutritional Biofortification

Horticulture plays a key role in addressing hidden hunger (micronutrient malnutrition). Biotechnology can enhance nutritional profiles beyond what is possible naturally.

- Golden Crops:** Similar to Golden Rice, metabolic engineering has been used to increase provitamin A (beta-carotene) in crops like Golden potato and Golden banana, targeting populations deficient in Vitamin A.
- Anthocyanin Enrichment:** Regulatory genes have been manipulated to increase antioxidant-rich anthocyanins in tomato (purple tomatoes) and citrus flesh, enhancing their health-promoting properties.

**Table 2. Selected Examples of Biotechnological Interventions in Horticultural Crops**

Crop	Target Trait	Biotechnological Approach	Status/Example
<b>Papaya</b>	Ringspot Virus Resistance	Transgenics (RNAi)	Commercialized ('Rainbow' papaya)
<b>Tomato</b>	Extended Shelf Life	CRISPR/Cas9 (targeting ethylene genes)	Research/Near Commercial
<b>Potato</b>	Reduced acrylamide & non-browning	RNA interference (RNAi)	Commercialized (Innate® Potato)
<b>Citrus</b>	Citrus Greening (HLB) Resistance	Transgenics (antimicrobial peptides)	Advanced Testing
<b>Banana</b>	Vitamin A Biofortification	Transgenics (metabolic engineering)	Advanced field trials in Africa
<b>Grapevine</b>	Powdery Mildew Resistance	CRISPR/Cas9 ( <i>MLO</i> gene knockout)	Research Phase
<b>Eggplant</b>	Fruit and Shoot Borer Resistance	Transgenics (Bt gene <i>CryIAc</i> )	Commercialized in Bangladesh

## 7. Challenges and Future Perspectives

While the potential is immense, several challenges impede the full realization of biotechnology in horticulture.

1. **Recalcitrance:** Many high-value woody crops (e.g., mango, avocado, many nuts) remain notoriously difficult to regenerate *in vitro*, which is a prerequisite for transformation or editing protocols.
2. **Complex Genetics:** Polyploidy in crops like strawberry and sugarcane complicates the application of CRISPR, as multiple alleles must be edited simultaneously to achieve a phenotypic effect.
3. **Regulatory and Cost Barriers:** The high cost of regulatory dossiers for GMOs has historically restricted their development to large multinational corporations focusing on major field crops. While CRISPR offers a cheaper pathway in some regions, global regulatory harmonization is lacking, complicating trade.
4. **Public Perception:** Consumer acceptance remains a significant hurdle, particularly for fresh produce compared to processed ingredients. Transparent communication regarding the safety and benefits of these technologies, especially the distinction between foreign DNA GMOs and gene-edited crops, is crucial.

#### Future Directions:

The future lies in multi-omics integration, combining genomics, transcriptomics, and metabolomics to fully understand complex horticultural traits. Furthermore, the integration of speed breeding protocols (using prolonged photoperiods and temperature control) with genomic selection and genome editing will drastically condense breeding cycles of perennial crops from decades to years.

#### 8. Conclusion

Biotechnology is no longer a futuristic concept but a present-day necessity in horticultural science. It does not replace conventional breeding but acts as a powerful, high-precision force multiplier. From the now-routine use of tissue culture for clean planting material to the cutting-edge precision of CRISPR for developing climate-resilient vegetables, these tools are essential for securing a diverse, nutritious, and sustainable food supply. Addressing the technical hurdles in recalcitrant crops and navigating the complex socio-political landscape of regulation and consumer acceptance will determine the speed at which these innovations reach the farmer's field and the consumer's plate.

#### References

- Collard, B. C. Y., & Mackill, D. J. (2007). Marker-assisted selection: An approach for precision plant breeding in the twenty-first century. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1491), 557–572. <https://doi.org/10.1098/rstb.2007.2170>
- De Mori, G., & Cipriani, G. (2023). Marker-assisted selection in breeding for fruit trait improvement: A review. *International Journal of Molecular Sciences*, 24(10), Article 8984. <https://doi.org/10.3390/ijms24108984>
- Jaganathan, D., Ramasamy, K., Sellamuthu, G., Jayabalan, S., & Venkataraman, G. (2018). CRISPR for crop improvement: An update review. *Frontiers in Plant Science*, 9, Article 985. <https://doi.org/10.3389/fpls.2018.00985>
- Karkute, S. G., Singh, A. K., Gupta, O. P., Singh, P. M., & Singh, B. (2017). CRISPR/Cas9 mediated genome engineering for improvement of horticultural crops. *Frontiers in Plant Science*, 8, Article 1635. <https://doi.org/10.3389/fpls.2017.01635>
- Lobato-Gómez, M., Hewitt, S., Capell, T., Christou, P., Dhingra, A., & Girón-Calva, P. S. (2021). Transgenic and genome-edited fruits: Background, constraints, benefits, and commercial opportunities. *Horticulture Research*, 8, Article 166. <https://doi.org/10.1038/s41438-021-00601-3>
- Xiong, J.-S., Ding, J., & Li, Y. (2015). Genome-editing technologies and their potential application in horticultural crop breeding. *Horticulture Research*, 2, Article 15019. <https://doi.org/10.1038/hortres.2015.19>

## Application of Controlled-Release Fertilizers in Field Crop Management



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### 1. Introduction

Synthetic fertilizers have been important in the enhancement of agriculture in the last hundred years. Although these inputs triggered the Green Revolution, their inconsistent or irrational utilisation has brought about systemic problems. In most field crop systems, particularly those which use traditional urea or ammonium nitrate, less than half the amount of nitrogen that is applied is absorbed in the crop. The rest usually disperses to the environment, where it pollutes groundwater with nitrates, the atmosphere with ammonia and nitrous oxide and aquatic ecosystems with eutrophication.

This is one of the inefficiencies that should be tackled to have sustainable agriculture. The issue with the traditional highly soluble fertilizers is in the fact that when they are applied, they are instantly available, which is rarely consistent with the uptake curve of the crop. Young plants have minimum nutrient needs, but the maximum level of nutrients in plants is in pre-plant applications.

A viable alternative is Controlled-Release Fertilizers (CRFs), commonly known as Enhanced Efficiency Fertilizers (EEFs). True CRFs, unlike slow-release fertilizers (SRFs), which are usually slow to degrade biologically and highly erratic, apply engineered physical barriers or semi-permeable membranes to control the rate of diffusion of the nutrients in reaction to particular environmental signals, namely temperature and moisture. CRFs should strive to align the S-curve of crop biomass build-up and nutrient absorption by delaying the original release, and lengthening nutrient availability periods in weeks or months.

### 2. Mechanisms of Action and Classifications

The release technology of a CRF dictates the efficacy. The procedure essentially entails encasing a soluble nutrient core into a coating material that limits water entry and solute exit.

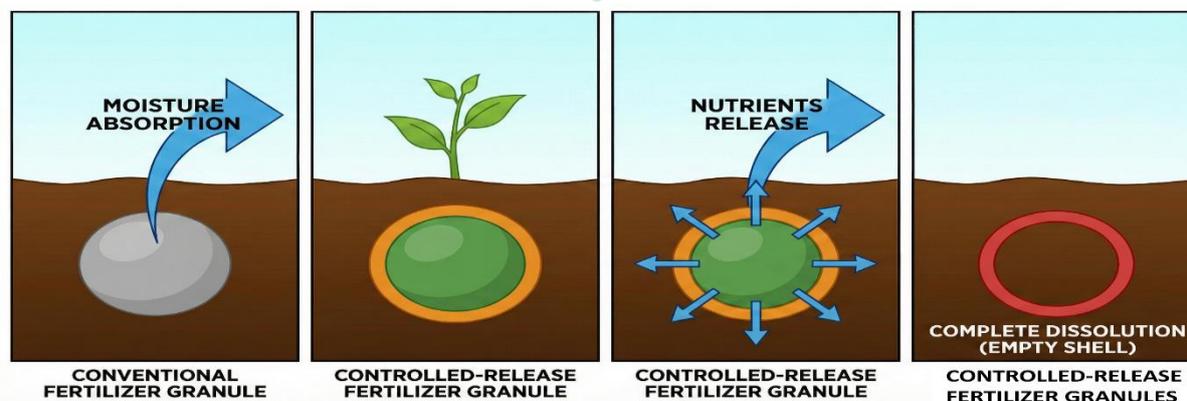


Figure 1. Schematic representation of the diffusion-based release mechanism in Polymer-Coated Controlled-Release Fertilizers

## 2.1. The Release Process

The release mechanism in coated CRFs generally follows a three-stage process:

- a. **Lag Phase:** The release technology of a CRF dictates the efficacy. The procedure essentially entails encasing a soluble nutrient core into a coating material that limits water entry and solute exit.
- b. **Linear Release Phase:** The solid nutrient core is dissolved in water, resulting in an interior osmotic pressure. The solution of dissolved nutrients is then diffused out through micropores or defects in the coating into the adjacent soil solution. Under polymer-coated versions, the rate of diffusion is regulated by the Fick Law and strongly depends on temperature, since the greater the temperature, the greater the permeability of the polymer and the diffusion rate of the solute.
- c. **Decay Phase:** When the core is dissolved by the major part, the concentration gradient decreases and the rate of release levels off to a zero point at which the granule is empty.

## 2.2. Types of Coatings

CRFs are broadly categorized by their coating materials:

- a) **Sulphur-Coated Urea (SCU):** This is one of the oldest types of CRF, where urea is dipped in the molten sulphur and then covered with a wax. The degradation of the wax and the oxidation of the sulphur coating by the microbial process are the major factors that initiate the release. SCUs tend to be less expensive and are prone to weak release rates as a result of a burst release of imperfectly coated granules, and release is highly affected by soil microbial activity and pH.
- b) **Polymer-Coated Fertilizers (PCF):** These are the most recent CRF technology. A semi-permeable membrane is made using thermoplastic or thermosetting resin. Compared to SCU, release follows more predictable patterns, and is controlled mainly by temperature and coating thickness and does not depend much on the pH of the soil or the microbial condition of the soil.
- c) **Polymer-Sulphur Hybrid Coatings:** These comprise the two materials in the ratio of balancing price and release predictability.

## 3. Agronomic Benefits in Field Crops

### 3.1. Enhanced NUE and Yield Stability

In more traditional systems, excessive pre-plant use of nitrogen may cause a high level of luxury consumption at the beginning of the season when the plant is absorbing more N than it actually needs at that moment, and it is not contributing to the ultimate yield. On the other hand, when heavy rain is experienced at the beginning of the season, soluble N is washed away, and at the end of the season, there is a shortage of N in the grain fill. CRFs mitigate both extremes. They ensure a constant amount of N supply around periods of rapid vegetative growth and reproductive phases, which ensures an ideal photosynthetic activity, as well as the grain-filling periods, which enhances stability in yields during fluctuating climatic conditions.

### 3.2. Reduced Application Frequency

In long-season crops like corn, cotton, or sugarcane, it is common to apply nitrogen in two doses split with a pre-plant application and a side-dress application, to enhance the efficiency of the crop. This involves several field passes, which raises the cost of fuel, labour requirements and soil compaction. The coating technology has been demonstrated to support a single-pass system, where all the seasonal nitrogen needs are deposited at planting, and the coating is deferred until the side-dressing window.

## 4. Environmental Implications: Mitigating Losses

In long-season crops like corn, cotton, or sugarcane, it is common to apply nitrogen in two doses, split with a pre-plant application and a side-dress application to enhance the efficiency of the crop. This involves several field passes, which raises the cost of fuel, labour requirements and soil compaction. The coating technology has been demonstrated to support a single-pass system, where all the seasonal nitrogen needs are deposited at planting, and the coating is deferred until the side-dressing window.

### 4.1. Reducing Nitrate Leaching

Since nitrate ( $\text{NO}_3^-$ ) is too mobile in the soil profile, it can be easily washed away below the root zone by heavy rain or irrigation, and ultimately pollute groundwater. This is a serious problem in sandy soils or areas of high

precipitation. CRFs considerably reduce the amount of leachable nitrogen by not permitting the concentration of nitrate in the soil solution at a given time to exceed that amount of nitrate that is actively taken up by the plant.

#### 4.2. Curbing Ammonia Volatilization

Upon hydrolysing, surface-applied urea increases the localised soil pH, favouring the production of ammonia gas (NH<sub>3</sub>), which is lost to the atmosphere. Under hot, humid conditions and heavy residue cover, this process may lead to N losses of over thirty per cent. The prominent physical barrier of CRFs reduces rapid hydrolysis on the soil surface, which significantly reduces the loss of volatilisation despite the absence of the immediate incorporation of the fertilizer by rainfall or tillage.

#### 4.3. Lowering Nitrous Oxide Emissions

Nitrous oxide (N<sub>2</sub>O) is a powerful greenhouse gas that is generated during soil nitrification and denitrification. These are substrate-dependent processes: the larger the quantity of ammonium and nitrate, the larger the potential emissions. CRFs have been demonstrated through multiple studies to lower the cumulative N<sub>2</sub>O emissions in comparison with traditional fertilizers by regulating the availability of these substrates, leading to a lowering of the carbon footprint of agriculture.

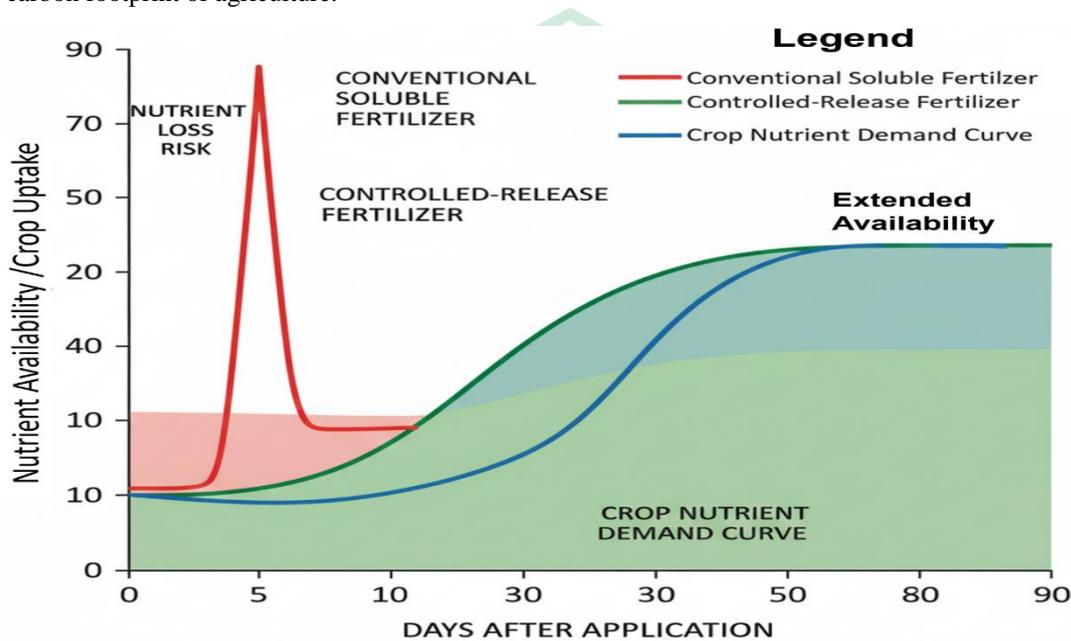


Figure 2. Comparative analysis of nitrogen availability dynamics between Conventional Soluble Fertilizers and Controlled-Release Fertilizers (CRFs).

### 5. Practical Application Strategies in Field Settings

The successful adoption of CRFs in broadacre agriculture requires agronomic calibration. They are not a set it and forget it solution but a sophisticated tool requiring strategic placement and timing.

#### 5.1. The Blending Strategy

Since the production cost of CRFs is usually two or three times more than the production cost of urea in terms of nitrogen consumed, the current trend in the industry involves the addition of CRFs to traditional urea. The common ratio can be between 25% and 50% CRF, and combined with ordinary urea. The rapid nitrogen availability provided by the urea enhances early maturation of vegetation, eliminating yellowing at the beginning of the season or dragging of nitrogen, whereas the CRF part is available later in the growth period, keeping the crop alive during the reproductive phases. The exact ratio must depend on the nitrogen uptake curve of the crop, the type of soil and the past rainfall patterns.

## 5.2. Placement and Timing

- Subsurface Banding:** This is generally the most efficient method. Placing the CRF band near the future root zone ensures that as nutrients diffuse, they are intercepted by roots. It also ensures adequate soil moisture contact necessary to initiate the diffusion process.
- Seed-Placed (Pop-up):** Because polymer coatings significantly reduce the salt index of fertilizers, higher rates of N can be safely placed in-furrow with the seed compared to conventional fertilizers. This can be advantageous in cold, wet soils where root growth is initially slow.
- Surface Broadcast:** While CRFs reduce volatilization compared to urea, surface application can still be risky in dryland systems. If the soil surface dries out, the CRF granules may not have enough moisture to initiate diffusion, leading to "stranded" nitrogen that is unavailable to the crop.

**Table 1. Comparative analysis of conventional Urea vs. Polymer-Coated Urea (PCU) in maize production systems**

Feature	Conventional Urea (46-0-0)	Polymer-Coated Urea (PCU)
<b>N Release Mechanism</b>	Rapid hydrolysis by the soil urease enzyme.	Diffusion through a semipermeable membrane.
<b>Release Drivers</b>	Immediately upon moisture contact.	Primarily, soil temperature and moisture.
<b>Nutrient Availability Duration</b>	Typically, 2–4 weeks, depending on rainfall.	4–16 weeks (engineered variable durations).
<b>Leaching Risk</b>	High (rapid conversion to mobile nitrate).	Low (N remains protected within the granule).
<b>Volatilization Risk</b>	High (if surface applied without incorporation).	Very Low (coating prevents immediate ammonia loss).
<b>Seed Safety</b>	Low (high salt index, risk of seedling burn in-furrow).	High (polymer barrier reduces salt effect near the seed).
<b>Application Strategy</b>	Usually requires split applications for high efficiency.	Potential for single-pass pre-plant application.

## 6. Economic Considerations and Challenges to Adoption

### 6.1. The Cost Barrier

The high-cost of CRFs is the major obstacle. Farmers with thin margins will often find it hard to afford an input that is more expensive than conventional equivalents. To make CRF adoption an economically feasible solution, the incremental cost should be compensated by:

- Increased yield (which is not guaranteed in years with optimal weather for conventional fertilizers).
- Reduced operational costs (e.g., eliminating a second pass for side-dressing).
- Potential future payments for ecosystem services (e.g., carbon credits for reduced N<sub>2</sub>O emissions or water quality credits).

### 6.2. The Knowledge Gap and Environmental Uncertainty

Predicting the exact release rate of a CRF in a dynamic field environment is complex. If an unusually cold spring occurs, release might be too slow, causing early-season deficiency. Conversely, extreme heat and moisture could accelerate the release faster than anticipated. Agronomists and farmers need localized data and decision-support tools to confidently select the right coating thickness (release duration) and blending ratio for their specific climate and soil conditions.

## 7. Conclusion and Future Perspectives

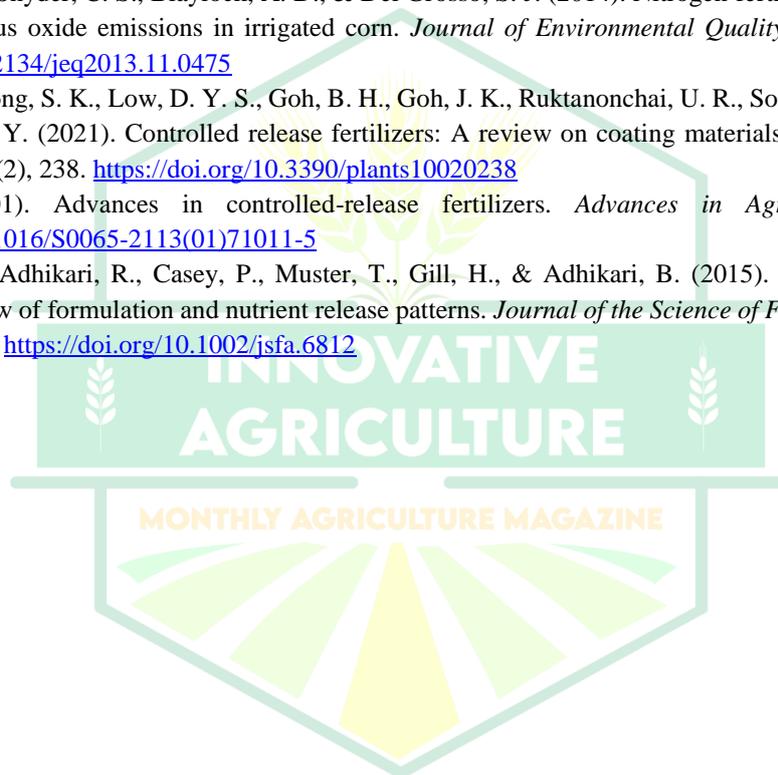
Controlled-release fertilisers form an important part of the instrumentation of sustainable agricultural intensification. They deal with the inefficiencies of the traditional nitrogenous fertilizers and provide a least of alternative to continue having high crop yields and dramatically reducing the cascading impact on the environment caused by the loss of nutrients.

Although the existing economic obstacles restrict their application as a pure source of nitrogen in most commodity crops, their application in strategic mixtures is growing at an elevated pace. The future in this regard should be aimed at lowering the cost of production and developing biodegradable coating material to get rid of possible microplastic residues in soils. In addition, combining CRF technology with precision agriculture, which is the differentiation of the blend ratio within a field within soil-management zones, is likely to open additional

efficiencies. With the increasing environmental regulation and the need to utilize resource-efficient farming systems, the use of CRFs in the field-crop management industry will become an industry norm and not a niche.

#### References

- Azeem, B., KuShaari, K., Man, Z. B., Basit, A., & Thanh, T. H. (2014). Review on materials & methods to produce controlled release coated urea fertilizer. *Journal of Controlled Release*, 181, 11–21. <https://doi.org/10.1016/j.jconrel.2014.02.020>
- Chien, S. H., Prochnow, L. I., & Cantarella, H. (2009). Recent developments of fertilizer production and use to improve nutrient use efficiency and minimize environmental impacts. *Advances in Agronomy*, 102, 267–322. [https://doi.org/10.1016/S0065-2113\(09\)01008-6](https://doi.org/10.1016/S0065-2113(09)01008-6)
- Grant, C. A., Wu, R., Selles, F., Harker, K. N., Clayton, G. W., Bittman, S., Zebarth, B. J., & Lupwayi, N. Z. (2012). Crop yield and nitrogen concentration with controlled release urea and split applications of nitrogen as compared to non-coated urea in Canadian prairie soils. *Field Crops Research*, 127, 84–98. <https://doi.org/10.1016/j.fcr.2011.11.002>
- Halvorson, A. D., Snyder, C. S., Blaylock, A. D., & Del Grosso, S. J. (2014). Nitrogen fertilization management for reducing nitrous oxide emissions in irrigated corn. *Journal of Environmental Quality*, 43(4), 1334–1341. <https://doi.org/10.2134/jeq2013.11.0475>
- Lawrencia, D., Wong, S. K., Low, D. Y. S., Goh, B. H., Goh, J. K., Ruktanonchai, U. R., Soottitantawat, A., Lee, L. H., & Tang, S. Y. (2021). Controlled release fertilizers: A review on coating materials and mechanisms of release. *Plants*, 10(2), 238. <https://doi.org/10.3390/plants10020238>
- Shaviv, A. (2001). Advances in controlled-release fertilizers. *Advances in Agronomy*, 71, 1–49. [https://doi.org/10.1016/S0065-2113\(01\)71011-5](https://doi.org/10.1016/S0065-2113(01)71011-5)
- Timilsena, Y. P., Adhikari, R., Casey, P., Muster, T., Gill, H., & Adhikari, B. (2015). Enhanced efficiency fertilizers: A review of formulation and nutrient release patterns. *Journal of the Science of Food and Agriculture*, 95(6), 1131–1142. <https://doi.org/10.1002/jsfa.6812>



## Applications of Artificial Intelligence in Modern Plant Breeding



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### 1. Introduction

The necessity to guarantee the world food security has never been more urgent. The breeders of plants are challenged to produce cultivars which in addition to their high yielding capabilities, have strong tolerance to abiotic stresses like drought and heat conditions as well as biotic resistance to the emergence of new pests and pathogens. Traditionally, breeding plants was a count and time contest across sites and seasons between different parents and painstakingly measuring offspring. Although this is a powerful method, this process of phenotypic selection is both sluggish and resource-intensive by nature.

With the introduction of the omics age genomics, transcriptomics, proteomics, and metabolomics, the nature of the data regarding the agricultural sector has been altered fundamentally. Genomes are now readily and cheaply sequenced. At the same time, sensor technology and remote sensing have facilitated high-throughput phenotyping (HTP) which produces terabytes of image and spectral data on a daily basis. This fact makes massive data a very large problem: the human cognitive ability and the old-fashioned statistics cannot synthesize such information well in order to make the selection choices.

And that is where Artificial Intelligence (AI) comes in. AI gives a calculation system to manage the quantity, speed, and diversity of current biological information. AI is not just an incremental tool by relying on high-level algorithms that can learn on data, extract patterns and make decisions with minimal human intervention, it is a disruptive force that is transforming the entire breeding pipeline.

### 2. High-Throughput Phenotyping and Computer Vision

The problem that the phenomics bottleneck is the failure to measure plant traits correctly as quickly as we can genotype them has been a long-term bottleneck in breeding. Manual phenotyping is tedious, subjective and destructive. This field has been transformed by AI and especially by Computer Vision (CV) with the use of Convolutional Neural Networks (CNNs).

Images taken on different platforms, including drones (UAVs), ground-based rovers, satellites, and cameras mounted on stationary fields, can be taken and then processed using CV algorithms to automatically find phenotypic information. These deep learning models are trained on massive datasets of annotated plant images to identify and estimate particular characteristics.

#### Key Applications in Phenotyping:

- a) **Biotic Stress Detection:** CV models can detect early disease or pest symptoms, on average earlier than the human eye detects them by tracking hidden variations in leaf colour, texture or thermal signatures. This enables the screening of the thousands of germplasm accessions in a relatively shorter time frame to identify the resistance traits.
- b) **Agronomic Trait Quantification:** Algorithms may automatically quantify plants, height, biomass, leaf area index (LAI) and flowering time. In root phenotyping, complex 2D and 3D root architecture images of rhizotrons or CT scans are analyzed using AI, which is almost inseparable by human eyes.
- c) **Abiotic Stress Assessment:** AI models use hypothesis testing of the hyperspectral and thermal imagery to match canopy temperature and spectral reflectance indices with water use efficiency, drought tolerance, and nitrogen status.

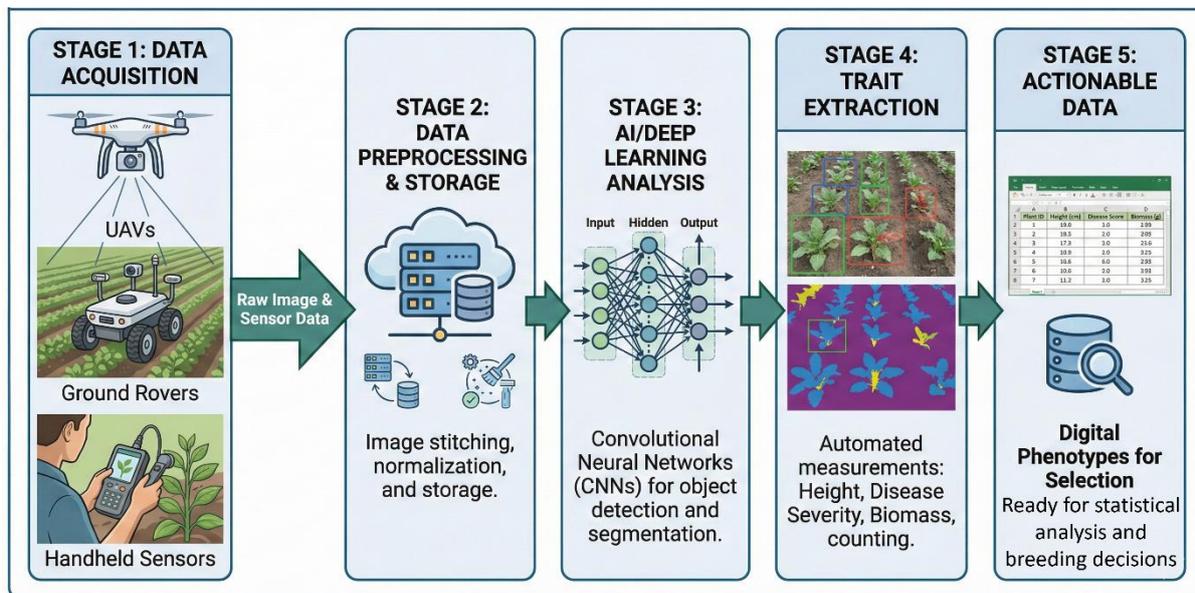


Figure 1. AI-Driven High-Throughput Phenotyping Pipeline

### 3. Genomic Selection and Predictive Modelling

Genomic Selection (GS) has emerged as a breeding playing field in modern breeding. In contrast to Marker-Assisted Selection (MAS), which makes use of a limited number of known markers associated with major quantitative trait loci (QTL), GS involves the use of all genome-wide markers to forecast the Total Genetic Value (GEBV) of a particular individual.

Traditionally, GS used linear statistical models such as Genomic Best Linear Unbiased Prediction (GBLUP). Although this type of model is useful in situations where the trait of interest is additive, in many cases, these linear models fail to adequately model non-linear genetic interactions, including dominance and epistasis (gene-gene interactions), which are important in numerous commercially important traits such as yield.

AI, in particular, Machine Learning (ML) and Deep Learning (DL) models, are better alternatives to predictive modelling in GS. Random Forests, Support Vector Machines (SVM), and Deep Neural Networks (DNNs) can all be directly configured to learn both complex and non-linear association relationships between high-dimensional genomic data without making pre-determined assumptions about the genomic architecture underlying the trait.

#### Advantages of AI in Genomic Prediction:

- 1. Handling High Dimensionality:** The number of genetic markers (SNPs) can easily significantly outnumber the number of individuals with phenotypes. The regularization methods and feature selection employed by AI models are more effective than most classical methods of working with this dimension.
- 2. Modeling Epistasis:** By default, deep learning models will implicitly learn concealed interactions among the various genomic regions, which can potentially enhance the accuracy of prediction of complex phenotypes.
- 3. Multi-Trait Prediction:** AI models can be constructed to make predictions of multiple correlated traits in parallel, and use information across traits to make joint predictions, particularly those of low heritability.

With a better GEBV precision, AI allows breeders to make promising distinctions on the parents and offspring at the seedling phase and saves the breeding cycle by several years of initial field testing.

DIAGRAM 2: AI-ENHANCED GENOMIC SELECTION MODELING.

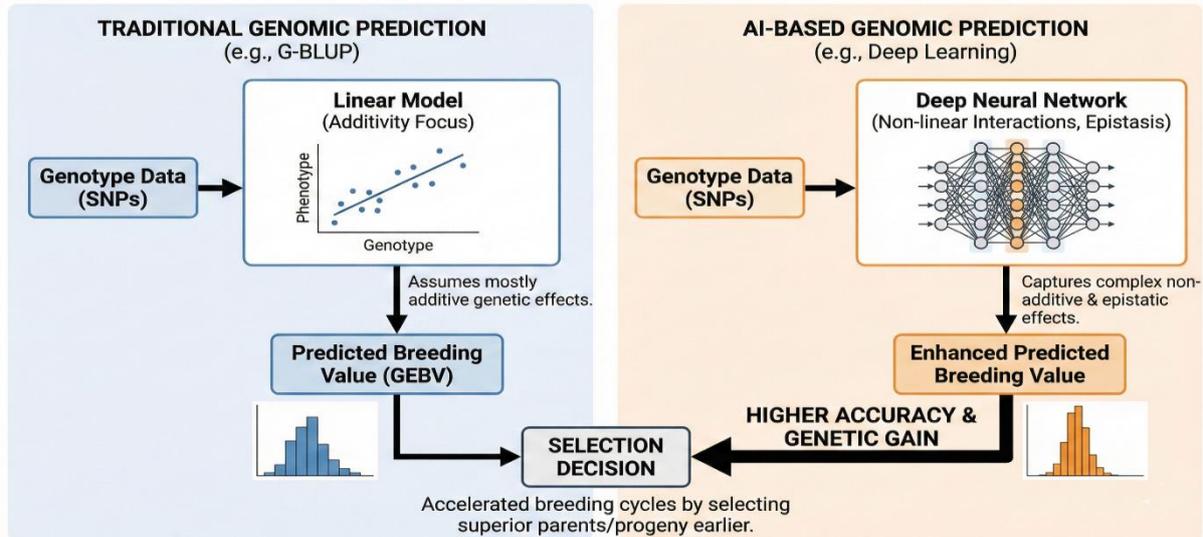


Figure 2. AI-enhanced genomic selection modelling

Table 1. Comparison of Traditional Statistical vs. AI Models in Genomic Selection

Feature	Traditional Models (e.g., G-BLUP, RR-BLUP)	AI/Machine Learning Models (e.g., Random Forest, Neural Networks)
Mathematical Basis	Linear mixed models; parametric.	Data-driven algorithms; often non-parametric.
Handling Non-linearity (Epistasis)	Limited ability; requires explicit modeling terms.	Inherent ability to model complex, non-linear interactions implicitly.
Data Dimensionality	Can struggle when markers (p) vastly outnumber observations (n) without pre-selection.	Designed to handle high-dimensional data through regularization and feature learning.
Computational Requirement	Moderate.	High; often requires GPUs for training deep learning models.
Interpretability	High; parameters have direct biological or statistical meaning.	Lower (Black Box nature); requires Explainable AI (XAI) techniques.
Performance on Complex Traits	Good for additive traits; may plateau for complex traits.	Potential for higher accuracy on complex traits dominated by non-additive effects.

#### 4. Integrating Multi-Omics and Envirotyping ( $G \times E \times M$ )

The genotype (G) of a plant is not the sole determinant of its phenotype, but it is a complex and complicated interaction between its genotype and the environment (E) and the management practices (M). Another important issue in breeding is the Genotype-by-Environment interaction ( $G \times E$ ), since what works best in one environment will do very poorly in a different environment.

AI is needed to go beyond simple  $G+E$  models to integrated  $G \times E \times M$  prediction. This necessitates the combination of different data types: genomic information, vast amounts of historical weather data, soil sensor data, and more and more, multi-omics data (transcriptomics and metabolomics) that represent a picture of the physiological condition of the plant in a given environment.

This is the data fusion that is practiced by machine learning models. As an example, yield can be predicted by using models that have SNP markers, daily temperature and precipitation data throughout the growing season, and soil properties as inputs.

#### Envirotyping via AI:

Rather than viewing locations as categorical variables (e.g. Site A vs. Site B), it is possible to envirotypes locations with a series of continuous parameters (thermal time, water deficit profiles, solar radiation) using AI. Training DL models on these environmental parameters in combination with genotypic data can enable breeders to

determine the performance of untested genotypes in untested environments, enable a greater targeting of varieties to specific agro-ecological zones, and get ready to manage future climatic conditions.

### 5. Optimizing Gene Editing (CRISPR/Cas9)

Although upstream biotechnology, namely CRISPR-Cas9 gene editing, is being simplified by AI, currently, it is phenotyping and genomic selection that act as workhorses. CRISPR relies on the design of the single-guide RNA (sgRNA) to be efficient and specific.

AI models trained using past experiment-collected datasets can predict:

1. **On-target efficiency:** The efficiency of a particular sgRNA to direct the Cas9 enzyme to cut the specific sequence of DNA.
2. **Off-target effects:** The probability of the sgRNA to cut the genome in other places.

With these predictive models, researchers can computationally screen through thousands of possible sgRNAs to pick the most likely to succeed and the least likely to cause off-target mutations, and save months of time in wet-labs.

### 6. Challenges and Future Prospects

Despite the immense potential, the integration of AI into routine breeding programs faces hurdles.

- a) **Data Quality and Standardization:** The quality of the AI models is only as good as the data they are trained. Agriculture is an industry that does not have the standardized data format as other industries. Garbage in, garbage out is also a relevant threat; annotated images of poorly fit fields or noisy field data may create biased models.
- b) **The Black Box Problem:** A significant number of sophisticated AI models are interpretable, especially deep neural networks. It is usually challenging to know the reason why the model predicted in a particular way. This lack of transparency can be an obstacle to adoption to breeders who need to know the biological basis of traits, and to the regulatory bodies. New directions in Explainable AI (XAI) are aimed at resolving it by developing methods to visualize and interpret model decision-making patterns.
- c) **Infrastructure and Talent:** AI implementation needs a lot of computational power (GPUs, cloud storage) and human resources capable of working in the intersection of biology, statistics and computer science, which is in short supply at present.

In the future, plant breeding surely will have a digital future. We are headed to breeding of the mind, where AI systems do not only analyze the information but also propose crossing blocks and the best way of conducting experiments. The combination of real-time sensor data of fields and its direct entry into predictive models will facilitate the process of making decisions regarding management on the fly and complete the circle between breeding and precision agriculture.

### 7. Conclusion

The use of Artificial Intelligence is no longer a futuristic idea in the field of agriculture; it is a reality that is being actively implemented in modern breeding of plants. The AI can facilitate the demands of the 21st century by unclogging the phenotyping bottleneck with computer vision, improving prediction accuracies in genomic selection with deep learning, and solving the complex GxE interactions with the use of big data integration. To achieve the development of climate resistant and high yielding crops, there is the need to shift empirical selection to AI-based predictive breeding to ensure food security in more generations. The implementation of these technologies will not only be successful due to algorithmic development, but also due to the interdisciplinary cooperation, investment in the digital infrastructure, and interest in data standardization.

### References

- Crossa, J., Pérez-Rodríguez, P., Cuevas, J., Montesinos-López, O., Jarquín, D., de los Campos, G., Burgueño, J., González-Camacho, J. M., Pérez-Elizalde, S., Beyene, Y., Dreisigacker, S., Singh, R., Zhang, X., Gowda, M., Roorkiwal, M., Rutkoski, J., & Varshney, R. K. (2017). Genomic selection in plant breeding: Methods, models, and perspectives. *Trends in Plant Science*, 22(11), 961–975. <https://doi.org/10.1016/j.tplants.2017.08.011>
- Harfouche, A. L., Jacobson, D. A., Kainer, D., Romero, J. C., Harfouche, A. H., Scarascia Mugnozza, G., Moshelion, M., Tuskan, G. A., Keurentjes, J. J. B., & Altman, A. (2019). Accelerating climate resilient plant

- breeding by applying next-generation artificial intelligence. *Trends in Biotechnology*, 37(11), 1217–1235. <https://doi.org/10.1016/j.tibtech.2019.05.007>
- Mochida, K., Koda, S., Inoue, K., Hirayama, T., Tanaka, S., Nishii, R., & Melgani, F. (2019). Computer vision-based phenotyping for improvement of plant productivity: A specialized view from plant science. *Plant and Cell Physiology*, 60(1), 98–103. <https://doi.org/10.1093/pcp/pcy223>
- Singh, A., Ganapathysubramanian, B., Singh, A. K., & Sarkar, S. (2016). Machine learning for high-throughput stress phenotyping in plants. *Trends in Plant Science*, 21(2), 110–124. <https://doi.org/10.1016/j.tplants.2015.10.015>
- Wang, H., Cimen, E., Singh, N., & Buckler, E. (2020). Deep learning for plant genomics and crop improvement. *Current Opinion in Plant Biology*, 54, 34–41. <https://doi.org/10.1016/j.pbi.2019.12.010>



## Biofertilizers for Enhancing Soil Nutrient Use Efficiency and Sustainable Crop Production



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### 1. Introduction

The Green Revolution radically altered the world agriculture by introducing high yielding varieties of crops and heavy use of chemicals. However, the continued use of synthetic nitrogen (N), phosphorus (P), and potassium (K) fertilizers to continue these yields has become unsustainable. It is projected that the world agriculture is consuming over 200 million tonnes of fertilizer nutrients annually. Even after such massive contributions, the productivity of crops as they use these nutrients is very dismal.

A large percentage of the applied fertilizers is either wasted to the environment through leaching, volatilisation, surface run off or fixed in the soil as plant-unavailable forms. This ineffectiveness is both a major economic waste to farmers and a leading cause to dire environmental impacts, such as groundwater contamination, greenhouse-gas emission (mainly nitrous oxide), and soil biological health decay.

Improving the use of the Nutrient Use Efficiency (NUE) is thus a pillar of sustainable agriculture. It needs strategies that maximise the nutrient uptake by the plant and minimise the losses. In this regard, biofertilizers have become a possible, ecologically sustainable technology intervention. As opposed to chemical fertilizers, which direct delivery of nutrients, biofertilizers carry living microorganisms which colonize the rhizosphere (root zone) or interior part of the plant to facilitate growth by enhancing the availability or supply of primary nutrients to the host plant. This paper explains the processes that govern the functioning of biofertilizers and how these processes are important in enhancing the NUE in sustainable agrosystems.

### 2. The Challenge of Low Nutrient Use Efficiency (NUE)

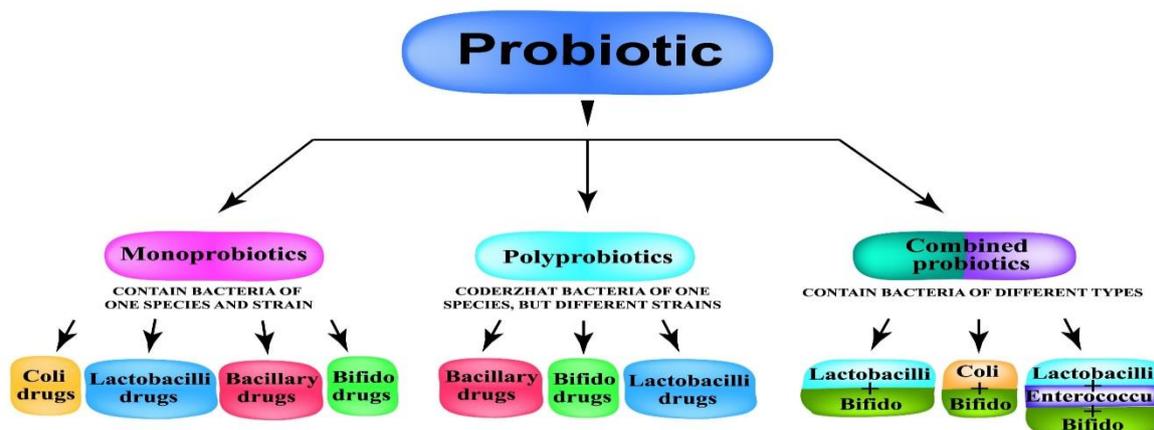
NUE is generally described as the production of harvested crop product in terms of nutrient used per unit. The prevailing global NUE of nitrogen is currently less than 50 per cent where that of phosphorus and potassium is often under 10 -25 per cent on the year of application.

The poor NUE is largely explained by the dynamic relationship of the soil, plant and microorganisms. An example is that applied phosphate fertilizers reacts quickly with calcium in alkaline soils or iron and aluminium in acidic soils to produce an insoluble compound not available to the plant (P -fixation). Similarly, nitrogen is very susceptible to leaching (in form of nitrate) and gaseous losses (in the form of ammonia or nitrous oxide). The solution to these natural soil inefficiencies needs agents which can actively regulate the soil environment in order to promote nutrient bioavailability.

### 3. Biofertilizers: Classification and Function

Biological fertilizers are products of biologic origin that include a certain strain of microorganisms (bacteria, fungi, algae or actinomycetes). They are categorised on the basis of their functions and the nutrients which they mobilise.

# CLASSIFICATION OF PROBIOTICS



Source: Shutterstock

**Table 1. Functional Classification of Major Biofertilizers in Agriculture**

Functional Category	Examples of Microorganisms	Primary Mechanism of Action	Target Crops
<b>Nitrogen Fixers (Symbiotic)</b>	<i>Rhizobium, Bradyrhizobium, Sinorhizobium</i>	Form nodules on legume roots, converting atmospheric N <sub>2</sub> into ammonia (NH <sub>3</sub> ).	Legumes (Soybean, pea, alfalfa)
<b>Nitrogen Fixers (Free-living/Associative)</b>	<i>Azotobacter, Azospirillum, Gluconacetobacter</i>	Fix atmospheric N <sub>2</sub> in the rhizosphere without forming nodules.	Cereals (Wheat, rice, maize), sugarcane
<b>Phosphate Solubilizers (PSM)</b>	<i>Bacillus megaterium, Pseudomonas striata, Aspergillus niger</i>	Secrete organic acids (e.g., gluconic, citric) to lower soil pH and dissolve fixed phosphates.	All crops, especially in alkaline/acidic soils
<b>Phosphate Mobilizers</b>	<i>Glomus spp., Gigaspora spp.</i> (Arbuscular Mycorrhizal Fungi - AMF)	Form symbiotic networks with roots, extending the depletion zone for P and micronutrient uptake.	Most agricultural crops (except Brassicaceae)
<b>Potassium Solubilizers (KSM)</b>	<i>Frateuria aurantia, Bacillus mucilaginosus</i>	Dissolve silicate minerals to release potassium.	All crops in K-deficient soils
<b>Plant Growth Promoting Rhizobacteria (PGPR)</b>	<i>Pseudomonas fluorescens, Bacillus subtilis</i>	Produce phytohormones (auxins, gibberellins) that enhance root architecture; suppress pathogens.	Wide range of horticultural and field crops

## 4. Mechanisms Enhancing Nutrient Use Efficiency

The biofertilizers do not simply ensure addition of nutrients to the soil but it optimises the ability of the soil-plant system to use available and added resources. The processes that facilitate improved NUE are complex.

### 4.1 Biological Nitrogen Fixation (BNF)

Nitrogen is known to be the most restrictive nutrient for crop growth. Although the air contains 78% of dinitrogen gas (N<sub>2</sub>), it is not usable by plants because the triple bond linking the atoms is so strong. In some prokaryotes, this enzyme, nitrogenase, is available, which can reduce N<sub>2</sub> to ammonia, a form usable by plants. Legumes have a highly selective relationship with symbiotic nitrogen fixers, including *Rhizobium*, which provide a substantial amount of N and eliminate the need for artificial N fertilisers by up to 50 -100 kg/ha. Free-living diazotrophs play a lesser role in the provision of N but play a key role in cereal systems. BNF can be used by delivering on-demand

nitrogen to the root zone to greatly decrease loss through leaching incurred in mass application of urea or nitrate fertilizers.

#### 4.2 Phosphate and Potassium Solubilization

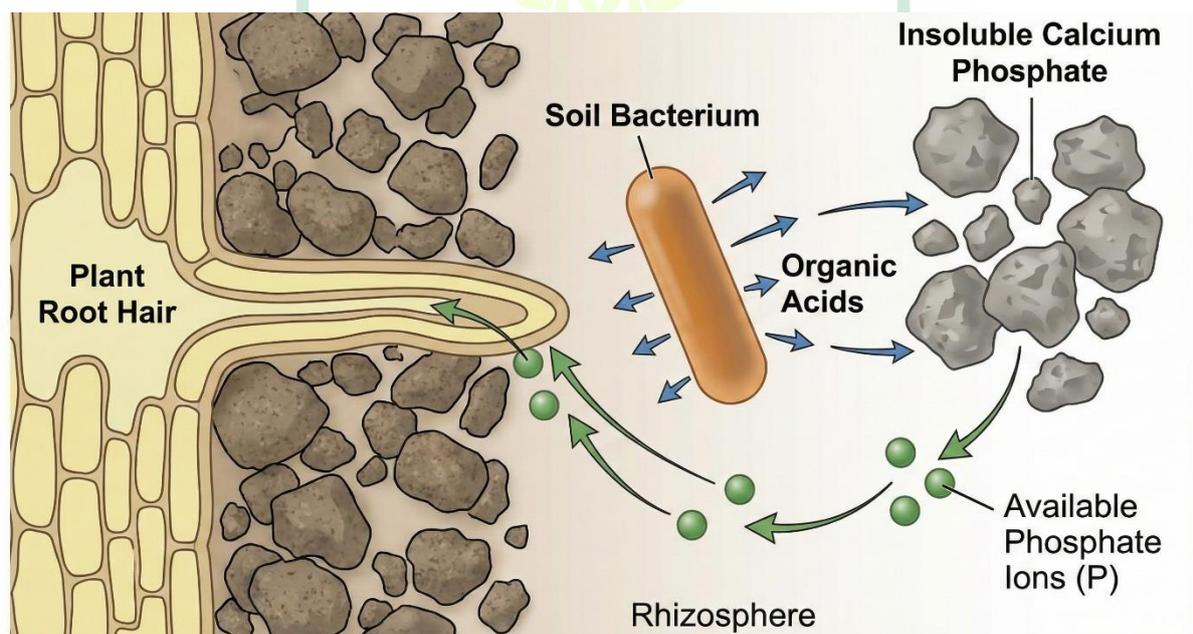
Next to nitrogen, phosphorus is the vital nutrient most often limiting crop production. Although soils may contain vast reserves of total phosphorus, very little is in the soluble orthophosphate form accessible to plants.

Phosphate solubilising microorganisms (PSMs) are important in opening this phosphorus legacy. They change insoluble inorganic phosphate compounds (like tricalcium phosphate) into soluble compounds. The main process is that the microbes produce low-molecular-weight organic acids (gluconic, citric and oxalic acids). These acids chelate cations (Ca, Fe, Al) that are attached to phosphate and reduce the pH of the rhizosphere causing the release of phosphate ions.

On the same note, potassium-solubilising microorganisms (KSMs) are able to acidify and enzymatically break down the insoluble minerals, such as micas and feldspars, so that an otherwise inaccessible pool of soil becomes available.

#### 4.3 Modification of Root System Architecture

Numerous biofertiliser strains, especially plant-growth-promoting rhizobacteria (PGPR), indirectly affect nutrient uptake by altering root architecture. These microorganisms generate phytohormones, which are auxins (indole-3-acetic acid or IAA), cytokinins, and gibberellins. High levels of auxin in the rhizosphere induce the growth of lateral roots and root hairs. A more developed branched root system has a greater surface area of nutrient interception and uptake and, in general, results in a higher NUE, particularly with immobile nutrients like phosphorus.



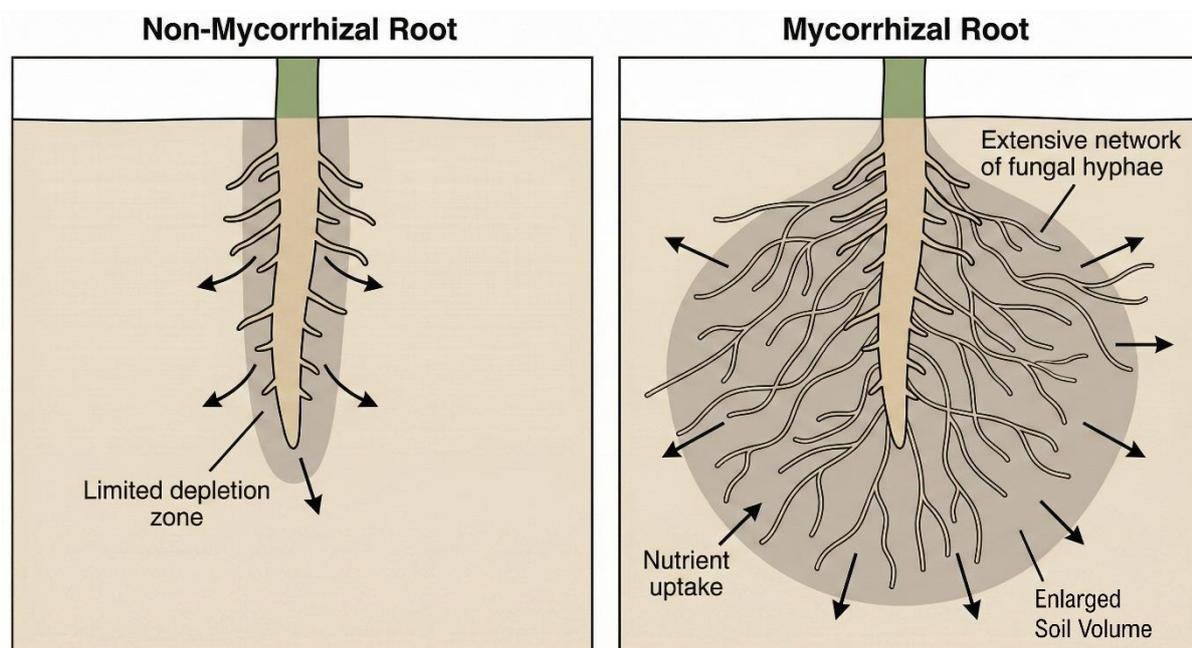
**Figure 1. Mechanism of Microbial Phosphate Solubilization in the Rhizosphere.** This diagram illustrates how a soil bacterium contributes to plant nutrition. The bacterium secretes organic acids into the rhizosphere (the soil region influenced by the root). These acids dissolve insoluble phosphate compounds, such as calcium phosphate, releasing phosphate ions (P) in a form that is available for uptake by the plant root hair

#### 5. The Role of Mycorrhizae in Extending Nutrient Reach

One of the greatest biotic effects on nutrient uptake efficiency is perhaps that of arbuscular mycorrhizal fungi (AMF). These fungi establish symbiotic relations with the root of about 80% of the terrestrial plant species.

The plant root cells are invaded by the fungal hyphae and run outwards into the bulk soil, much further than the root hairs themselves. This hypha network is effective to a greater degree of increasing the absorptive surface area of the root system by several orders of magnitude.

AMF are especially good scavengers of immobile soil nutrients like phosphorus, zinc, and copper that can be absorbed by soil pores that are too small to be taken up by root hairs. Mycorrhizae enable the nutrient depletion region around the root, thereby making sure that the plant is able to take advantage of the soil nutrient reserves, which would otherwise go unexploited, increasing the efficiency with which soil P is utilised by many orders of magnitude.



**Figure 2. Comparison of Nutrient Uptake Zones in Non-Mycorrhizal and Mycorrhizal Roots**

### 6. Integrated Nutrient Management (INM):

It is important to point out that, in the majority of intensive agricultural systems, biofertilizers do not replace chemical fertilizers but become a complement. Integrated nutrient management (INM) can be used to realise the highest NUE and sustainable yields.

INM is a combination of mineral fertilizers, organic manures and biofertilisers. Chemical fertilizers in this system give an immediate nutrient response to satisfy peak crop requirements, whereas biofertilisers give the nutrients a long-term response, minimize fixation losses, and enhance the biological health of the soil. As an example, the use of reduced dose of superphosphate fertilizer, which is combined with the use of PSMs, can ensure that the applied P is not fixed very quickly, and it remains useable by the plant.

**Table 2. Comparative Analysis of Nutrient Management Approaches**

Feature	Chemical Fertilizers Alone	Biofertilizers Alone	Integrated Nutrient Management (INM)
<b>Nutrient Release</b>	Rapid, immediate availability.	Slow, sustained release over the growing season.	Balanced: rapid start and sustained supply.
<b>Nutrient Use Efficiency (NUE)</b>	Low (high losses via leaching/fixation).	Moderate to High (dependent on conditions).	Highest (synergistic effects minimize losses).
<b>Impact on Soil Health</b>	Deteriorates over time; kills beneficial microbes; alters pH.	Improves soil structure, organic matter, and microbial diversity.	Maintains and improves long-term soil fertility and health.
<b>Environmental Impact</b>	High (eutrophication, GHG emissions).	Minimal; ecologically safe.	Reduced environmental footprint compared to chemicals alone.
<b>Yield Sustainability</b>	High initial yields, declining long-term stability.	Lower initial yields in intensive systems, but stable long-term.	High and sustainable long-term yields.

## 7. Challenges and Limitations in Adoption

Although they have proven to be beneficial, the mainstream application of biofertilizers is facing a series of challenges in the contemporary farming sector.

- 1. Field Variability:** Biofertilizer efficacy is strongly dependent on the environmental factors such as the soil type, pH, temperature, and moisture and on the competitive interaction with the native soil microbiota. A strain that grows best in the controlled laboratory environment is likely to perform poorly in the field environment.
- 2. Shelf-life and Quality Control:** It is quite challenging to maintain viable populations of microbes in carrier materials in storage and transport, especially in high temperature regions. Poor quality of products which cannot sustain high viable counts of cells tend to cause farm-level failures and destroy farmer confidence.
- 3. Specificity:** A number of biofertilizers are host-specific. An example of this is that *Rhizobium* strains, which are adapted to soy beans, do not fix nitrogen in peas, and thus there has to be an exact matching between the product and crop.
- 4. Slow Action:** Biofertilizers do not show an immediate response like those of conventional fertilizers like urea and they need time to establish in the rhizosphere and provide the farmers with concrete agronomic benefits hence requiring a certain level of tolerance on the part of farmers who are used to immediate chemical solutions.

## 8. Future Perspectives and Conclusion

Biofertilizers have a bright future as the creation of technologies that can overcome the existing restrictions. Modern studies are swinging towards the development of consortia biofertilizers that integrate complementary strains e.g., a nitrogen fixing bacterium with a phosphate solubilizing species to give a multi-pronged nutrient delivery. Simultaneously, nanotechnology is being used to manufacture nano-encapsulated biofertilizers, which increases microbial survival, increases shelf-life and controlled release over specific areas of the soil.

To sum up, decoupling agricultural productivity and the extensive use of fossil-based chemical inputs is the process which should be performed to guide the transition towards sustainable agriculture. Biofertilizers can be a significant biological intervention that can fill this gap. Biofertilizers provide a potential avenue that can support crop production, and at the same time, improve the soil health and prevent environmental degradation through increased nutrient use efficiency through biological nitrogen fixation, mineral solubilization and enhancement of better root architecture. The biofertilizer application in a holistic integrated nutrient management concept is not only another agro-nomical methodology, but an environmental imperative to the future of world food security.

### References

- Bhardwaj, D., Ansari, M. W., Sahoo, R. K., & Tuteja, N. (2014). Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microbial Cell Factories*, 13, Article 66. <https://doi.org/10.1186/1475-2859-13-66>
- Glick, B. R. (2012). Plant growth-promoting bacteria: Mechanisms and applications. *Scientifica*, 2012, Article 963401. <https://doi.org/10.6064/2012/963401>
- Kumar, A., Kumar, A., & Patel, H. (2017). Role of biofertilizers in agriculture. *Popular Kheti*, 5(4), 63–66.
- Smith, S. E., & Read, D. J. (2008). *Mycorrhizal symbiosis* (3rd ed.). Academic Press.
- Subba Rao, N. S. (2017). *Bio-fertilizers in agriculture and forestry* (4th ed.). Medtech.
- Vessey, J. K. (2003). Plant growth promoting rhizobacteria as biofertilizers. *Plant and Soil*, 255(2), 571–586. <https://doi.org/10.1023/A:1026037216893>
- Wu, S. C., Cao, Z. H., Li, Z. G., Cheung, K. C., & Wong, M. H. (2005). Effects of biofertilizer containing N-fixer, P and K solubilizers and AM fungi on maize growth: A greenhouse trial. *Geoderma*, 125(1–2), 155–166. <https://doi.org/10.1016/j.geoderma.2004.07.003>

## Climate Change Impacts on Marine Fish Stocks and Coastal Fisheries Sustainability



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### 1. Introduction

The connection between the health of marine ecosystems and the wellbeing of human beings is most visible in the fisheries industry. The commercial capture fisheries take an estimated 80 million tonnes of aquatic life each year, supporting a global economy that is worth hundreds of billions of dollars, and places a nutritional safety net that keeps dozens of the most vulnerable groups in the world. In the past, fisheries science was focused on fishing effort management to maintain maximum yielding stocks of fishes. The current studies, however, acknowledge that the existential threat to fisheries sustainability goes beyond overfishing to include the fast-changing physical and chemical environment of the global ocean.

Climate change is not a spectre threatening marine ecosystems, but it is a reality that is manifesting itself. Since the 1970s, the ocean has taken up over 90 per cent of the excess heat created by greenhouse gas emission and it has also taken up an estimated 30 per cent of the anthropogenic carbon dioxide. There is a very high price to this buffering capacity: increased sea-surface warming, extreme ocean acidification, and increasing areas of reduced oxygen conditions.

### 2. The Physio-chemical Drivers of Marine Change

Physical and chemical changes in the marine environment are a complex interaction that regulates the consequences of fish stocks. Although inundated infrastructure and high temperatures are physically threatening along a coastline, there are three primary stressors that essentially alter the physiology and structure of habitats in fish.

#### 2.1 Ocean Warming

Ocean warming is the ultimate force, and temperature acts as the ecological master variable of the ectothermic marine life. It controls the levels of metabolism, growth patterns, reproductive activity and geographical density. It has been found that the global sea-surface temperatures have risen by an average of 0.11 °C/per decade since 1971, although in recent years, the warming rate has been higher. Notably, not all warming is equal: marine heatwaves, which can be defined as prolonged periods of abnormally high sea-surface temperatures, have increased twofold over the last four decades since the 1980s and cause profound pressure on the marine ecosystem, especially on coral reefs and kelp forests, which act as nursery habitats of fish.

## 2.2 Ocean Acidification

The consumption of atmospheric CO<sub>2</sub> is increasingly causing oceanic overloading, depleting the levels of saturation of carbonate ions and because of the decreased pH. Although the adult finfish have a higher tolerance to changes in pH compared to the calcifying organism, shellfish and corals, a reduction in pH may affect the olfactory capacity of fishes, and behavioural patterns and development of larvae, disrupting the backbone of marine food webs.

## 2.3 Deoxygenation

High temperature decreases the dissolved oxygen solubility. Combined with increased stratification, preventing vertical distribution of oxygen-rich surface waters into lower strata, and nutrient runoff that will stimulate eutrophication, surface ocean oxygen levels have dropped by an estimated 2 per cent since the middle of the 20th century. Growth of the oxygen-minimum areas crowd out the environment of high-oxygen-needs species like tuna and billfish into even smaller and more shallow layers where they are more vulnerable to fishing equipment.

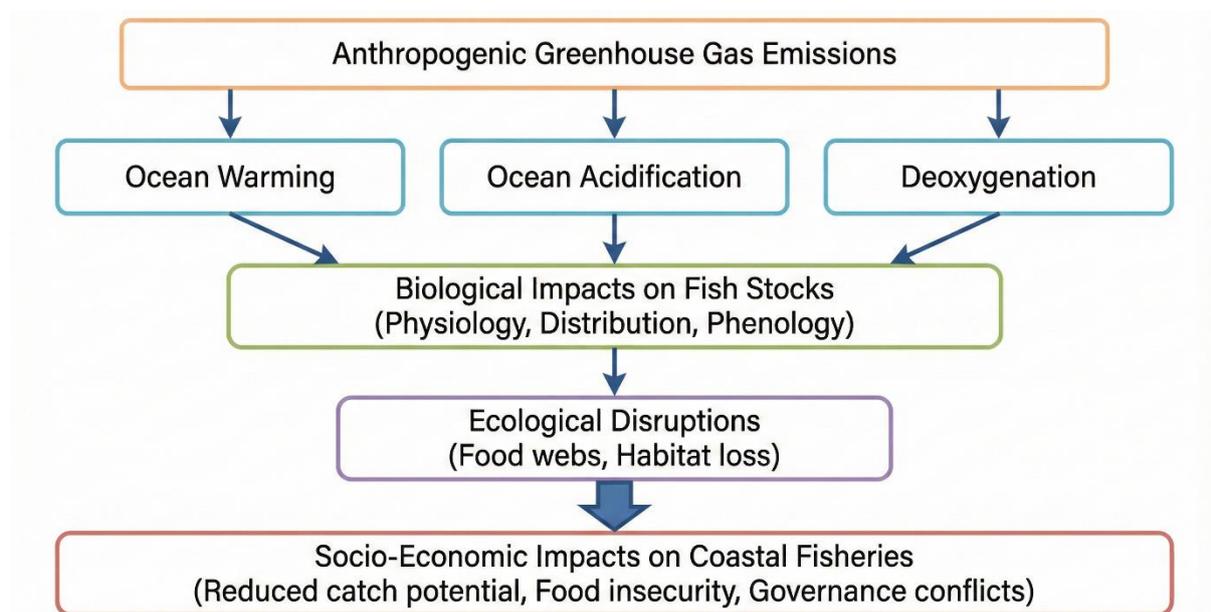


Figure 1. Conceptual Framework of Climate Drivers and Impacts on Fisheries

## 3. Biological Impacts on Marine Fish Stocks

The way marine organisms react to the action of these physio-chemical drivers is transforming the demographic and geographic structure of the world fish stocks.

### 3.1 Shifts in Distribution and Range

The most documented response to ocean warming is the geographical redistribution of species. To maintain their thermal niches, fish populations are shifting poleward and into deeper waters. While some high-latitude regions (e.g., the Barents Sea) are experiencing increases in biomass as subpolar species move in, tropical and subtropical regions are seeing a net exit of species without replacement by warmer-tolerant counterparts.

This tropicalization of temperate seas and the concomitant hollowing out of tropical biodiversity is not theoretical. Research indicates that marine taxa are shifting towards the poles at an average rate of 72 kilometres per decade, significantly faster than terrestrial species. These shifts disrupt established fishing grounds and force fleets to travel further, increasing operational costs and carbon footprints.

### 3.2 Disruption of Life Cycles and Phenology

Phenology - sequencing of biological occurrences with time is essential in marine life. Many fish species are dependent on the environment, especially temperature, to initiate spawning migrations or hatching of eggs. These events are being brought about earlier by climate change. The danger is in the phenological misfits. The very existence of new fish larvae depends on the instant access to the appropriate food, which is generally

phytoplankton or zooplankton blooms. When the warming causes earlier spawning and the plankton bloom, which is determined by the unchanging photoperiod, occurs later, then the larvae may be hatched into a low prey environment, leading to recruitment failure and possible stock collapse.

### 3.3 Altered Productivity and Body Size

Increased temperature increases metabolic rates, which increases energy requirements to maintain the metabolic rate at a low level. As a result, reduced energy is left to grow and reproduce until food consumption rises accordingly- something that hardly happens. This is a metabolic burden, which is augmented by deoxygenation. The temperature rule is based on the assumption that fish that live in warmer water will reach maturity at smaller body sizes. High-emission scenarios predict cuts in the maximum body weight of marine fish of 1424 by 2050. Reduced sizes of fish also mean reduced reproduction intensity, since fecundity is positively related to body size and reduced total biomass to be exploited by fisheries.

**Table 1: Observed Biological Responses of Selected Commercial Species to Climate Change**

Species / Fishery Type	Primary Climate Stressor(s)	Observed/Projected Biological Response	Implications for Stock Status
Atlantic Cod ( <i>Gadus morhua</i> ) (North Sea)	Warming	Northerly distribution shift; decreased recruitment due to plankton mismatch.	Stock recovery hindered despite reduced fishing pressure; traditional grounds becoming less viable.
Coral Reef Fishes (e.g., Groupers, Snappers - Tropics)	Warming (Heatwaves) & Acidification	Habitat loss due to coral bleaching; impaired larval sensory perception/behavior.	severely reduced productivity and carrying capacity of reef environments.
Skipjack Tuna ( <i>Katsuwonus pelamis</i> ) (Pacific)	Warming & Deoxygenation	Eastward shift in the warm pool of the Western Pacific; vertical habitat compression.	Changes in spatial availability impacting purse-seine fleet operations and regional allocations.
Peruvian Anchoveta ( <i>Engraulis ringens</i> ) (Humboldt Current)	Warming (El Niño frequency)	Increased volatility in population boom-and-bust cycles; spatial displacement during warm events.	highly variable annual catches affecting global fishmeal markets.

## 4. Implications for Coastal Fisheries Sustainability

The biological turmoil in the above-mentioned can be directly transformed into serious socio-economic weaknesses of the coastal fisheries, which can be classified broadly in the large-scale commercial fishery and the artisanal fishery. Although they both have problems, their adaptive abilities are quite different.

### 4.1 The Tropical Squeeze and Food Security

Climate change is expected to have the most dramatic effects on fisheries in tropical developing countries, where dietary protein and micronutrient supplies are utterly reliant on fish, where there is a lack of economic diversification, and where the institutional capacities of adaptive management are low. With migration of fish stocks northwards, there will be serious losses in maximum catch potential (MCP) in tropical Exclusive Economic Zones (EEZs). Models suggest that there will be a potential decrease in MCP by up to 40 per cent in certain tropical regions by the mid 21 st century in business-as-usual emission paths. On the other hand, the high-latitude areas like Norway, Iceland, and Russia might experience an increase in catch potential on a short term basis. Such a situation creates a deep unfairness in the world: countries that have been least contributing to historical greenhouse gas emissions will be the most deprived of marine resources. In the case of coastal communities of Southeast Asia, West Africa and the Pacific Islands, the economic impact is not the only problem to consider since it represents a major threat to food security.

#### 4.2 Economic Vulnerability and Livelihood Threats

Coastal fisheries are more than just food sources; they are socio-cultural systems. Small-scale fisheries employ over 90% of the world's capture fishers. Climate-induced volatility undermines the economic viability of these livelihoods. Increased frequency of extreme weather events destroys boats, gear, and coastal infrastructure (ports, processing plants), leading to down days where fishing is impossible. Furthermore, as traditional high-value species become scarce or move offshore, artisanal fishers with limited-range vessels cannot chase the stock, leading to reduced income and increased poverty traps.

#### 4.3 Governance and Transboundary Challenges

The current global fisheries governance framework is largely based on static geographical boundaries (EEZs). Fish, however, do not recognize borders. As climate change drives stocks across jurisdictional lines, it creates unprecedented governance challenges.

New stocks appearing in a nation's waters may lead to unregulated opportunistic fishing, while nations losing stocks may resist lowering quotas in a desperate attempt to maintain historical catch levels. This dynamic increases the risk of international conflicts, so-called fish wars and undermines cooperative management bodies like Regional Fisheries Management Organizations (RFMOs). The recent disputes over mackerel stock shifts in the Northeast Atlantic serve as a prelude to future conflicts as species distributions become increasingly fluid.

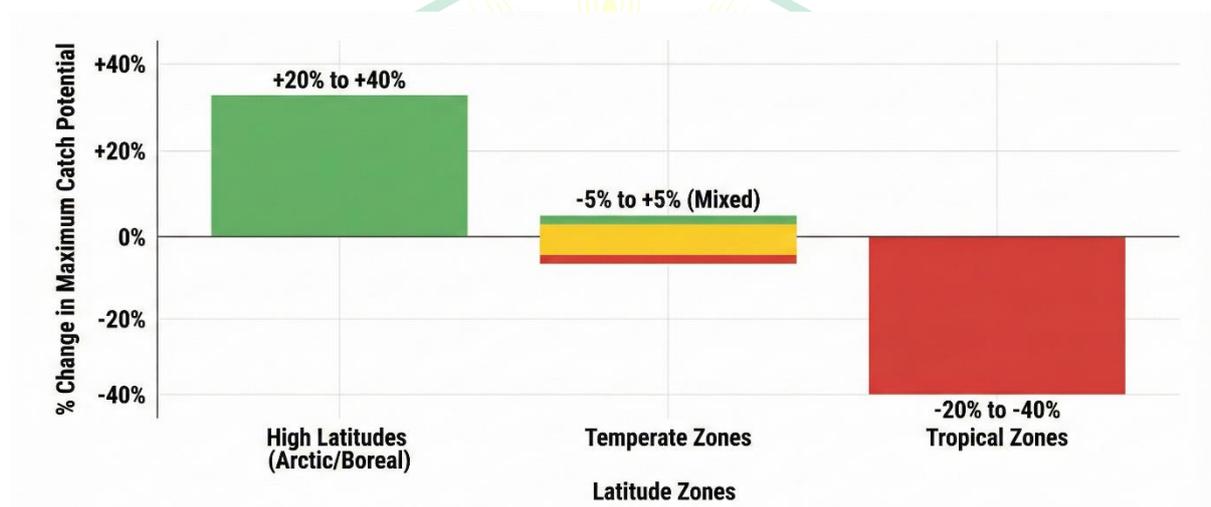


Figure 2. Projected Changes in Maximum Catch Potential (Mid-21st Century)

### 5. Adaptation Strategies and Future Pathways

Given the inertia in the climate system, significant impacts on fish stocks are locked in for the coming decades, regardless of immediate mitigation efforts. Therefore, adaptation is paramount to ensure the continued viability of coastal fisheries.

#### 5.1 Towards Dynamic Ecosystem-Based Management (EBM)

The traditional single-species management approach, relying on historical data to set future quotas, is obsolete in a rapidly changing ocean. Fisheries management must transition to Ecosystem-Based Management (EBM) that explicitly incorporates climate variables. This requires:

- Dynamic Reference Points:** Moving away from fixed biomass targets to dynamic targets that adjust based on prevailing environmental regimes (e.g., temperature-dependent recruitment models).
- Adaptive Governance:** Creating flexible legal frameworks that allow for rapid adjustments to quotas and fishing seasons in response to real-time monitoring of stock shifts and environmental conditions.
- Climate-Smart Marine Protected Areas (MPAs):** Designing networks of MPAs that protect climate refugia areas naturally more resistant to warming or acidification and establishing stepping stone reserves that accommodate shifting species ranges.

## 5.2 Building Resilience in Coastal Communities

Adaptation is not just about managing fish; it is about managing human expectations and behaviours.

- a. **Livelihood Diversification:** Reducing total reliance on capture fisheries by promoting supplementary income streams, such as sustainable marine tourism or climate-resilient aquaculture (e.g., farming low-trophic species like seaweed and bivalves that are less resource-intensive).
- b. **Enhanced Monitoring and Early Warning Systems:** Investing in accessible oceanographic data collection and providing coastal communities with seasonal forecasts of fish distribution and extreme weather events, enabling proactive decision-making.

## 6. Conclusion

Climate change is acting as a potent threat multiplier for marine fisheries, compounding existing pressures from overfishing and habitat degradation. The evidence is clear: ocean warming, acidification, and deoxygenation are fundamentally reorganizing marine ecosystems, driving fish stocks poleward, shrinking their average sizes, and disrupting the delicate timing of their life cycles.

The implications for coastal fisheries sustainability are profound, particularly threatening the food security and economic stability of tropical developing nations. The era of assuming environmental stationarity in fisheries science is over. Maintaining the crucial role of fisheries in the global food system requires an accelerated transition to dynamic, climate-informed governance structures and a robust commitment to building social and ecological resilience in coastal regions. The future of fishing is no longer just about how many fish we catch, but how quickly we can adapt to where they are going.

## References

- Cheung, W. W. L., Lam, V. W. Y., Sarmiento, J. L., Kearney, K., Watson, R., Zeller, D., & Pauly, D. (2010). Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology*, 16(1), 24–35. <https://doi.org/10.1111/j.1365-2486.2009.01995.x>
- Food and Agriculture Organization of the United Nations. (2022). *The state of world fisheries and aquaculture 2022: Towards blue transformation*. FAO. <https://doi.org/10.4060/cc0461en>
- Free, C. M., Thorson, J. T., Pinsky, M. L., Oken, K. L., Wiedenmann, J., & Jensen, O. P. (2019). Impacts of historical warming on marine fisheries production. *Science*, 363(6430), 979–983. <https://doi.org/10.1126/science.aau1758>
- Gaines, S. D., Costello, C., Owashi, B., Mangin, T., Bone, J., García Molinos, J., Burden, M., Dennis, H., Halpern, B. S., Kappel, C. V., Kleisner, K. M., & Ovando, D. (2018). Improved fisheries management could offset many negative effects of climate change. *Science Advances*, 4(8), eaar5509. <https://doi.org/10.1126/sciadv.aar5509>
- IPCC. (2019). *IPCC special report on the ocean and cryosphere in a changing climate* (H.-O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegria, M. Nicolai, A. Okem, J. Petzold, B. Rama, & N. M. Weyer, Eds.). Cambridge University Press. <https://doi.org/10.1017/9781009157964>
- Pinsky, M. L., Reygondeau, G., Caddell, R., Palacios-Abrantes, J., Spijkers, J., & Cheung, W. W. L. (2018). Preparing ocean governance for species on the move: Policy must anticipate conflict over geographic shifts. *Science*, 360(6394), 1189–1191. <https://doi.org/10.1126/science.aat2360>

## Climate-Resilient Cultivation and Post-Harvest Management of Custard Apple under Tropical Conditions



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### 1. Introduction

Custard apple (*Annona squamosa* L.) or sugar apple or sitaphal is one of the key fruit crops in arid and semi-arid tropics. Its nutritional value, especially high in carbohydrates and vitamins C and A and minerals like potassium, and its sweet and aromatic pulp make it an essential source of livelihood to many smallholder farmers, especially in India, Brazil, Thailand and Mexico. The crop is widely planted on marginal lands using little input, hence exploiting its natural hardiness.

Nevertheless, tropical agriculture is becoming more susceptible to climatic changes. Although the custard apple is relatively drought-tolerant, it is vulnerable to extreme temperatures and water shortages in particular stages of reproduction. According to projections of climate in the key production areas, there will be an increase in average temperature at the surface, and the frequency of heatwaves will increase. The average ambient temperature in the tropical climate during fruit maturation is usually above 35 °C, which is harmful to physiology. Moreover, losses after harvest in a tropical environment are very high, up to 20-40, mostly because the fruit is highly climacteric, and there is a lack of cold chain infrastructure. When ambient heat is high, it promotes metabolic activities, which causes it to ripen and spoil with microorganisms within 2-4 days of harvest.

In order to achieve the future of cultivating custard apples, there is a need to shift the paradigm to climate-smart agriculture. This transition necessitates a connection of the robust agronomic activities in the field to the technologically sophisticated post-harvest management systems that are intended to be used in a high-temperature environment.

### 2. Physiological Vulnerabilities to Climate Stress

Although *A. squamosa* is adjusted to wet and dry seasons, frequently shedding leaves during a drought to conserve water, its reproductive biology is weakened under extreme conditions of climate.

**Thermal Stress on Reproduction:** Flowering and fruit set represent the most vulnerable climatic situations. Hot weather (above 35 °C) and low relative humidity (less than 50%) lead to dehydration of stigmas, decreased pollen longevity and low pollen-tube development. It leads to poor fruit set or the formation of asymmetric and small fruits because of partial fertilization. The high temperature at the early stage of fruit development may result in fruit mummification, whereby fruits stop growing, harden, and become black.

**Water Stress Impact:** Severe water shortage of the enlargement phase of the fruit, although the extreme drought is tolerated, decreases the fruit size, pulp content and marketability. On the other hand, unpredictable weather conditions, which manifest themselves through heavy and unseasonable rains at the time of maturation, crack the fruit, thus rendering it vulnerable to fungus, including *Botryodiplodia theobromae*.

### 3. Pre-Harvest Strategies for Climate Resilience

Developing climate resilience requires a multi-pronged approach involving genetic resources, optimized water usage, and agronomic manipulations to modify the crop microclimate.

#### 3.1 Genetic Resources and Rootstock Breeding

Standard cultivars often lack the robustness required for future climate scenarios. Research must prioritize selecting genotypes exhibiting high pollen viability under thermal stress.

Crucially, the use of resilient rootstocks offers a near-term solution. Grafting *A. squamosa* onto related, hardier species such as *Annona reticulata* (bullock's heart) or *Annona cherimola* × *A. squamosa* hybrids (atemoya) has shown promise. *A. reticulata* rootstocks, for instance, possess deeper, more vigorous root systems, improving

water uptake efficiency and anchorage under drought conditions, while potentially conferring some degree of flood tolerance during extreme rainfall events.

### 3.2 Water Management Innovations: Regulated Deficit Irrigation (RDI)

In the tropical areas where there is a shortage of water, the replacement of flood irrigation with precision drip systems is essential. In addition to the effective application, the use of Regulated Deficit Irrigation (RDI) strategies is becoming effective. RDI means concurrent application of water stress on transient periods in non-critical phenological phases to enhance water-use efficiency (WUE) without reducing yield dramatically. Custard apple. Mild water stress during the vegetative flush (following harvest and before flowering) has the potential to inhibit excessive vegetative growth and coordinate flowering. But it should be completely irrigated in flowering and during fruit set.

**Table 1. Comparison of Conventional vs. Climate-Resilient Pre-Harvest Practices**

Practice Area	Conventional Approach	Climate-Resilient Approach	Expected Outcome under Climate Stress
<b>Irrigation</b>	Flood irrigation is often erratic based on water availability.	Drip irrigation with Regulated Deficit Irrigation (RDI) scheduling.	Increased Water Use Efficiency (WUE); reduced fungal root diseases; synchronized flowering.
<b>Soil Management</b>	Clean cultivation (bare soil); heavy reliance on synthetic fertilizers.	Organic mulching (straw, crop residues); addition of FYM/compost; cover cropping.	Reduced soil water evaporation; lower soil surface temperature; improved soil organic carbon and water holding capacity.
<b>Canopy Management</b>	Minimal or unsystematic pruning resulting in dense canopies.	High-density planting with intense training and pruning (e.g., open centre).	Improved air circulation reduces humidity-related pathogens, better light penetration improves fruit quality, and easier management.
<b>Pollination</b>	Reliance solely on natural insect pollinators (often unreliable under heat stress).	Assisted hand pollination during cooler morning hours.	Significantly increased fruit set and uniform fruit shape despite adverse weather.

### 3.3 Canopy and Soil Microclimate Management

It is important to adjust the immediate surroundings of the tree in order to counter macroclimatic extremes.

- a) **Mulching:** It is absolutely vital to apply organic mulches (e.g., paddy straw, dried leaves) with a thickness of 10-15 cm in tropical conditions. By mulching the soil surface, there is less surface-water evaporated, a weed is inhibited from competing for moisture and, most importantly, the soil surface temperatures are less in heatwaves, and the surface feeder roots are safe.
- b) **Pruning and Training:** The dense planting systems need pruning to be done frequently to ensure the open canopy is maintained. This improves air circulation, decreasing micro-climatic moisture that supports fungal pathology such as anthracnose (*Colletotrichum gloeosporioides*), which grows in warm and wet climate conditions that are likely to grow in certain areas in the tropics.

## 4. Post-Harvest Challenges in Tropical Climates

It is not the problem of cultivating the fruit of the custard apple that ceases at harvest time; it only augments. Custard apple is a climacteric fruit that is characterized by a spectacular surge in ethylene production and respiration rate soon after detaching from the tree.

This physiological process is over-accelerated in tropical ambient temperatures of 28 °C -35 °C. The fruit becomes soft quickly, the segments open up and the fruit pulp ferments. As a result, the marketing time frame is often less than 72 hours. Moreover, the fruit produced on trees that had suffered pre-harvest water/heat stress is characterised by senescence acceleration and uneven ripening after harvest.

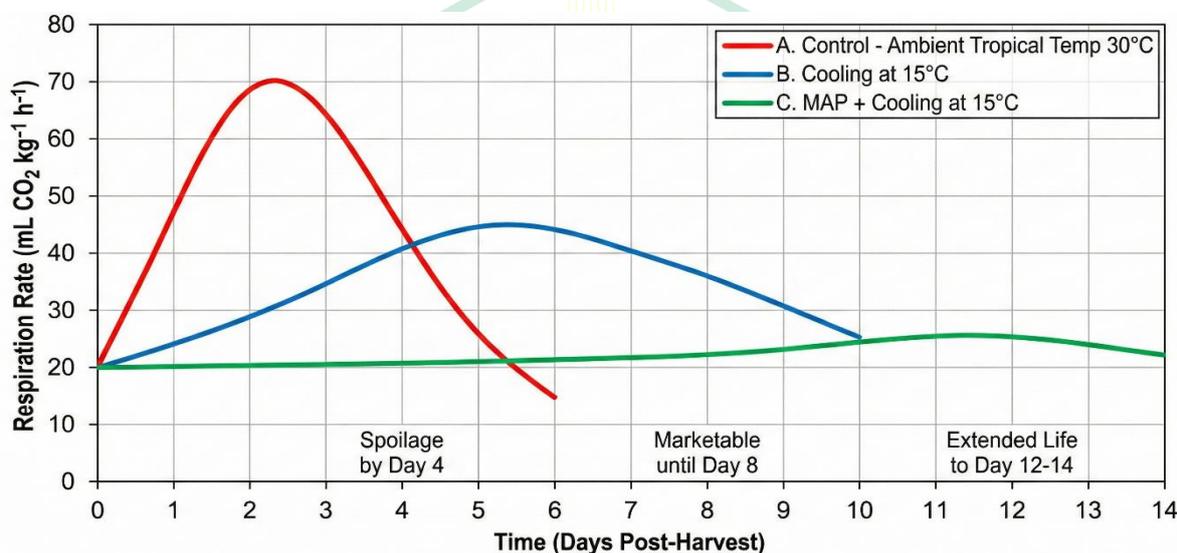
One of the greatest constraints to post-harvest management is that the fruit is susceptible to chilling injury (CI). The storage temperatures at the lower limit of 10 -12 °C cause various physiological diseases, such as discoloration of skin (browning), inability to ripen, and pulp hardening. Such circumstances make the traditional cold-storage procedures, which are designed for temperate fruit species, useless to the custard apple.

### 5. Advanced Post-Harvest Technologies

The technologies needed to control the supply chain under tropical climatic conditions without causing chilling injury have to suppress metabolic rates at moderately low temperatures (13°C–15°C).

#### 5.1 Modified Atmosphere Packaging (MAP)

MAP is a technology that is cost-effective and applicable in the tropical supply chains. It entails coating fruit in polymeric films having outlined gas-permeability characteristics. Oxygen (O<sub>2</sub>) is used in the natural respiration of the fruit, and carbon dioxide (CO<sub>2</sub>) is released. The movie is chosen to create a balanced environment within the package, which is low in O<sub>2</sub> (usually 3 -5 per cent) and with the high intensity of CO<sub>2</sub> (5 -10 per cent). This altered climate significantly reduces the rates of respiration and ethylene production, which postpones the process of ripening and senescence. In the case of custard apple, micro-perforated low-density polyethylene (LDPE) or polypropylene bags have been effective in prolonging the shelf life of custard apple, which initially had a shelf life of 3 days, to 10-14days when used together with cooling at 15 °C.



**Figure 1. Schematic Representation of Respiration Rate (CO<sub>2</sub> Production) in Custard Apple under Different Post-Harvest Conditions**

#### 5.2 Ethylene Action Inhibitors: 1-Methylcyclopropene (1-MCP)

1-MCP is a gas that irreversibly binds to the ethylene receptors in fruit tissue, inhibiting the hormonal signal that causes fruit to become ripe. 1-MCP (300-500ppb 12-24 hours) treatment immediately following harvest has shown to be very effective in tropical conditions. It prevents rapid softening and colour changes, with the possibility of a long distance of transportation. Nevertheless, dosage has to be maximized or too much of it will inhibit ripening permanently, leading to the fruit bearing rubbery fruit.

#### 5.3 Edible Coatings

Shrivelling caused by desiccation (loss of water) is a significant quality problem in high-heat environments. Polymerized polysaccharide (e.g. chitosan, alginate) or lipid (e.g. beeswax emulsions) edible coatings form a semi-permeable barrier on the surface of the fruit. Chitosan coatings offer the greatest potential to the tropical regions since they reduce transpiration and respiration rates, have natural antimicrobial properties and hence prevent post-harvest fungal rots, which are common in hot and humid areas.

## 6. Integrated Supply Chain Model

To be climate resilient, there is a need to integrate on-farm activities and post-harvest logistics. Any failure along the line would jeopardize the end product. Field heat is the most important in tropical climates.

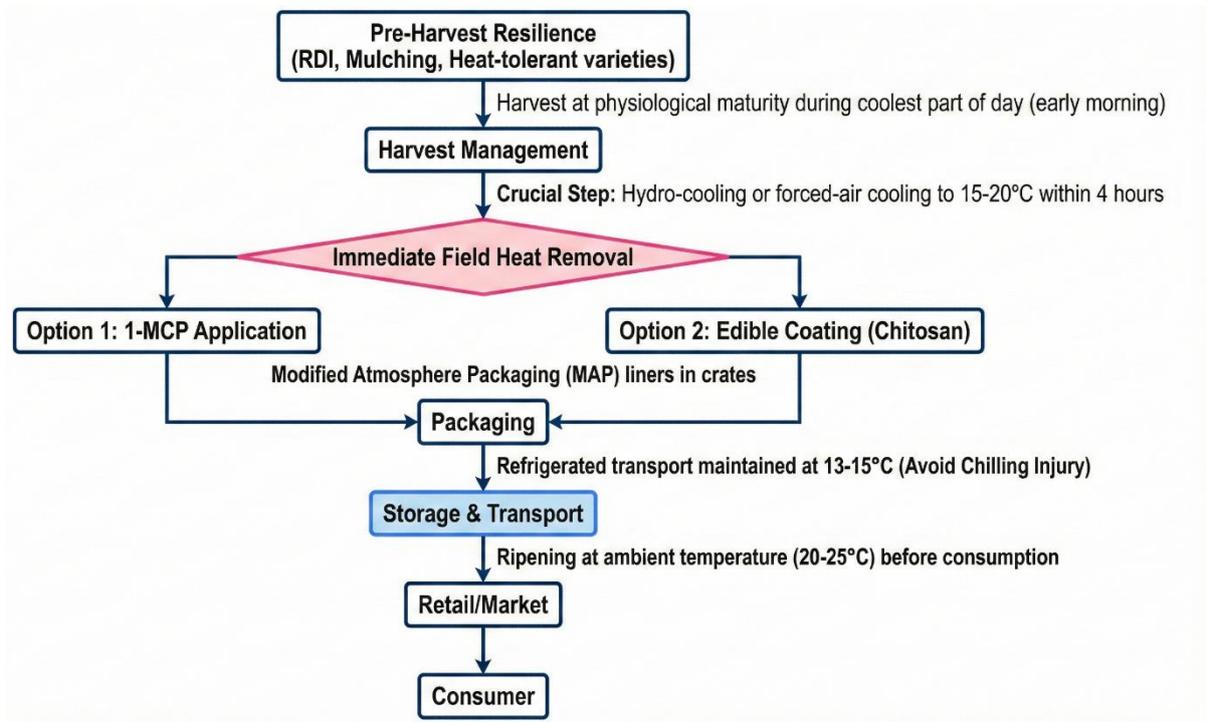


Figure 2. Integrated Climate-Resilient Supply Chain Flow for Custard Apple

## 7. Conclusion and Future Directions

Cultivation of custard apple in tropical areas stands at a crossroads. Although the crop has a tremendous economic promise to the resource-poor farmers, the escalating climate unpredictability is threatening critical threats to the stability of the yield as well as the quality of fruit. No longer can a business-as-usual strategy based on rainfed systems and crude handling after harvesting be an option. Strength should be constructed systematically. This starts by embracing rainwater harvesting and mulching as a way of levelling soil moisture and temperature extremes. It entails the transition to thermal tolerance-validated genotypes during pollination. Importantly, it is necessary to note that the post-harvest is a continuation of the climate adaptation. Without extensive cold-chain infrastructure in several of the developing countries in the tropics, the introduction of low-cost MAP and edible coatings is a buffer that is needed to counteract the rapid ripening of high ambient temperatures. Future studies ought to focus on achieving marker-assisted breeding of heat-tolerant varieties at the gametophytic stage and designing inexpensive, solar-powered on-farm precooling systems to overcome the very important gap that exists between harvesting and transporting products in remote tropical areas.

### References

- Benassi, G., Correa, G. A. S. F., Kluge, R. A., & Jacomino, A. P. (2003). Shelf life of custard apple treated with 1-methylcyclopropene: An antagonist to the ethylene action. *Brazilian Archives of Biology and Technology*, 46(1), 115–120. <https://doi.org/10.1590/s1516-89132003000100016>
- Fernandes, E. A., Soares, L. A. dos A., Lima, G. S. de, Silva Neta, A. M. de S., Roque, I. A., Silva, F. A. da, Fernandes, P. D., & Lacerda, C. N. de. (2021). Cell damage, gas exchange, and growth of *Annona squamosa* L. under saline water irrigation and potassium fertilization. *Semina: Ciências Agrárias*, 42(3), 999–1018. <https://doi.org/10.5433/1679-0359.2021v42n3p999>
- George, A. P., Broadley, R. H., Nissen, R. J., & Hamill, S. D. (2002). Control of tree size and vigour in custard apple (*Annona* spp. hybrid) cv. African Pride in subtropical Australia. *Australian Journal of Experimental Agriculture*, 42(4), 503–511. <https://doi.org/10.1071/EA01078>

Patil, R. A., Sudhakar Rao, D. V., & Manasa, B. (2013). Effect of modified atmospheric packaging on chilling injury and shelf-life of custard apple fruits. *Journal of Applied Horticulture*, 15(2), 100–105.

<https://doi.org/10.37855/jah.2013.v15i02.18>

Wang, W., Bai, T., & Liu, X. (2024). Effects of water, fertilizer and heat coupling on soil hydrothermal conditions and yield and quality of *Annona squamosa*. *Agronomy*, 14(10), Article 2189.

<https://doi.org/10.3390/agronomy14102189>



## Drone- and Sensor-Based Precision Weed Management Technologies in Agriculture



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### 1. Introduction

Contemporary agriculture is on a crucial crossroad. Although the modernization of agricultural activity has led to a massive increase in yields due to the intensification of agricultural activities over the last half-century, the use of prophylactic and whole-field chemical weed control is becoming less and less sustainable. The cost of agrochemicals to the economy and the extreme agronomic threat involving herbicide-resistant weeds that have now been reported in hundreds of species across the globe demonstrate the need to break with tradition. Precision agriculture, namely Site-Specific Weed Management (SSWM) is the answer. SSWM does not look at fields as homogeneous units, rather it looks at areas in terms of the local needs. The fundamental assumption here is very straightforward; implementation of control measures where weeds exist. The implementation is however, complicated and needs a high spatial resolution data and high processing speed.

Scalable SSWM has been offered by the development of the Unmanned Aerial Vehicles (UAVs) or drones with advanced miniaturized sensors. Drones provide spatial and temporal flexibility as they bridge the gap between satellite (which is usually too coarse or too infrequent) and ground-based scouting (which is a time-consuming and slow activity). In this article, the authors investigate the ways in which the technologies are making the weed management more of a proactive and targeted science rather than a reactive, blanket approach.

### 2. The Technological Ecosystem

The efficacy of precision weed management relies on the synergy between the aerial platform and its sensor payload.

#### 2.1 Unmanned Aerial Vehicles (UAVs) as Platforms

UAVs are used as a delivery system of sensors. In farming there are two major constructions:

- **Multi-rotor UAVs (e.g., quadcopters, hexacopters):** This type is typified by the capability of vertical take-off and landing (VTOL) and the power to hover. They provide great manoeuvrability and fit well in smaller fields or scanning of low altitude where intensive scanning is required to provide detailed maps. Their main disadvantage is that of battery life and flights.
- **Fixed-wing UAVs:** This category is similar to a conventional aeroplane that needs runways or catapults to take-off. They can fly longer and they can cover huge acreages in one mission; thus, they are applicable in large scale farm surveying. They are however usually more expensive in altitude of flights and speed and, therefore, may be less effective than multi-rotors in resolving ground sampling distance (GSD).

#### 2.2 Sensor Technologies: The Spectrum of Detection

Spectral reflectance is the basis of the precision weed detection, and it is defined as the way various surfaces reflect sunlight at different wavelengths. The spectral signatures of crops and weeds are usually different, especially when it is not in the visible band.

- a) **RGB Cameras (Visible Spectrum):** RGB Cameras (Visible Spectrum): Standard cameras with the ability to record red, green, and blue. They are economical and offer high-resolution visual data that

would be of use in detecting weeds in terms of colour, shape, and texture in the early crop development stage.

- b) **Multispectral Sensors:** Multispectral sensors obtain information in discrete bands of wavelengths such as near-infrared (NIR) and red-edge. The importance of NIR is that it is strongly reflected by healthy vegetation cover of plants. These sensors are able to differentiate live vegetation and soil and unhealthy vegetation by computing indices of vegetation like the Normalized Difference Vegetation Index (NDVI).
- c) **Hyperspectral Sensors:** The most improved one which records hundreds of narrow, continuous spectral bands. The effect of this is a continuous spectral curve per pixel which gives a distinct fingerprint of different plant species. This is necessary in the green-on-green scenario which is challenging and differentiating between a green weed and a green crop in the canopy.
- d) **LiDAR (Light Detection and Ranging):** It is based on laser pulses in measuring the distance, which generates detailed map of the field in 3-D structure. LiDAR is able to distinguish the weed on the basis of height differences in relation to the crop cover.

**Table 1: Comparative Analysis of Sensor Technologies for Weed Detection**

Sensor Type	Spectral Bands	Key Capability	Primary Scenarios	Application	Cost & Complexity
<b>RGB (Visible)</b>	3 Wide Bands (R, G, B)	High spatial resolution; textural analysis.	Green-on-brown (fallow fields); Early-stage weeds.	(fallow fields); Early-stage distinct weeds.	Low / Low
<b>Multispectral</b>	4–12 Discrete Bands (incl. NIR, Red-Edge)	Vegetation health indices (NDVI, NDRE).	Distinguishing vegetation from soil; General weed patches vs. healthy crop.	Distinguishing vegetation from soil; General weed patches vs. healthy crop.	Medium / Medium
<b>Hyperspectral</b>	>100 Narrow, Contiguous Bands	Spectral "fingerprinting" of species.	Green-on-green (species differentiation within canopy); Resistant biotype identification.	Green-on-green (species differentiation within canopy); Resistant biotype identification.	High / High
<b>Thermal IR</b>	Infrared spectrum (heat)	Detecting water stress/transpiration differences.	Supplementary data; distinguishing stressed weeds/crops.	Supplementary data; distinguishing stressed weeds/crops.	Medium / Medium

### 3. The Workflow: From Data Acquisition to Actuation

Weed management operations using drones is a multi-phase data pipeline. It is not just about flying but it is about creating an actionable prescription map.

#### 3.1 Phase I: Data Acquisition and Mission Planning

An effective mission must be well planned in terms of flying altitude, speed and picture overlap (front and side). These aspects define Ground Sampling Distance (GSD), the physical pixel size on the ground. A GSD of sub-centimetre to 2 cm may be necessary to ensure a high level of weed detection at an individual plant. It is important to implement radiometric calibration with reflectance panels just to ensure consistency of data in variations in lighting conditions through flights.

#### 3.2 Phase II: Data Processing and Analytics

Raw aerial imagery is useless without processing.

- a) **Orthomosaic Generation:** Individual images will be assembled through photogrammetry software to generate a geometrically corrected map of the whole field.
- b) **AI and Machine Learning:** This is where it is detected. Previously the plain thresholding by NDVI could have worked in the case of green-on-brown. Convolutional Neural Networks (CNNs) are the norm nowadays and are known as Deep Learning.
  - o *Training:* The models are trained on large bodies of annotated images and learnt the morphological and spectral features of particular crops and weeds.
  - o *Classification:* The AI classifies areas or individual objects as crop, weed, or soil.

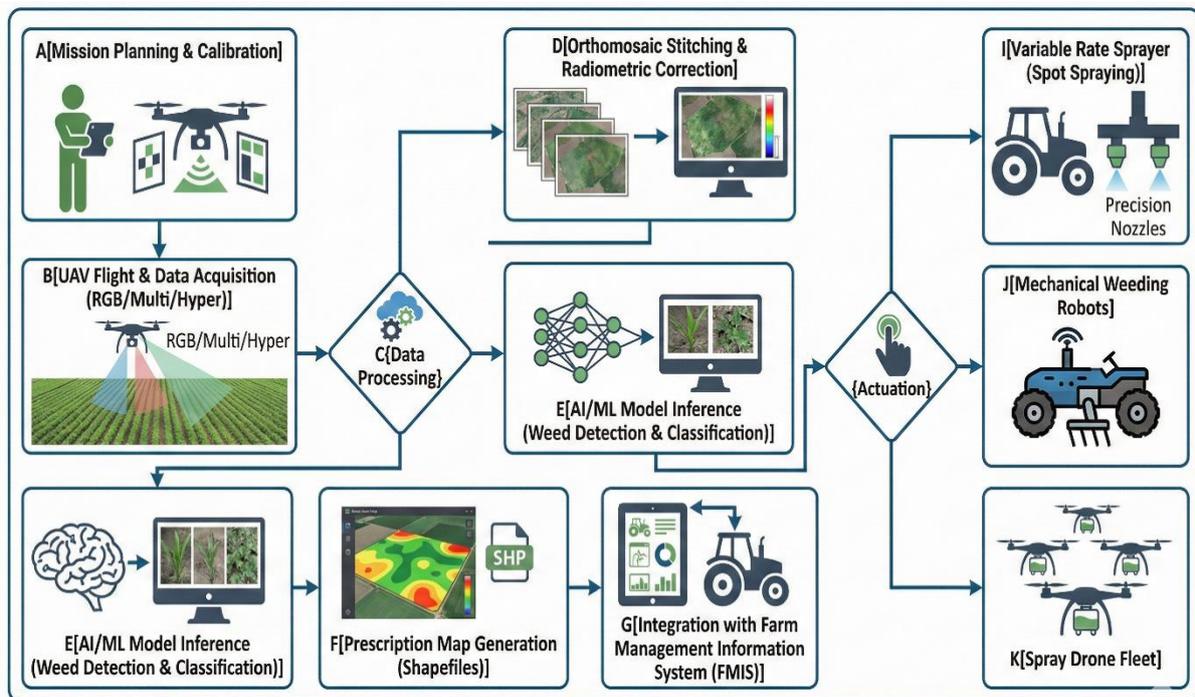


Figure 1. Operational Workflow Diagram of Drone-Based SSWM

### 3.3 Phase III: Actuation

The final output is a prescription map (e.g., a Shapefile) indicating precise GPS coordinates of weed infestations. This map is loaded into sprayer terminals.

- Variable Rate Application (VRA):** In any modern ground sprayer with pulse width modulation (PWM) nozzles and controlled operation of each nozzle, the flow rates can be switched on / off or changed in real time according to the map and only specific areas are sprayed.
- Spray Drones:** Larger multi-rotor drones equipped with tanks and nozzles act as aerial spot-sprayers, particularly useful in difficult terrain or wet soil conditions where ground rigs cannot enter.

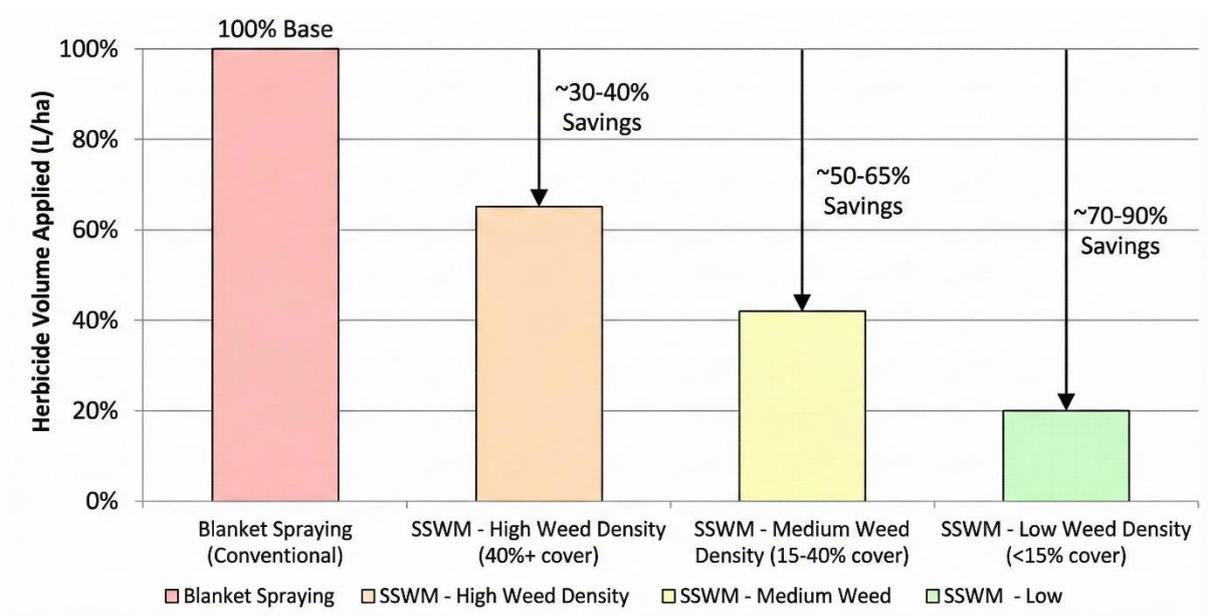
### 4. Economic and Environmental Implications

The transition to drone-based SSWM is driven by significant potential gains in efficiency and sustainability.

**Economic Benefits:** Herbicide savings are the most vital economic motivation. Chemical applied has been shown to be reduced by 30 per cent to more than 80 per cent, depending on the density of the weed pressure and its distribution, by the replacement of blanket spraying with spot spraying. Although, initially, the technology cost (drones, sensors, software, VRA-enabled sprayers) is substantial, the payoff (ROI) of the investment can be achieved within 2-3 seasons on large-acreage farms alone through the savings in the cost of chemicals alone.

**Environmental Benefits:** The overall amount of active ingredients deposited on the soil will be reduced; this will address a number of environmental risks:

- Reduced Runoff and Leaching:** Fewer chemicals in the system will reduce the chances of groundwater contamination and groundwater pollution into the surrounding water pools.
- Slower Resistance Evolution:** The mode of action is better focused on the targeted weeds, and mode of action rotation is likely enhanced in the problem areas, which makes the selection pressure that drives resistance to herbicides less.
- Biodiversity Preservation:** Non-competitive weeds in field margins or inter-rows have the potential to support beneficial insects and soil health, which have wider agroecological objectives.



**Figure 2. Estimated Herbicide Volume Reduction Potential using SSWM**

Figure 2 illustrates that the benefits of SSWM are highly dependent on weed distribution. In fields with uniform, high-density weed pressure, blanket spraying may remain the only viable option. The technology excels in fields with patchy or low-to-medium weed prevalence.

### 5. Challenges and Barriers to Adoption

Despite the promise, widespread on-farm adoption faces substantial hurdles.

- Data Friction and Connectivity:** High-resolution multispectral and hyperspectral imagery generates terabytes of data. Uploading this to the cloud for processing in rural areas with poor internet connectivity is a major bottleneck.
- The Green-on-Green Challenge:** While distinguishing green weeds on brown soil is relatively mature technology, reliably differentiating grass weeds within cereal crops, or broadleaf weeds within broadleaf crops, remains computationally difficult and often requires expensive hyperspectral data and complex AI models.
- Regulatory Environment:** Aviation regulations regarding Beyond Visual Line of Sight (BVLOS) operations currently limit the operational range of drones in many jurisdictions, hampering the efficiency of scanning massive farms.
- Interoperability:** Moving data seamlessly from a drone's processed map to a specific brand of tractor terminal often involves frustrating file conversions and compatibility issues between proprietary systems.

### 6. Future Trajectories: Real-Time and Beyond Chemistry

The future of this domain is moving toward increasing autonomy and speed.

**Edge Computing and Real-Time Processing:** The current fly-then-process-then-spray workflow is too slow for some operations. The frontier is edge computing, integrating powerful AI processors (like NVIDIA Jetson modules) directly onto the drone or the sprayer. This enables see-and-spray capability in real-time, eliminating the need for offline map generation. Drones could identify a weed and trigger an onboard spot-sprayer immediately, or ground rigs could process camera data on the fly to actuate nozzles.

**Alternative Actuation:** As herbicide resistance worsens, sensors will guide non-chemical control methods. High-powered lasers mounted on robots, guided by precise AI vision systems, are already in commercial testing to thermal-blast weed meristems. Similarly, precision mechanical weeding tools, guided by camera vision, are becoming more sophisticated for in-row weeding.

## 7. Conclusion

Drone- and sensor-based weed management represents a necessary evolution in agricultural practice, aligning agronomic imperatives with economic and environmental realities. It transforms weed control from a brute-force chemical application into a data-driven, surgical operation. While challenges in data handling, regulatory frameworks, and deep learning complexities persist, the trajectory is clear. As sensor costs decrease and onboard computing power increases, precision weed management will move from niche adoption to industry standard, serving as a cornerstone of sustainable 21st-century agriculture.

## References

- Cavalaris, C., Tagarakis, A. C., Kateris, D., & Bochtis, D. (2023). Cost analysis of using UAV sprayers for olive fruit fly control. *AgriEngineering*, 5(4), 1925–1942. <https://doi.org/10.3390/agriengineering5040118>
- Che'Ya, N. N., Dunwoody, E., & Gupta, M. (2021). Assessment of weed classification using hyperspectral reflectance and optimal multispectral UAV imagery. *Agronomy*, 11(7), 1435. <https://doi.org/10.3390/agronomy11071435>
- Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S., & Kaliaperumal, R. (2022). Smart farming: Internet of Things (IoT)-based sustainable agriculture. *Agriculture*, 12(10), 1745. <https://doi.org/10.3390/agriculture12101745>
- Gokool, S., Mahomed, M., Clulow, A., Sibanda, M., Kunz, R., Naiken, V., & Mabhaudhi, T. (2024). Exploring the potential of remote sensing to facilitate integrated weed management in smallholder farms: A scoping review. *Drones*, 8(3), 81. <https://doi.org/10.3390/drones8030081>
- Nobre, F. L. L., Santos, R. F., Herrera, J. L., Araújo, A. L. de, Johann, J. A., Gurgacz, F., Siqueira, J. A. C., & Prior, M. (2023). Use of drones in herbicide spot spraying: A systematic review. *Advances in Weed Science*, 41, Article e020230028. <https://doi.org/10.51694/advweedsci/2023;41:00028>
- Pai, D. G., Kamath, R., & Balachandra, M. (2024). Deep learning techniques for weed detection in agricultural environments: A comprehensive review. *IEEE Access*, 12, 113193–113214. <https://doi.org/10.1109/ACCESS.2024.3418454>
- Silva, J. A. O. S., Siqueira, V. S. de, Mesquita, M., Vale, L. S. R., Marques, T. d. N. B., Silva, J. L. B. da, Silva, M. V. da, Lacerda, L. N., Oliveira-Júnior, J. F. de, Lima, J. L. M. P. de, & Oliveira, H. F. E. de. (2024). Deep learning for weed detection and segmentation in agricultural crops using images captured by an unmanned aerial vehicle. *Remote Sensing*, 16(23), 4394. <https://doi.org/10.3390/rs16234394>
- Sulaiman, N., Che'Ya, N. N., Mohd Roslim, M. H., Juraimi, A. S., Mohd Noor, N., & Fazlil Ilahi, W. F. (2022). The application of hyperspectral remote sensing imagery (HRSI) for weed detection analysis in rice fields: A review. *Applied Sciences*, 12(5), 2570. <https://doi.org/10.3390/app12052570>
- Zhao, Y., & Wang, Y. (2025). Deep learning-based approaches for weed detection in crops. *Frontiers in Plant Science*, 16, 1746406. <https://doi.org/10.3389/fpls.2025.1746406>

## Eco-Friendly Aquaculture Strategies to Enhance Productivity and Farm Profitability



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### 1. Introduction

Aquaculture is one of the most critical areas for securing food security worldwide, as it now contributes over 50 per cent of the total fish consumed by humans globally. However, the Blue Revolution has received considerable criticism regarding its environmental impact. Eutrophication of aquatic environments has been associated with traditional vigorous monocultures by releasing nutrients, destroying important habitats like mangroves, overreliance on wild-harvested forage fish as food, and the spread of pathogens, which require the extensive application of antimicrobial agents. The environmental stressors translate directly into financial risks in terms of farm-management: the deteriorating water quality decreases the rate of growth, increases mortality, disease outbreaks can destroy whole production cycles, and unstable feed prices squeeze profit margins. Thus, there is a need to undergo a paradigm shift, namely, to focus more on the long-term ecosystem functioning rather than on the short-term biomass production.

The current article reviews evidence-based, environmentally-friendly aquaculture measures, which reduce the environmental effects but at the same time improve the on-farm productivity and profitability. Our thesis is that sustainable practices are the most sensible financial approach to the modern aquaculture business that will result in the establishment of robust mechanisms that can withstand biological and market shocks.

### 2. The Nexus of Ecology and Economy in Aquaculture

In the past, environmental regulations were viewed by the producers as cost drivers only. The modern analyses however have shown that economic efficiency in aquaculture is a requirement of ecological efficiency. The connection is based on three critical pillars:

- a) **Resource Efficiency:** Environmentally friendly systems are designed to make use of the inputs, water, energy, and feed, in a more efficient manner. Since feed can be 50-70 percent of the operational costs, any strategy that can increase the ratio of the Feed to Conversion (FCR) will have an immediate impact on the bottom line.
- b) **Biosecurity and Risk Reduction:** Systems that maintain high environmental quality reduce stress on aquatic organisms, bolstering their natural immune responses. This decreases reliance on costly veterinary interventions and reduces the catastrophic financial risk of mass mortality events.
- c) **Market Differentiation:** A consumer desire to buy certified sustainable seafood (e.g., ASC, BAP) at a high price is increasing. Availability of these markets requires an indication of compliance to green practices.

### 3. Core Eco-Friendly Strategies for Enhanced Production

Sustainable aquaculture will need certain technological and managerial interventions to be adopted in order to transition to sustainable aquaculture. The following plans signify the leader of this change.

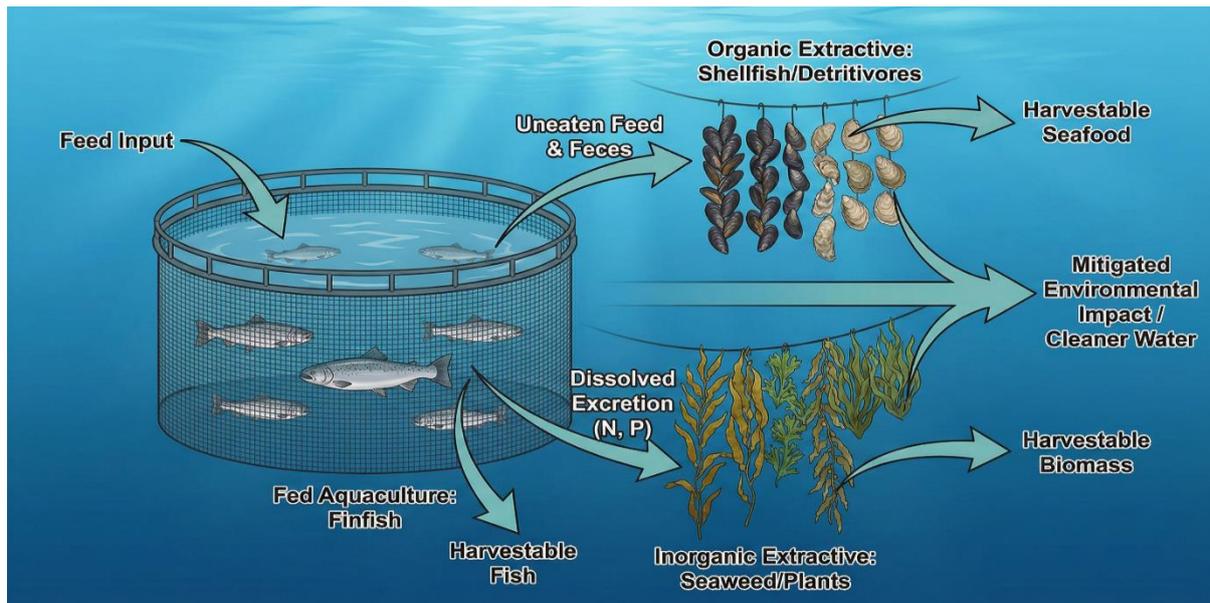
#### 3.1 Integrated Multi-Trophic Aquaculture (IMTA)

IMTA is a concept based on ecological engineering, moving away from monocultures toward polycultures that mimic natural ecosystems. In an IMTA system, species from different trophic levels are cultivated together. The uneaten feed and wastes (excreta) of a high-trophic fed species (e.g., finfish like salmon or tilapia) become nutrients for extractive species.

Inorganic extractive species, such as seaweeds or aquatic plants, absorb dissolved inorganic nutrients (nitrogen and phosphorus), mitigating eutrophication. Organic extractive species, such as shellfish (mussels, oysters) or deposit feeders (sea cucumbers, polychaetes), consume particulate organic matter.

**Productivity and Profitability Implications:**

IMTA is able to convert waste to a resource and generate ancillary commercial crops that do not require high amounts of extra feeds. Empirical examination shows that seaweed grown near to fish cages would experience a significantly increased growth rate due to the increase of nutrient availability. The financial benefit is two-fold: with diversified income sources, it serves as a hedge against the fluctuations in the commodity prices, and expenses on environmental compliance and waste management are minimized.



**Figure 1. Conceptualization of nutrient flows in IMTA**

**3.2 Recirculating Aquaculture Systems (RAS)**

RAS represents a shift from open-system interaction with the environment to highly controlled, land-based closed systems. RAS technology treats and reuses over 90-95% of culture water through mechanical filtration (removing solids), biological filtration (converting toxic ammonia to nitrate), aeration, and disinfection (UV or ozone).

**Productivity and Profitability Implications:**

RAS requires a high capital investment (CAPEX) and power requirement, but it provides unrivaled control over the rearing conditions. This control allows year-round production, the most favourable temperature to achieve the optimum growth rate, and the elimination of pathogens, which minimises mortality drastically. The eco-friendly aspect is that it has a small water footprint and the ability to harvest solid waste that would have been used as fertilizer thus avoiding environmental leakage. High stocking level, fast production cycle and strategic position of farms in relation to urban markets contributes to profitability in RAS by lowering transportation costs and carbon footprints.

**3.3 Biofloc Technology (BFT)**

Biofloc technology is a low-cost sustainable method, especially being one of the forefront in shrimp and tilapia shoal farming. It focuses on the equilibrium of carbon and nitrogen to stimulate increase of heterotrophic bacteria. These bacteria decompose toxic ammonia released by fish into microbial biomass by the incorporation of a carbon source (e.g., molasses or wheat bran). This biomass is gathered in form of flocs (bacteria, algae, protozoa, and particulate organic matter) which make an additional source of food rich in proteins to the cultured species, which is continuously accessible.

### Productivity and Profitability Implications:

BFT is highly effective in enhancing productivity through recycling waste nutrients into food hence reducing the FCR. It makes less water exchange more biosecurity as it breaks off ingress of external pathogens. The main source of profitability is a significantly reduced commercial feed costs which may reduce by 1525% based on species and management methods.

**Table 1. Comparative Analysis of RAS and Biofloc Technology (BFT)**

Feature	Recirculating Aquaculture Systems (RAS)	Biofloc Technology (BFT)
<b>Primary Mechanism</b>	Mechanical and biological filtration for water reuse.	Manipulation of C:N ratio to generate microbial protein in situ.
<b>Water Exchange</b>	Very Low (<5% daily replacement)	Low to Zero (only to replace evaporation/sludge removal)
<b>Capital Expenditure</b>	High (requires specialized infrastructure)	Moderate (can be adapted to existing ponds/tanks)
<b>Operational Cost</b>	High energy dependence (pumping, aeration, temperature).	Moderate energy (high aeration requirement), low feed supplement cost.
<b>Technical Skill</b>	High (engineering and water chemistry management).	High (microbial ecology and water quality management).
<b>Key Profit Driver</b>	Year-round high-density production; proximity to markets.	Reduced feed costs (lower FCR) and improved biosecurity.

### 3.4 Precision Feed Management and Alternative Ingredients

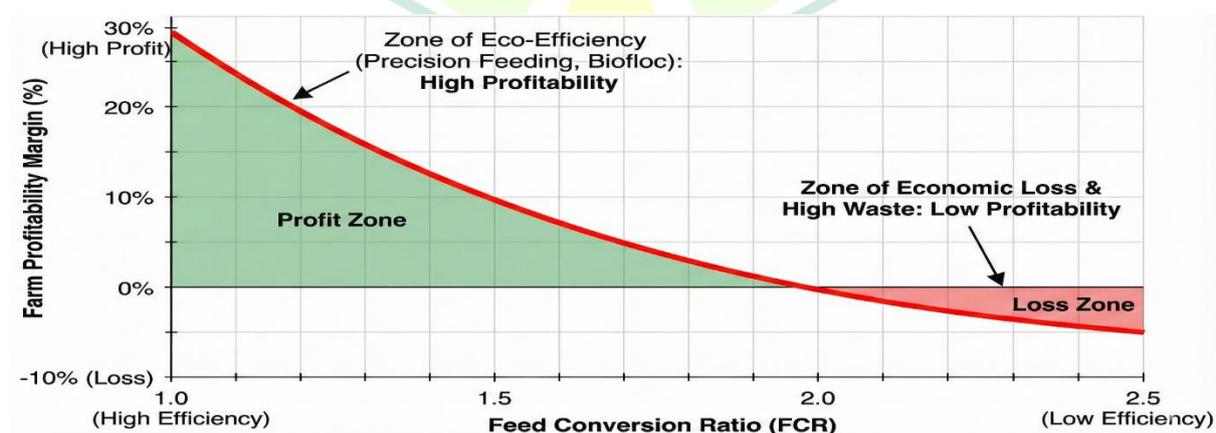
Environmental sustainability and economic performance are based on feed management. Feeding it too much wastes money and contaminates the water body; feeding it too little stifles growth.

**Precision Feeding:** With the help of acoustic sensors (detecting the lack of feeding), underwater cameras, and AI algorithms, farmers can adjust the feed feed to the state of appetite with minimal wastage and maximised FCR.

**Alternative Ingredients:** Reduction of marine ingredient (fishmeal and fish oil) is the key to sustainability of marine ecosystems. Alternative proteins are quickly embraced by the industry, such as plant-derived concentrates (soy, corn gluten), insect meal (black soldier fly larvae), microbial proteins and algae oils.

### Productivity and Profitability Implications:

Other alternative feeds can now fetch a small premium price, but they would protect the farmers against the very high volatility of fishmeal prices. In addition, the issue of precision feeding is, perhaps, the only most effective lever that a farmer can pull to improve short-term profitability.



**Figure 2. The relationship between Feed Conversion Ratio (FCR) and farm profitability**

#### 4. Enhancing Biosecurity through Ecological Means

The conventional use of antibiotics is becoming unsustainable because of the emergence of antimicrobial resistance (AMR) and regulatory bans. Green measures are also focused on prevention (prophylaxis) as opposed to treatment (therapy).

##### Probiotics and Prebiotics:

The application of beneficial bacteria (probiotics) directly into the water or feed can improve water quality by outcompeting pathogenic bacteria and enhancing the gut health of the cultured animal. Prebiotics (non-digestible fibres) encourage the growth of these beneficial gut bacteria.

##### Functional Feeds and Immunostimulants:

Feeds enriched with immunostimulants (e.g., beta-glucans, nucleotides) boost the nonspecific immune system of fish and shrimp, making them more resistant to endemic pathogens.

**Economic Impact:** These strategies reduce mortality rates and the need for expensive medications. A robust, healthy stock grows faster and more uniformly, securing final harvest value.

#### 5. Economic Analysis and Profitability Pathways

Adopting these eco-friendly strategies often requires a shift in business modeling. While some strategies, like RAS, entail high initial investment, others, like BFT or improved feed management, are primarily knowledge-intensive.

The profitability pathways can be categorized as follows:

- Cost Leadership through Efficiency:** (BFT, Precision Feeding). Reducing the unit cost of production by lowering feed and water costs.
- Premium Pricing through Differentiation:** (IMTA, Organic certification). Targeting niche markets willing to pay for environmental attributes.
- Risk Mitigation:** (RAS, Probiotics). Ensuring consistent supply by minimizing climate and disease risks.

Table 2. Economic Impact Matrix of Eco-Friendly Strategies

Strategy	Impact on Productivity (Yield/Growth)	Impact on Operational Costs	Primary Profitability Driver	Long-Term Viability Rating
IMTA	Moderate increase (synergistic growth)	Reduced waste treatment costs; Additional revenue streams	Diversified income; regulatory compliance	High
RAS	Very High (controlled environment, high density)	High energy costs; Low water costs	Consistency of supply; proximity to market	High (if energy costs are managed)
Biofloc (BFT)	High (continuous natural feed availability)	Reduced commercial feed costs; Moderate energy (aeration)	Significantly lowered Feed Conversion Ratio (FCR)	High
Precision Feeding	High (optimized nutrient intake)	Significant reduction in wasted feed	Direct feed cost savings; improved water quality	Very High
Ecological Biosecurity	Moderate to High (reduced mortality)	Reduced veterinary/chemical costs	Avoidance of catastrophic stock losses	Very High

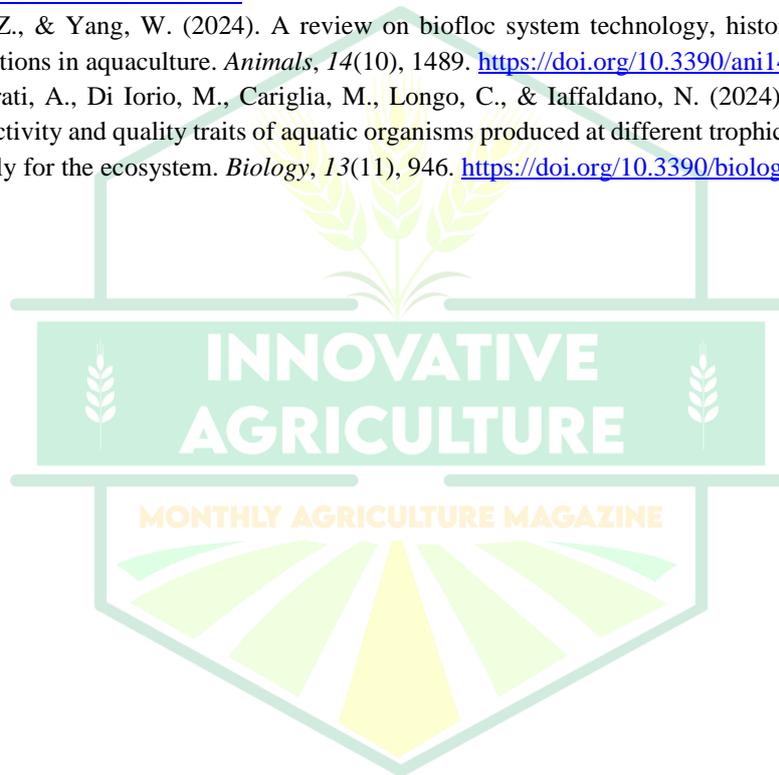
#### 6. Conclusion

The future of aquaculture lies not in the intensification of inputs, but in the intensification of knowledge. The strategies outlined IMTA, RAS, Biofloc, and precision nutrition demonstrate that environmental responsibility is not a burden on the aquaculture industry but its most viable path forward.

By shifting toward eco-friendly production, farmers can break the cycle of boom-and-bust caused by disease and environmental degradation. While the transition requires technical expertise and, in some cases, capital investment, the return on investment is realized through stabilized production, reduced operating costs via efficiency, and access to higher-value markets. For the modern aquaculture producer, profitability is inextricably linked to the ecological health of their farming systems.

## References

- Bergman, K., Henriksson, P. J. G., Hornborg, S., Troell, M., Borthwick, L., Jonell, M., Philis, G., & Ziegler, F. (2020). Recirculating aquaculture is possible without major energy tradeoff: Life cycle assessment of warmwater fish farming in Sweden. *Environmental Science & Technology*, *54*(24), 16062–16070. <https://doi.org/10.1021/acs.est.0c01100>
- Fachri, M., Amoah, K., Huang, Y., Cai, J., Alfatat, A., Ndandala, C. B., Shija, V. M., Jin, X., Bissih, F., & Chen, H. (2024). Probiotics and paraprobiotics in aquaculture: A sustainable strategy for enhancing fish growth, health and disease prevention—A review. *Frontiers in Marine Science*, *11*. <https://doi.org/10.3389/fmars.2024.1499228>
- Loayza-Aguilar, R. E., Huamancondor-Paz, Y. P., Saldaña-Rojas, G. B., & Olivos-Ramirez, G. E. (2023). Integrated Multi-Trophic Aquaculture (IMTA): Strategic model for sustainable mariculture in Samanco Bay, Peru. *Frontiers in Marine Science*, *10*. <https://doi.org/10.3389/fmars.2023.1151810>
- Nisar, U., Peng, D., Mu, Y., & Sun, Y. (2022). A solution for sustainable utilization of aquaculture waste: A comprehensive review of biofloc technology and aquamimicry. *Frontiers in Nutrition*, *8*. <https://doi.org/10.3389/fnut.2021.791738>
- Raza, B., Zheng, Z., & Yang, W. (2024). A review on biofloc system technology, history, types, and future economical perceptions in aquaculture. *Animals*, *14*(10), 1489. <https://doi.org/10.3390/ani14101489>
- Rusco, G., Roncarati, A., Di Iorio, M., Cariglia, M., Longo, C., & Iaffaldano, N. (2024). Can IMTA system improve the productivity and quality traits of aquatic organisms produced at different trophic levels? The benefits of IMTA—Not only for the ecosystem. *Biology*, *13*(11), 946. <https://doi.org/10.3390/biology13110946>



## Effect of UV Light and Temperature on Pest Reproductive Physiology



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### 1. Introduction

Control of pests of agriculture is essentially a struggle against their fertility. Survival is not the sole factor that dictates the ability of an insect population to exploit a cropping system, but the rate at which an individual can attain sexual maturity and produce viable offspring. Pest reproductive physiology is a sequence of biological events, hormonal signalling and gamete production to mating behaviours and oviposition, which are all very sensitive to external environmental signals.

The most important abiotic factors are temperature and solar radiation, i.e. ultraviolet (UV) radiation spectrum. Insects, being ectotherms, use external sources of heat to control the rate of metabolism, and so their breeding time is inherently tied to ambient temperature. At the same time, the solar UV radiation is a strong agent of environmental stress, which can lead to direct cellular damage and change the behavioural patterns.

Conventionally, they have typically been contrasted, where temperature is considered a cause of phenology and UV is considered a stressor, or vice versa, a navigation signal. Nonetheless, these variables combine in the field where pests are subjected to. The current changes in the world climate patterns, which have been in the increase in temperature averages and the changes in the cloud cover affecting the UV penetration, require a greater and combined knowledge of the two factors co-regulating the pest reproduction. This paper will discuss the independent and interactive physiological action of temperature and UV light on the pest reproductive biology and explain the ramifications of the study in terms of future agricultural defence operations.

### 2. The Thermal Imperative: Temperature and Reproductive Kinetics

Perhaps the most important abiotic insect life history regulator is temperature. It determines the velocity of biochemical reactions, which regulate development as well as physiological functioning. All species of pests have a certain thermal window, characterized by critical thermal minima (CT<sub>min</sub>) and maxima (CT<sub>max</sub>), beyond which they cannot reproduce, and survival becomes hindered.

#### 2.1 Thermal Effects on Gametogenesis and Hormonal Regulation

The process of reproduction begins far earlier than the process of mating and starts with the formation of eggs (oogenesis) and sperm (spermatogenesis). These are metabolically costly and controlled by hormones, mainly the juvenile hormone (JH) and the ecdysteroids.

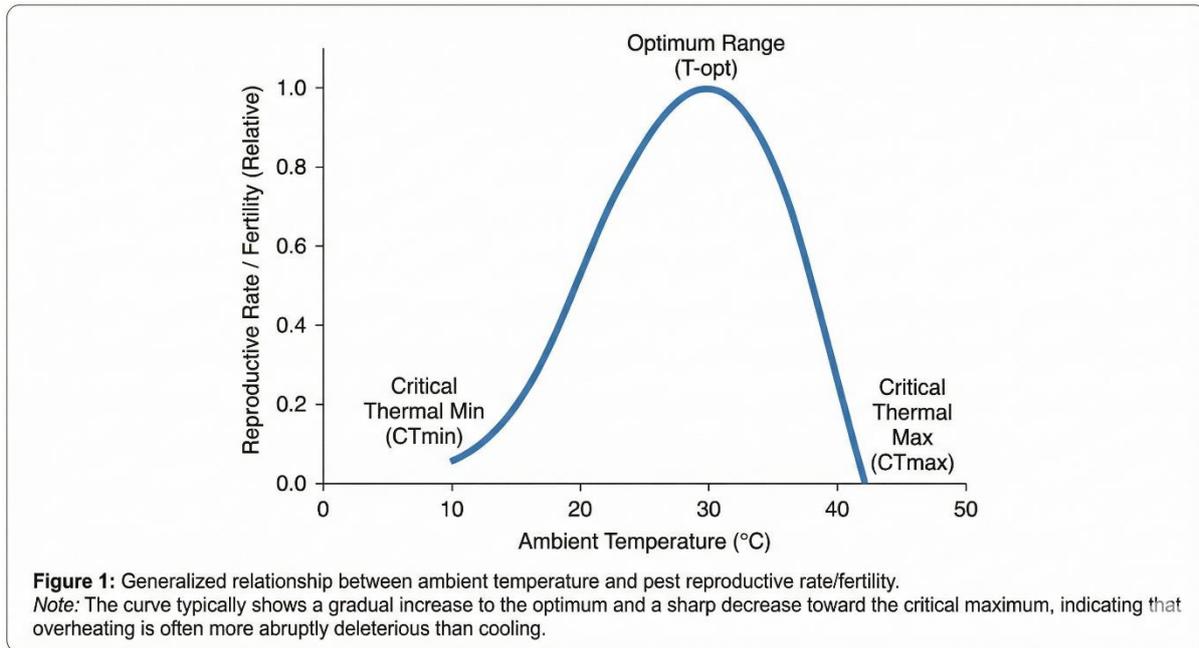
The synthesis and the titer of these hormones are affected by temperature. The neuroendocrine system can be perturbed by sub-optimal temperatures, causing the lack of vitellogenin production, the egg yolk protein precursor, and, in its turn, the reabsorbed eggs or full reproductive diapause.

In addition, spermatogenesis is famously heat-sensitive. Sub-lethal temperatures in the adult insect can cause temporary or permanent sterility in the male in most arthropod pests. The increased temperature would either denature vital proteins needed to make sperms move or cause damage to the sperm cells during their meiotic process, and thus make them unable to fertilise ova even in case they are successful in mating.

#### 2.2 Impact on Fecundity and Fertility

The correlation that exists between temperature and reproductive output is usually nonlinear and asymmetrical. With increases in temperatures past the lower threshold of a species, the reproductive rate (eggs per unit time) and fecundity (maximum) rises to an optimum (T<sub>opt</sub>). Above T<sub>opt</sub>, the reproductive success decays drastically with the onset of thermal stress.

It is important to note the difference between fecundity (the possible number of eggs), and fertility (the ratio of those eggs which hatch). Although moderate heat stress may merely have some slight effects on the number of eggs laid, it generally has dire effects on the viability of the embryos contained in those eggs.



**Figure 1. Generalized relationship between ambient temperature and pest reproductive rate/fertility.**

Note: The curve typically shows a gradual increase to the optimum and a sharp decrease toward the critical maximum, indicating that overheating is often more abruptly deleterious than cooling.

Increased temperatures increase the cost of life in metabolism. When a female adult is thermally stressed, the resources that otherwise would be directed into egg production are instead used in cellular maintenance and repair (e.g. heat-shock protein synthesis), thus decreasing fecundity.

### 3. The Invisible Stressor: Ultraviolet (UV) Radiation

The UV ray that gets to the surface of the earth is mainly UV-A (315-400nm) and UV-B (280-315nm). Although UV-A is sometimes used in insect vision and navigation, UV-B which is of shorter wavelength is biologically harmful. Insect exoskeletons, particularly those highly melanic, provide some level of protection, but high-energy photons of the UV can still penetrate through the cuticles and produce an effect on internal tissues.

#### 3.1 Mechanisms of UV-Induced Reproductive Damage

The primary mode of action for UV toxicity is direct DNA damage and the generation of Reactive Oxygen Species (ROS).

- a) **Direct DNA Damage:** UV-B radiation absorbs in DNA and results in the formation of cyclobutane pyrimidine dimers (CPDs). When these lesions develop in germline cells (sperm or eggs) and are not repaired by cellular repair mechanisms e.g. photoreactivation, they result in mutations. This is commonly observed in agricultural pests, in the form of so-called dominant lethal mutations, where the gametophyte is viable enough to undergo fertilisation, but the embryo born lives just long enough to develop into an adult before catastrophic mutations cause its death during early development.
- b) **Oxidative Stress:** UV radiations form ROS (e.g., superoxide anions, hydrogen peroxide) in the cells. These are very reactive molecules that destroy lipids, proteins and nucleic acids. Oxidative damage is especially vulnerable to the gonads since they are areas of high metabolism during reproduction. Motility and viability of sperm cells are greatly impaired by oxidative stress.

#### 3.2 Behavioural Modulation and Reproductive Trade-offs

Pests do not simply receive UV radiation. Numerous species show great behavioural avoidance to high-UV environments. Although this is a guarantee of survival, it tends to have a reproductive cost.

As an example, pests that feed and mate on the adaxial (top of) surface of leaves might be displaced to the abaxial (lower) surface or even into the plant canopies, during high UV index periods. This altered microhabitat may decrease the rate of mating encounters, be restrictive to accessing the best oviposition sites, or decrease feeding efficiency, all of which indirectly reduce lifetime reproductive output.

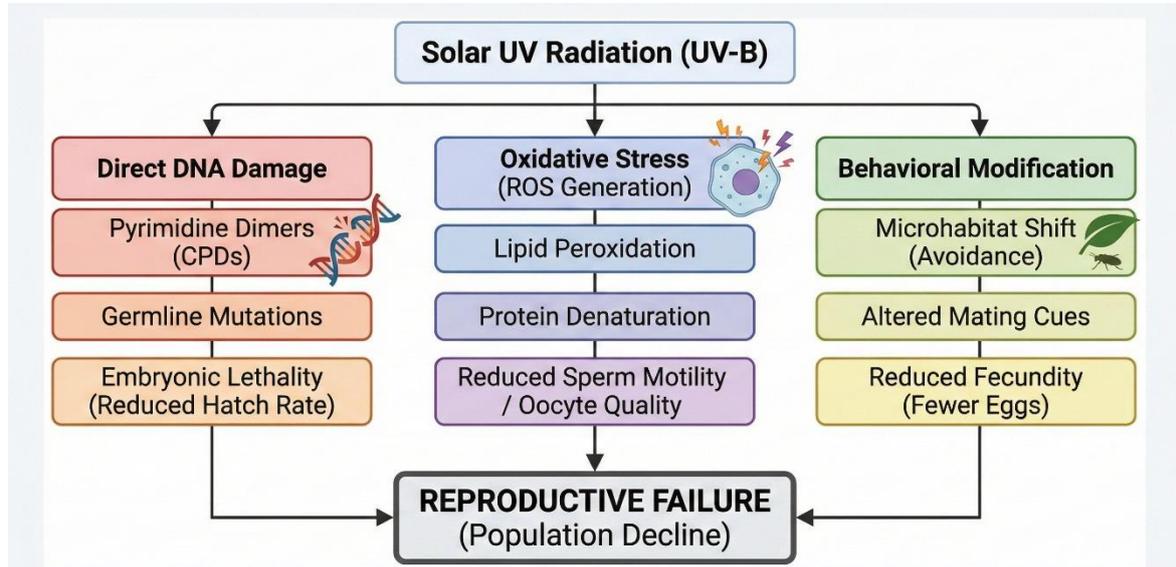


Figure 2. Pathways of UV-Induced Reproductive Failure in Agricultural Pests

#### 4. The Synergy of Stress: Interaction between Temperature and UV

Household In high temperature and UV radiation often coincide in agricultural settings (e.g. mid-summer sunny days). The studies continue to reveal that the influence of these two factors is seldom additive; often it turns out to be synergistic i.e. the aggregate effect is more than the aggregate of the individual effects.

##### 4.1 Compromised Repair Mechanisms

The strongest synergistic process is associated with DNA repair. The insects have enzyme systems, including photolyases, that repair UV induced damage to the DNA. These are temperature-sensitive enzymes.

Repair mechanisms can match moderate UV damage at optimum temperatures. There is, however, a possibility that these enzymatic proteins may denature or perform inefficiently when subjected to heat stress. This causes lesions caused by UV to accumulate more rapidly than they are being repaired thus resulting in much higher sterility at lower UV doses than would be the case at lower temperatures.

##### 4.2 The Double Hit on Metabolic Resources

Thermal as well as ultraviolet stress triggers costly physiological adaptations. Heat shock response (HSR) is triggered by high temperatures, and repair of DNA and the production of antioxidants is triggered by ultraviolet radiation. When these stress factors work together, then they place a heavy burden on the energetic resources of the organism. Therefore, the energy spent in weathering the integrated attack is nearly completely diverted out of the reproductive activities and fecundity sharply reduced.

#### 5. Implications for Integrated Pest Management (IPM)

The realization of the physiological limits on temperature and ultraviolet radiation promotes the formulation of more well-defined and viable Integrated Pest Management (IPM) plans.

##### 5.1 Predictive Modeling and Climate Change

The modern day pest demographic models often rely on the use of degree-days (thermal time) as the most important predictor.<sup>12</sup> However, with the rise in temperature due to anthropogenic climate change and the potential restructuring of the ultraviolet regimes, the use of UV variables is essential to model faithfulness. To take a case in point, a model calibrated entirely on temperature can predict a pest outbreak, but in a case where ultraviolet irradiance is unusually high in the risky egg or early larvae stage, then population dynamics achievable with such a model may be greatly shortened by UV-induced mortality.

## 5.2 Cultural and Physical Controls

The microclimate can be manipulated through agricultural practices that can take advantage of these physiological vulnerabilities:

- a) **Plasticulture:** The use of ultraviolet-absorbing plastic wraps in polytunnels or greenhouses could unintentionally increase the populations of certain pests, including the whiteflies or thrips, by removing the enzymatic UV radiation they avoid. Conversely, clear plastics that allow UV radiation could be utilized to eliminate pest species which are UV sensitive.
- b) **Canopy Management:** Ultraviolet exposure and ambient temperature in the micro-habitat of insects are increased by pruning and training crops to increase the canopy openness, which may in turn suppress the reproductive potential of certain pests, e.g. mites or aphids, in a natural process.
- c) **Solarization:** This sterilization practice of the soil uses the confluence of retained heat and solar radiation under clear plastic covers to achieve temperatures in the soil to mortal levels, eliminating soil-pests' stages and weed propagules.

**Table 1. Comparative Effects of Temperature and UV Stress on Pest Reproduction**

Physiological Aspect	Optimal Temperature & Low UV	High Temperature Stress (Heat)	High UV Stress	Synergistic Stress (High Temp + High UV)
<b>Gametogenesis</b>	Normal rate and quality of sperm/eggs.	Impaired spermatogenesis; protein denaturation in gametes.	DNA damage in germ cells; oxidative damage to lipids in yolk.	Severe germ cell damage; inhibited repair enzymes leading to high mutation accumulation.
<b>Mating Behavior</b>	Active; optimal frequency.	Reduced activity to conserve energy; altered signals.	Microhabitat shifts to avoid exposure; reduced encounters.	severely restricted activity; forced into shaded, potentially suboptimal habitats.
<b>Fecundity (Eggs Laid)</b>	High (Species maximum).	Moderate to severe reduction due to resource diversion.	Slight to moderate reduction (behavioral/resource based).	Severe reduction; energy diverted entirely to survival/repair.
<b>Fertility (Hatch Rate)</b>	High (>90%).	Reduced; embryo mortality due to heat stress.	Reduced; dominant lethal mutations cause embryo failure.	Very Low; combined effects of genetic damage and physiological heat stress on embryo.

## 6. Conclusion

The biological functioning of farming pests is closely intertwined with the nature of their physical surroundings. The temperature sets the pace of metabolic rate of reproduction, pinpointing the boundaries of possibilities, whereas the ultraviolet radiation acts as the ubiquitous stressor undermining the genetic quality of the viable offspring.

Temperature and ultraviolet radiation are in a complex interaction whose importance is increasingly becoming relevant in the face of a warming planet. That synergistic negative interaction between heat and ultraviolet stress on pest fertility suggests that, despite the potential expansion of pest ranges by thermal stress, the reproductive ability of a particular pest in a particular area might be counterintuitive to solar radiation. Future agricultural studies need to address these interrelations to come up with effective crop protection measures that do not go against but go in line with the environmental forces that are currently shaping the population of pests.

## References

- Chirault, M., Lucas, C., Goubault, M., Chevrier, C., Bressac, C., & Lécureuil, C. (2015). A combined approach to heat stress effect on male fertility in *Nasonia vitripennis*: From the physiological consequences on spermatogenesis to the reproductive adjustment of females mated with stressed males. *PLOS ONE*, 10(3), e0120656. <https://doi.org/10.1371/journal.pone.0120656>
- Dong, W., Hou, D., Hou, Q., Jin, H., Li, F., & Wu, S. (2024). Effects of ultraviolet light stress on protective and detoxification enzymes in insects. *Tropical Plants*, 3, 8. <https://doi.org/10.48130/tp-0024-0008>

- Escobar-Bravo, R., Klinkhamer, P. G. L., & Leiss, K. A. (2017). Interactive effects of UV-B light with abiotic factors on plant growth and chemistry, and their consequences for defense against arthropod herbivores. *Frontiers in Plant Science*, 8, 278. <https://doi.org/10.3389/fpls.2017.00278>
- Harvey, J. A., Heinen, R., Gols, R., & Thakur, M. P. (2020). Climate change-mediated temperature extremes and insects: From outbreaks to breakdowns. *Global Change Biology*, 26(12), 6685–6701. <https://doi.org/10.1111/gcb.15377>
- Hu, J., Medison, R. G., Zhang, S., Ma, P., & Shi, C. (2022). Impacts of non-lethal high-temperature stress on the development and reproductive organs of *Bradysia odoriphaga*. *Insects*, 13(1), 74. <https://doi.org/10.3390/insects13010074>
- Khan, M., Ali, A., Memon, S. A., Qambrani, T. K., Khaliq, G., Khan, J., Ahmed, S., Abro, A. H., & Baloch, S. A. (2021). Function of ultraviolet radiation (UV-B) light on the survival of red flour beetle *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) and their body fitness. *Pakistan Journal of Agricultural Research*, 34(4), 748–757. <https://doi.org/10.17582/journal.pjar/2021/34.4.748.757>
- Sun, J., Tan, X., Li, Q., Francis, F., & Chen, J. (2022). Effects of different temperatures on the development and reproduction of *Sitobion miscanthi* from six different regions in China. *Frontiers in Ecology and Evolution*, 10, 794495. <https://doi.org/10.3389/fevo.2022.794495>
- Zhang, H., Xu, D., Deng, X., Liu, Z., He, Z., Wu, J., & Zhuo, Z. (2025). Impact of temperature variation on the biological traits and lifecycle of *Spodoptera exigua* (Lepidoptera: Noctuidae): A meta-analysis approach. *Insects*, 16(2), 155. <https://doi.org/10.3390/insects16020155>



## Evaluation of Aquaculture Activities on Water Quality Dynamics and Ecosystem Functions



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### 1. Introduction

The systematic production of aquatic life known as aquaculture has become the rapidly growing branch of the world food production, presently supplying over fifty percent of fish eaten by humans. With the stagnation of capture fisheries, aquaculture will become an essential part of the food security and economic development of the coastal and rural areas of the world. The accelerating increase of this production with its high stocking levels and large input of exogenous factors has, however, subjected the aquatic ecosystems, which were formerly regulated by natural assimilation capacities, to anthropogenic stressors.

The key issue of contemporary aquaculture is the loss of interdependence between the growth of production and the environment degradation. Water quality is the main point of this interaction. Water will serve as both the culture medium, the means of transportation of inputs (oxygen, feed), and a waste product (faeces, metabolites, uneaten feed). Through an increased rate of loading of the pollutant by aquaculture activities compared to the carrying capacity or the assimilative capacity of the body of water that receives the effluent, water quality processes are interrupted, resulting in a series of effects on the functions of the entire ecosystem.

### 2. Mechanisms of Interaction: The Nutrient Load

The inherent environmental effects of fed aquaculture systems are based on the mass balance inefficiencies. A large percentage of the nutrients delivered by the formulated feed are not stored in harvested fish biomass in intensive systems such as cage culture or flow-through raceways.

Research has shown that a maximum percentage of nitrogen (N) and phosphorus (P), added with the feed, is recovered in the harvested product (20-30 percent). The 70-80 percent that is not captured is emitted into the environment and is discharged by three major routes:

- a) **Uneaten Feed:** percentage of the feed follows a direct slope to the bottom or is dissolved in the water column, depending on the feeding management procedures and the feed buoyancy.
- b) **Faecal Waste (Particulate Organic Matter):** Faecal matter is excreted as undigested nutrients, and it forms the suspended solids and finally settles to form organic benthic deposits.
- c) **Metabolic Excretion (Dissolved Inorganic Nutrients):** The gills allow the fish to excrete ammonia (NH<sub>3</sub>) as a protein-metabolic byproduct, and dissolved urea and phosphate.

This constant supply of organic carbon, nitrogen and phosphorus fundamentally changes the trophic status of the receiving waters by transforming them and turning them into eutrophic rather than oligotrophic or mesotrophic waters.

### 3. Impacts on Water Quality Dynamics

These waste streams lead to acute and chronic changes in physicochemical parameters of water. Such changes are interdependent; the changes in one parameter tend to make the other worse.

#### 3.1 Dissolved Oxygen (DO) Depletion

In the majority of water bodies, the limiting factor is dissolved oxygen. The effect of aquaculture on DO occurs in two ways. First, even the cultured stock itself has a high respiratory demand. Second, and usually more serious in an open system is the Biological Oxygen Demand (BOD) generated by waste. Largely, as heterotrophic bacteria break down uneaten feed and faeces (both in the water column and sediment), they use large amounts of oxygen. This may cause a localized hypoxia ( $DO < 2\text{mgL}^{-1}$ ) or anoxia, especially in the bottom waters or at nighttime when algal photosynthesis is interrupted, but the respiration process persists.

#### 3.2 Nitrogenous Compounds Accumulation

Nitrogen is one of the main factors of aquatic productivity. The excretory product is un-ionised ammonia ( $\text{NH}_3$ ), and it is very toxic to aquatic organisms even at low doses. Although ammonia is transformed by nitrifying bacteria into nitrite ( $\text{NO}_2^-$ ) and then into a less toxic nitrate ( $\text{NO}_3^-$ ), this biofiltration capacity might be overstretched by intensive aquaculture. High nitrate concentrations, though not as acute toxins, are a good fertilizer to algal growth.

#### 3.3 Phosphorus Loading

Phosphorus is normally the limiting nutrient in primary production in freshwater ecosystems. This constraint is released by aquaculture effluent, which is a soluble reactive phosphorus (due to metabolic excretion) and particulate phosphorus (due to faeces and feed bones). The slight changes in the amount of phosphorus can cause disproportionately high algal growth.

#### 3.4 Turbidity and Suspended Solids

Particulate waste elevates the turbidity of water and cuts down light diffusion through the column of water. This prevents the growth of desirable submerged macrophytes (aquatic plants) and encourages phytoplankton that grows on the surface, further disrupting the ecosystem structure.

**Table 1: Summary of Major Aquaculture Inputs and Associated Water Quality Parameter Alterations**

Input Source	Primary Constituents	Key Water Quality Parameter Affected	Consequence of Alteration
Uneaten Feed	Organic Carbon, Organic N, Organic P	Increased Biological Oxygen Demand (BOD); Increased Turbidity	DO depletion; Sediment enrichment; Reduced light penetration.
Fecal Waste	Particulate Organic Matter, Particulate P	Increased Total Suspended Solids (TSS); Sediment Oxygen Demand (SOD)	Benthic smothering; Benthic anoxia; Resuspension of nutrients.
Metabolic Excretion (Gills/Urine)	Total Ammonia Nitrogen (TAN), Urea, Dissolved Inorganic P (DIP)	Increased Ammonia ( $\text{NH}_3/\text{NH}_4^+$ ); Increased Nitrate ( $\text{NO}_3^-$ ); Increased Soluble Reactive Phosphorus (SRP)	Acute toxicity to aquatic fauna; Nutrient enrichment stimulating algal blooms (Eutrophication).
Therapeutic Agents (Antibiotics/Chemicals)	Bioactive compounds, heavy metals (e.g., Copper in antifoulants)	Presence of micro-pollutants; Persistence in sediment	Development of antimicrobial resistance in bacteria; Toxicity to non-target organisms.

### 4. Alterations to Ecosystem Functions

The change in the water quality parameters is not a complete goal, but a trigger of much wider changes in the ecology. These changes tend to be a form of degradation of ecosystems services, which are benefits that human beings get in the natural environments.

#### 4.1 The Eutrophication Trajectory and Harmful Algal Blooms (HABs)

Eutrophication of the most noticeable ecosystem imbalance created by the nutrient loading caused by aquaculture is faster. The N and P surplus trigger high phytoplankton. Although greater primary productivity may have in some cases a temporary beneficial effect upon local fisheries, unregulated blooms have disastrous effects. The resultant bacteria degradation of these large populations of algae deprives the water column of oxygen leading to

dead zones. Moreover, nutrient enrichment has tended to select particular, opportunistic species of algae, such as cyanobacteria or dinoflagellates generating potent toxins. Such Harmful Algal Blooms (HABs) may lead to huge fish kill (farmed and wild), the build-up of toxins in shellfish rendering them unsafe to people, and overall destabilize whole food webs, by outcompeting beneficial algae.

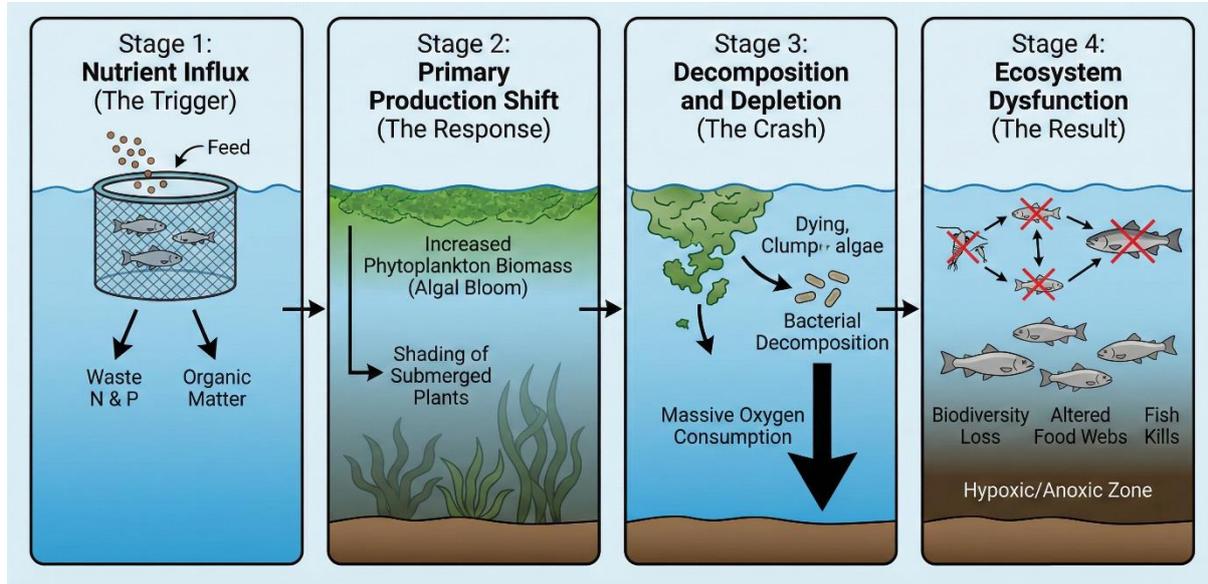


Figure 1. The Aquaculture Eutrophication Cascade

#### 4.2 Benthic-Pelagic Coupling and Sediment Souring

An aquaculture breaks the usual interactions between benthic and pelagic energy. In nature, when the primary production at the surface tends to stabilize and sustain the benthos, it is ultimately eaten away. The high deposition of organic material in cage aquaculture overloads the benthic community to the extent that it is resistant to aerobic treatment. With the exceeding demand of sediment oxygen (SOD) in comparison to the supply, the sediment becomes anoxic. The microbial flora changes to an anaerobic bacterium (e.g. sulphate-reducer and methanogens). These anaerobic activities produce toxic wastes such as hydrogen sulphide ( $H_2S$ ) and methane ( $CH_4$ ).  $H_2S$  is very toxic to both bottom-dwelling fish and benthic invertebrates. This, which is called souring, results in sporadic defaunation underneath cages, forming barren areas overgrown by bacterial mats like *Beggiatoa* spp., a representation of a benthic ecosystem failure.

#### 4.3 Biodiversity and Community Structure Shifts

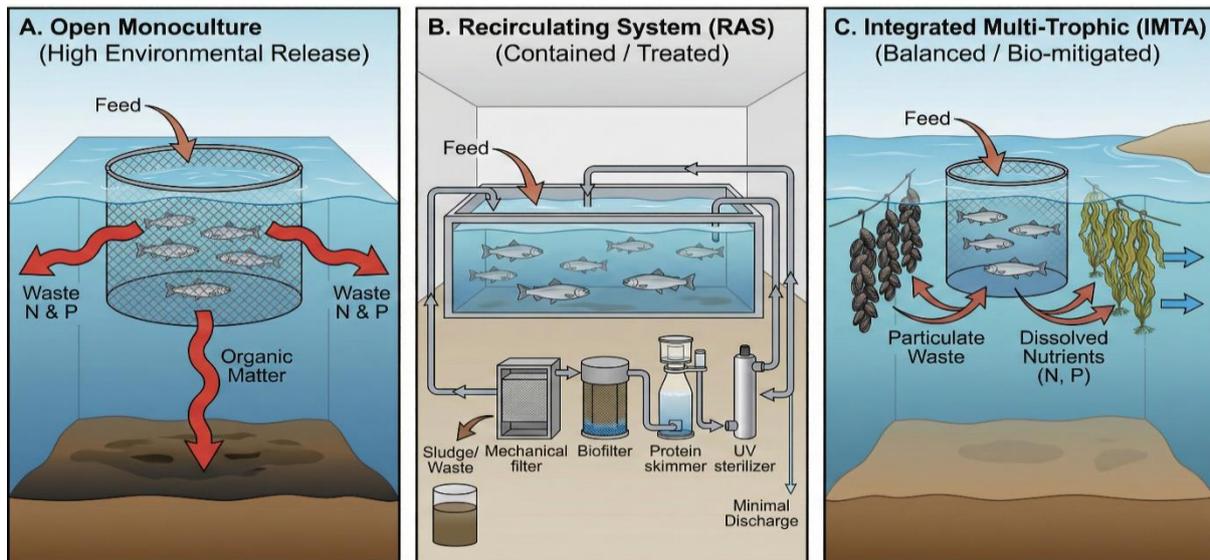
Chronic- nutrient enrichment and water quality degradation always contribute to a decrease in biodiversity. Sensitive species (e.g., some macroinvertebrates indicators of clean water, such as stoneflies or mayflies in freshwater) are wiped out. These are supplanted by pollution-tolerant opportunistic species (e.g. polychaete worms, such as *Capitella capitata* in the sea, or tubificid worms in freshwater). Such homogenization of the biotic community decreases the resilience of the ecosystem and exposes it to any additional disturbances, including disease outbreaks or climatic fluctuations.

### 5. Mitigation Strategies towards Sustainable Ecosystem Functions

Given the projected continued growth of aquaculture, relying solely on the assimilative capacity of natural water bodies is no longer viable. Moving toward ecological intensification requires strategies that internalize environmental costs and actively manage waste streams.

#### 5.1 Nutritional Strategies and Feed Technology

The first line of defence is reducing nutrient input at the source. Modern feeds have shifted towards higher digestibility and better amino acid balances, significantly lowering the Feed Conversion Ratio (FCR, the amount of feed needed to grow 1 kg of fish). Lower FCR means less waste. Furthermore, the development of low-phosphorus feeds and the use of phytase enzymes to make plant-based phosphorus more bioavailable to fish have reduced phosphorus discharge in effluents.



**Figure 2. Conceptual models of aquaculture systems and nutrient flows**

### 5.2 Recirculating Aquaculture Systems (RAS)

RAS represents a technological shift from open to closed systems. By treating and reusing >90% of culture water, RAS separates production from the external environment. Water treatment involves mechanical filtration (removing solids), biological filtration (nitrifying bacteria converting ammonia to nitrate), and disinfection (UV/ozone). While highly energy-intensive, RAS allows for near-total control over effluent release, enabling waste capture for use as agricultural fertilizer rather than aquatic pollutant.

### 5.3 Integrated Multi-Trophic Aquaculture (IMTA)

IMTA is an ecosystem-based approach that attempts to recreate a simplified natural food web. It involves co-culturing fed species (e.g., finfish) with extractive species. Dissolved inorganic nutrients (N and P) excreted by the fish are absorbed by inorganic extractors like seaweeds (macroalgae). Particulate organic waste (faeces/feed) is consumed by organic extractors like shellfish (mussels, oysters) or deposit feeders (sea cucumbers). IMTA converts waste products into valuable secondary commercial crops, biomitigating the environmental impact while increasing the overall economic productivity of the farm site. It directly addresses the uncoupled biogeochemical cycles inherent in monoculture.

**Table 2. Comparative Evaluation of Aquaculture Production Systems and Environmental Interactions**

Feature	Traditional Open Cage/Pond Monoculture	Recirculating Aquaculture Systems (RAS)	Integrated Multi-Trophic Aquaculture (IMTA)
<b>Waste Management</b>	Externalized: Released directly into surrounding environment.	Internalized: Highly treated; solids captured; dissolved nutrients accumulate or are denitrified.	Bio-mitigated: Waste is converted into secondary biomass by co-cultured species.
<b>Water Quality Impact</b>	High: Significant localized risk of eutrophication, hypoxia, and benthic souring.	Low/Negligible (off-site): Minimal discharge; high on-site control required.	Moderate/Reduced: Significant reduction in net nutrient loading compared to monoculture.
<b>Ecosystem Integration</b>	Low: Often disrupts local ecosystem functions.	Very Low: De-coupled from natural ecosystem functions.	High: Attempts to engineer complementary ecosystem functions.
<b>Key Challenges</b>	Environmental regulation; site carrying capacity limits; disease transfer to wild populations.	High capital expenditure; high energy consumption; technical complexity.	Complex site management (balancing different species' needs); regulatory frameworks for multi-species crops.

## 6. Conclusion

The evaluation of aquaculture activities reveals a clear dichotomy: the sector is an indispensable component of global food systems, yet serves as a potent driver of aquatic ecosystem alteration when improperly managed. The primary mechanism of impact is the decoupling of nutrient cycles, where massive inputs of exogenous feed result in waste streams that overwhelm natural assimilative capacities.

The consequences manifested as dissolved oxygen depletion, hyper-nutritification, harmful algal blooms, and benthic ecosystem collapse detract from the long-term viability of the very natural resources aquaculture depends upon.

Future sustainability rests not merely on incremental improvements in feed efficiency but on a paradigm shift toward ecosystem-based management. Technologies like RAS offer a pathway to decouple production from environmental interaction almost entirely, while ecological engineering approaches like IMTA offer a means to integrate aquaculture positively into natural cycles. The challenge for policy-makers, researchers, and industry stakeholders is to incentivize the adoption of these systems, ensuring that the Blue Revolution continues to feed the world without compromising the functional integrity of aquatic ecosystems.

## References

- Ahmed, N., & Thompson, S. (2019). The blue dimension of the Green New Deal: The potential of sustainable aquaculture to transform food systems. *Nature Food*, 1, 21–28.
- Beveridge, M. C. M. (2004). *Cage Aquaculture* (3rd ed.). Blackwell Publishing.
- Boyd, C. E., & Tucker, C. S. (2014). *Pond Aquaculture Water Quality Management*. Springer Science & Business Media.
- Chopin, T., Cooper, J. A., Reid, G., Cross, S., & Moore, C. (2012). Open-water integrated multi-trophic aquaculture: Environmental biomitigation and economic diversification of fed aquaculture by co-cultivation with extractive organisms. *Reviews in Aquaculture*, 4(4), 209–220.
- Dauda, A. B., Ajadi, A., Tola-Fabunmi, A. S., & Akinwole, A. O. (2019). Waste production in aquaculture: Sources, components and managements. *Aquaculture and Fisheries*, 4(3), 81–88.
- FAO. (2024). *The State of World Fisheries and Aquaculture 2024: Blue Transformation*. Food and Agriculture Organization of the United Nations. Rome.
- Holmer, M., & Heilskov, A. C. (2008). Distribution of benthic carbon and nitrogen cycling in a cage fish farm. *Marine Pollution Bulletin*, 56, 283–293.
- Martins, C. I. M., Eding, E. H., Verdegem, M. C. J., Heinsbroek, L. T. N., Schneider, O., Blancheton, J. P., ... & Verreth, J. A. J. (2010). New developments in recirculating aquaculture systems in Europe: A review. *Aquacultural Engineering*, 43(3), 83–93.
- Paerl, H. W., & Otten, T. G. (2013). Harmful cyanobacterial blooms: Causes, consequences, and controls. *Microbial Ecology*, 65(4), 995–1010.
- Primavera, J. H. (2006). Overcoming the impacts of aquaculture on the coastal zone. *Ocean & Coastal Management*, 49(9-10), 531–545.
- Randall, D. J., & Tsui, T. K. N. (2002). Ammonia toxicity in fish. *Marine Pollution Bulletin*, 45(1-12), 17–23.
- Wu, R. S. S. (1995). The environmental impact of marine fish culture: Towards a sustainable future. *Marine Pollution Bulletin*, 31(4-12), 159–166.

## Growth Response of Carp Species Under Varied Feeding Schedules and Nutritional Plans



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### 1. Introduction

The Cyprinid culture remains a foundation of inland aquaculture in the world, giving a significant contribution to food security, and forming the foundation of economic strength in most of the emerging economies. As the sector changes slowly but surely towards a less extensive and more pasture-based types of systems to semi-intensive and fully intensive systems, the reliance on the use of formulated exogenous feeds has become increasingly pronounced. Feed cost in most of the operations forms about 60-70 percent of the total variable cost and as such, feed ratio to fish biomass optimisation becomes economical, rather than biological, imperative.

The modern aquaculture nutrition aim is two-fold: on the one hand, the accurate composition of diets that meet the exact metabolic needs of the target taxa at different ontogenetic stages; on the other hand, the establishment of delivery mechanisms that ensure effective absorption and use of them, in order to reduce the excretion of excessive nitrogen and phosphorus. Poor feeding behaviors trigger poor growth rates, increase vulnerability to pathogenesis caused by nutritional stress, and generate a series of negative environmental effects in the form of eutrophication, which is exacerbated by feed wastage and metabolic excretion.

### 2. Nutritional Requirements and Metabolic Demands

Carp species exhibit diverse feeding habits, ranging from herbivory (e.g., Grass Carp, *C. idella*) to omnivory (e.g., Common Carp, *C. carpio*) and column feeding (e.g., Rohu, *L. rohita*). This diversity places different physiological functions on digestion and assimilation of diverse macronutrients.

#### 2.1 Protein and Essential Amino Acids

Protein and Essential Amino Acids are frequently utilized in the designing of the diet. It is possible to mention that 2.1 Protein and Essential Amino Acids are commonly used when designing the diet.

Protein is the costliest and the main factor of determining somatic growth in aquafeeds currently. Carp has an obligatory need of ten endogenously inorganic crucial amino acids (EAAs). During the grow-out stage, carp species require 25-35 percent of crude protein whereas fry and fingerlings require 35-45 percent of protein to support the rapid growth of tissues. Notably, the stoichiometric equivalence of amino acids rather than the concentration of crude protein dictates the growth efficiency. The insufficiency of one of the limiting EAA, often lysine or methionine in the case of plant-proteins being the primary source of protein, inhibits protein synthesis and, as a consequence, growth, regardless of the total protein intake.

#### 2.2 The Protein-to-Energy (P/E) Ratio

The Protein-to-Energy (P/E) ratio is considered a critical concept in the development of nutritional strategies. The inability of lipids and carbohydrates to provide sufficient caloric contributions causes this protein to be deconstructed by fish to meet basal energetic needs a protein-sparing effect that reduces muscle accretion. On the

other hand, dietary energy may reduce the appetite leading to fish rationing, and visceral adiposity and carcass quality damage simultaneously.

Optimisation of the proportion between the digestible protein to digestible energy (DP/DE) is species-specific. Omnivorous carp use carbohydrates more efficiently than carnivorous species allowing them to use cost-effective formulations that include cereal grains.

**Table 1. Generalized Nutritional Requirements for Grow-out Phase of Selected Carp Species (Source: Synthesized data from NRC and recent trials)**

Parameter	Common Carp ( <i>C. carpio</i> )	Rohu ( <i>L. rohita</i> )	Grass Carp ( <i>C. idella</i> )	Catla ( <i>C. catla</i> )
Feeding Habit	Omnivorous/Benthic	Column feeder/Planktivorous	Herbivorous	Surface/Zooplanktivorous
Crude Protein (%)	28 - 35	30 - 35	25 - 30	30 - 35
Crude Lipid (%)	6 - 10	6 - 9	4 - 7	6 - 8
Carbohydrate (%)	30 - 40	25 - 35	35 - 45	25 - 35
Opt. P/E Ratio (mg protein/kJ)	18 - 22	19 - 23	16 - 20	19 - 22

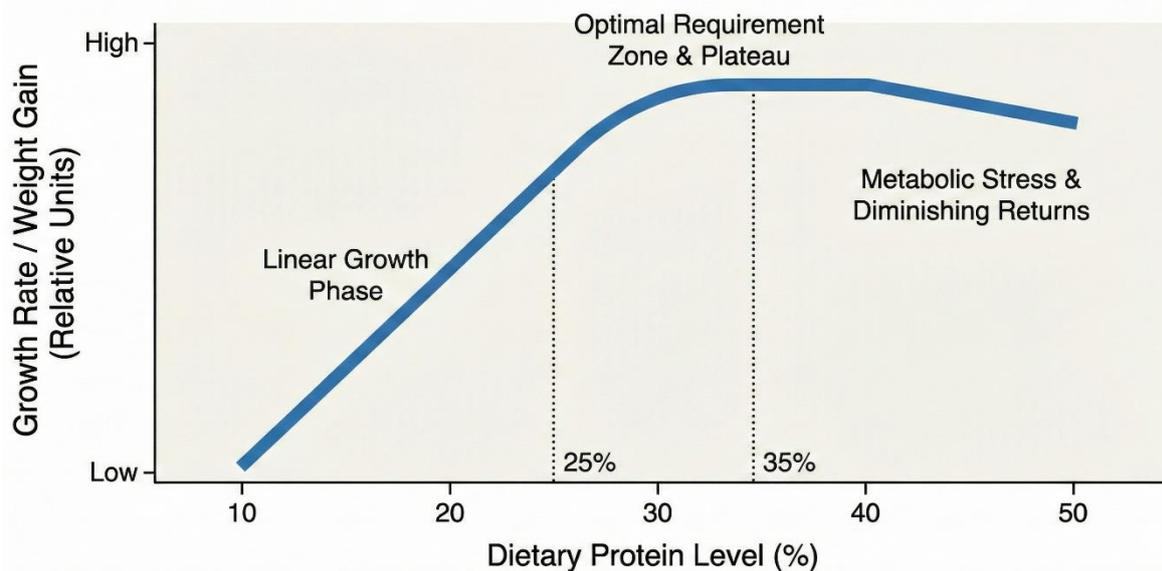
### 3. The Impact of Nutritional Plans on Growth

The nutritional plan encompasses not just the nutrient levels but also the ingredients used to achieve them. The modern drive for sustainability has led to a reduction in fishmeal dependence, replacing it with plant-based proteins like soybean meal, rapeseed meal, and corn gluten meal.

#### 3.1 Dietary Protein Levels and Diminishing Returns

It has always been shown through empirical data that dietary protein has a quadratic relationship with growth. The growth rates are increasing in a linear manner with the increase in protein intake but these levels level off even with an increase in the protein intake after optimum level. Subsequent growth of protein does not cause any serious weight gain but in fact compromises on feed conversion ratio (FCR) since the surplus nitrogen is deaminated and excreted which is an energy-demanding process.

The diagram below illustrates a typical dose-response curve representing weight gain against increasing dietary protein percentages.



**Figure 1. Conceptual Growth Response Curve to Increasing Dietary Protein**

### 3.2 Ingredient Quality and Digestibility

An exclusive plan on crude protein is not enough. As an example, a 35 per cent crude protein diet composed of feather meal or plant proteins which are high in anti-nutritional factors (ANFs) will induce significantly retarded growth as compared to a 30 per cent protein diet made of high-digestibility fishmeal or processed soy isolate. In recent diets, exogenous enzymes such as phytase, proteases, carbohydrases should be included in order to release nutrients in plant-based compounds especially in cyprinid in which the stomach is not acid.

### 4. Influence of Feeding Schedules and Frequency

The engine timing is the feeding schedules as long as nutritional plans are the fuel. The physiology and anatomy of the digestive tract determine the most superior feeding plan.

#### 4.1 The Significance of Agastric Physiology

The common carp and rohu are many cyprinids with an anatomically agastric stomach or a tiny true stomach. They are devoid of the esophageal sphincter which separates the esophagus and intestine as well as have no acidic stomach to bulk protein by depleting its denaturation properties. Of course, they graze all day long, eating little portions during the day time. Therefore, feeding them a large daily ration in a single feeding overloads their digestive system: the transit time of their gut decreases, poor hydrolysis of the food by the enzymes and absorption of nutrients are impaired, leading to ineffective FCR and excessive release of nutrients into the water column.

#### 4.2 Feeding Frequency and Growth Performance

According to several studies, it is a well-known fact that upgrading the daily feeding rate of one to two, three, or four times has a significant positive impact on the growth of carp fingerlings and grow-out phases. The frequent feeding ensures a relatively constant supply of nutrients in the alimentary canal, which maximises the rate of enzyme activity and absorption.

The cost of labour or mechanical difficulty of further feedings of a child is, however, above a certain point, greater than the marginal benefit of growth. At the economic optimum, two to three feedings a day are the norm with most grow-out carp.

**Table 2: Simulated Impact of Feeding Frequency on Growth Parameters in *Labeo rohita* (Rohu) over a 60-day Trial.**

Feeding Frequency	Initial Weight (g)	Final Weight (g)	Specific Growth Rate (SGR %/day)	Feed Conversion Ratio (FCR)	Protein Efficiency Ratio (PER)
Once Daily (09:00)	50.0	145.5	1.78	1.85	1.55
Twice Daily (09:00, 16:00)	50.0	182.2	2.15	1.55	1.89
Thrice Daily (09:00, 13:00, 17:00)	50.0	205.0	2.35	1.42	2.05
Four Times Daily	50.0	210.5	2.39	1.40	2.08

#### 4.3 Chronobiology and Feeding Time

Fish also have circadian rhythms which regulate levels of metabolism, hormone release (growth hormone, insulin) and levels of digestive enzymes. The feeding times are to be in harmony with these endogenous rhythms. In the majority of carp species, the metabolic activity is optimal in spreads of the highest level of dissolved oxygen and temperature, usually late morning and late afternoon. Scheduling the feeds so that they fall within these windows will make sure that the Specific Dynamic motion does not interfere with other physiological activities.

### 5. Synergistic Effects: Interaction Between Plan and Schedule

The crucial takeaway for aquaculture management is that nutritional plans and feeding schedules cannot be viewed in isolation. They interact dynamically.

A diet with a high degree of nutrient density (high protein/high energy) fed to agastric carp occasionally will not be used efficiently since the digestive tract is not able to digest the high-proportion nutrients effectively. On the other hand, the high frequency of a low energy content diet can have a relative positive effect on utilisation, but the fish itself might not have the physical ability to consume the quantity of dietary material needed to meet its daily metabolic and protein needs of maximum growth.

The goal is to synchronize nutrient delivery with digestive capacity. Lower protein diets may require higher feeding frequencies to ensure sufficient total daily protein intake, whereas higher protein diets can be fed slightly less frequently, provided the meal size doesn't exceed gut capacity.

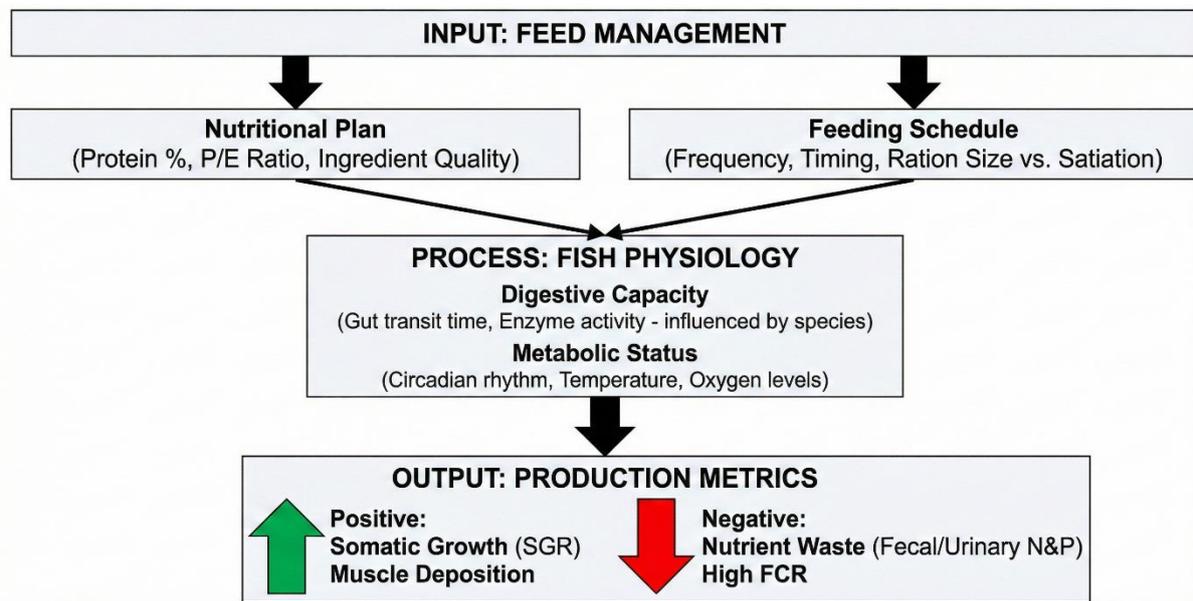


Figure 2. The Interaction Model of Feed Management in Carp Aquaculture

## 6. Conclusion and Practical Recommendations

Optimizing the growth response of carp species requires a holistic approach that integrates nutritional biochemistry with feeding behaviour and digestive physiology. The traditional approach of feeding to satiation once a day is increasingly recognized as economically inefficient and environmentally deleterious for many major carp species.

Based on the review of current research, the following practical recommendations are proposed for commercial carp farming enterprises:

- Species-Specific Formulations:** Abandon generic carp feed. Utilize feeds formulated with protein levels and P/E ratios appropriate for the specific species (e.g., lower protein for Grass Carp, moderate for Rohu/Catla) and life stage.
- Adopt Multiple Feedings:** Transition from single daily feedings to at least twice daily for grow-out operations, and 3-5 times daily for nurseries. This aligns with the agastric nature of many carp.
- Synchronize with Metabolism:** Schedule feedings during periods of optimal water temperature and dissolved oxygen (usually mid-morning and late afternoon) to maximize metabolic utilization.
- Monitor FCR Continuously:** Use FCR as a dynamic management tool. A rising FCR indicates either poor feed quality or an inappropriate feeding schedule (overfeeding or wrong timing) that requires immediate adjustment.

Future research must focus on the precise interplay between novel protein sources (like insect meal or single-cell proteins) and feeding frequencies to refine these protocols further in the face of changing raw material availability.

## References

- Du, Z.-Y., Clouet, P., Zheng, W.-H., Degrace, P., Tian, L.-X., & Liu, Y.-J. (2007). Biochemical hepatic alterations and body lipid composition in the herbivorous grass carp (*Ctenopharyngodon idella*) fed high-fat diets. *British Journal of Nutrition*, 98(2), 337–347. <https://doi.org/10.1017/s0007114507742618>
- Isorna, E., de Pedro, N., Valenciano, A. I., Alonso-Gómez, Á. L., & Delgado, M. J. (2017). Interplay between the endocrine and circadian systems in fishes. *Journal of Endocrinology*, 232(3), R141–R159. <https://doi.org/10.1530/joe-16-0330>

- Le, H. T. M. D., Shao, X., Krogdahl, Å., Kortner, T. M., Lein, I., Kousoulaki, K., Lie, K. K., & Sæle, Ø. (2019). Intestinal function of the stomachless fish, Ballan Wrasse (*Labrus bergylta*). *Frontiers in Marine Science*, 6, 140. <https://doi.org/10.3389/fmars.2019.00140>
- Serban, D.-A., Barbacariu, C.-A., Burducea, M., Ivancia, M., & Creangă, Ș. (2024). Comparative analysis of growth performance, morphological development, and physiological condition in three Romanian *Cyprinus carpio* varieties and Koi: Implications for aquaculture. *Life*, 14(11), 1471. <https://doi.org/10.3390/life14111471>
- Volkoff, H., & Rønnestad, I. (2020). Effects of temperature on feeding and digestive processes in fish. *Temperature*, 7(3), 307–320. <https://doi.org/10.1080/23328940.2020.1765950>



## Influence of Aquatic Pollution on Physiological Stress and Reproductive Efficiency in Fish



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### 1. Introduction

The worth of the aquatic ecosystem integrity to the global food security is of utmost importance especially in the fisheries and aquaculture sectors. Fish are a main source of protein to billions of people and also a major source of economy in most parts of the globe. However, the augmentation of agricultural activities, alongside the growth of industries and urbanization has triggered an unprecedented inflow of pollutants into the fresh water as well as the marine systems. Aquatic pollution has become not an isolated phenomenon but a ubiquitous worldwide stressor impacting negatively on aquatic organism cellular, organismal and population levels.

In the case of fish, the aquatic environment is not merely a habitat but the place where all the physiological processes are mediated, i.e. respiration and osmoregulation, as well as reproduction. Homeostasis of the organism is disregarded when this medium is contaminated. Even though being exposed to high levels of pollutants may cause instantaneous death in the case of acute exposure, chronic exposure to sub-lethal levels may be more insidious and may have more economic consequences to the aquaculture operations.

The article discusses the harmful impacts of large water contaminants on the physiology of fish. It specifically deals with how chronic exposure causes physiological responses of stress and the responses along with the direct chemical interference seriously impairs reproductive efficiency. Learning how to unite pollution, stress physiology, and reproductive failure is crucial to agricultural stakeholders and aquaculturists who are in charge of the water resources and fish health.

### 2. Major Categories of Aquatic Pollutants Affecting Fish

The combination of chemicals present in modern waterways is complicated, but some groups of them should be investigated in more detail in terms of fish physiology and interactions with aquaculture.

#### 2.1 Agricultural Runoff: Pesticides and Nutrients

Modern farming is dependent on the use of pesticides, including insecticides, herbicides and fungicides to optimize the harvest. Organophosphates, carbamates, and triazines (e.g. atrazine) are commonly found in waterways through surface runoff. The chemicals are neurotoxic, and they are strong endocrine disruptors in fish. The surplus of fertilizer runoff, which majorly contains nitrogen and phosphorus, results in eutrophication. The blooms of algae that form as a result, and the consequential hypoxia, cause extreme metabolic stress to fish populations, although not directly as toxicants.

#### 2.2 Heavy Metals

The heavy metals that are non-essential, including mercury (Hg), cadmium (Cd), and lead (Pb), or the surplus of essential metals, including copper (Cu) and zinc (Zn), are environmental pollutants that are persistently found. They have been known to bioaccumulate in fish tissues, especially liver, gills, and kidneys, where they become

infamous in causing oxidative stress by the production of reactive oxygen species (ROS) and by interfering with the antioxidant enzyme systems.

### 2.3 Endocrine Disrupting Chemicals (EDCs)

The heavy metals that are non-essential, including mercury (Hg), cadmium (Cd), and lead (Pb), or the surplus of essential metals, including copper (Cu) and zinc (Zn), are environmental pollutants that are persistently found. They have been known to bioaccumulate in fish tissues, especially liver, gills, and kidneys, where they become infamous in causing oxidative stress by the production of reactive oxygen species (ROS) and by interfering with the antioxidant enzyme systems.

**Table 1. Primary Aquatic Pollutants and their General Physiological Impacts on Fish**

Pollutant Category	Common Examples	Primary Sources	General Physiological Impact
<b>Pesticides/Herbicides</b>	Atrazine, Chlorpyrifos, Roundup (Glyphosate)	Agricultural runoff	Neurotoxicity, endocrine disruption, immunosuppression.
<b>Heavy Metals</b>	Mercury, Cadmium, Lead, Copper	Industrial waste, mining, some fertilizers	Oxidative stress, tissue damage (gills/liver), enzyme inhibition.
<b>EDCs</b>	BPA, Phthalates, synthetic estrogens (EE2)	Municipal wastewater, plastics, agriculture	Reproductive hormonal imbalance, altered sex differentiation, reduced fecundity.
<b>Nutrients</b>	Nitrogen, Phosphorus	Fertilizers, livestock waste	Eutrophication leading to hypoxia (low oxygen stress).

### 3. Physiological Stress Mechanisms Induced by Pollution

Stress in fish is an adaptive response aimed at regaining homeostasis after a challenge. However, when the challenge (pollution) is chronic, the adaptive response becomes maladaptive.

#### 3.1 The Neuroendocrine Stress Response

Hypothalamic-pituitary-interrenal (HPI) axis is the main stress response of fish. When a chemical stressor is perceived, the hypothalamus is activated to release corticotropin-releasing factor (CRF) which activates the pituitary to release adrenocorticotropic hormone (ACTH). ACTH requests the interrenal cells (which is similar to the mammalian adrenal cortex) to produce and secrete cortisol which is the major stress corticosteroid in teleost fish.

High cortisol is necessary in the mobilization of energy (glucose) to address immediate threats. Nevertheless, the chronic cortisol increase as a result of chronic pollution has disastrous side effects:

- Immunosuppression:** Increased susceptibility to pathogens.
- Growth Inhibition:** Energy is diverted from somatic growth to metabolic maintenance and detoxification.
- Reproductive Suppression:** Cortisol directly inhibits the reproductive hormonal axis (discussed further in Section 4).

#### 3.2 Oxidative Stress and Cellular Damage

Several pollutants especially heavy metals and some organic pesticides have their toxic effects by the production of ROS, e.g., superoxide anions, and hydrogen peroxide. In the case of normal conditions, fish have antioxidant defence mechanisms of superoxide dismutase (SOD) and catalase (CAT) to counteract the presence of ROS. These defences may be overwhelmed by exposure to pollutants and result in a condition of oxidative stress. ROS damage important cellular constituents, and lead to lipid peroxidation (cell membrane damage), protein oxidation, and DNA damage. The metabolic energy needed to heal such cellular damage is very high, only exacerbating the reserves of the organism.

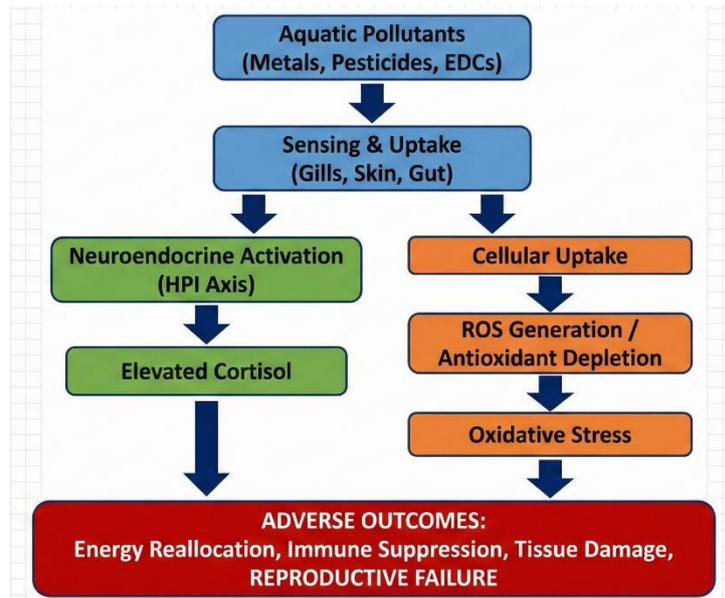


Figure 1. Schematic representation of pollution-induced physiological stress cascade in fish

#### 4. The Impact on Reproductive Efficiency

Reproduction is a strenuous process, which is closely controlled by the brain-pituitary-gonadal (BPG) axis. Pollutants interfere with this axis both directly by direct chemical interference as well as indirectly by the above-described stress responses.

##### 4.1 Disruption of the BPG Axis

BPG axis regulates the production of sex steroids estradiol ( $E_2$ ) and testosterone (T). The brain produces gonadotropin-releasing hormone (GnRH), which triggers the release of gonadotropins (GtHs) by the pituitary, which proceeds to stimulate gonadal steroidogenesis.

- a) **EDC Interference:** EDCs can bind to estrogen receptors (ER) or androgen receptors (AR). For example, ethinylestradiol (EE2) from contraceptive pills found in wastewater is a potent estrogen agonist. Exposure of male fish to EE2 can induce the production of vitellogenin (an egg yolk precursor protein normally found only in females), leading to feminization, testicular atrophy, and reduced sperm quality.
- b) **Cortisol Interference:** GnRH and GtHs are inhibited by a chronically high level of cortisol. It also prevents the responses of the gonads to these hormones, virtually halts reproduction in the process of saving energy to survive.

##### 4.2 Impairment of Gametogenesis and Gamete Quality

Pollutants affect the physical development of eggs and sperm.

- **In Females:** Eggs and sperms grow physically to develop into the zygote upon fertilization.
- Ovaries of females might store heavy metals like cadmium that disrupts follicular growth and reduces the growth of yolks (vitellogenesis). This makes smaller eggs with fewer energy stores which decrease the levels of hatching and survival of larvae.
- **In Males:** Exposure to pesticides has been associated with reduced milt volume, decreased sperm count and impaired sperm motility in males. Sperm DNA is directly damaged by oxidative stress, which may result in developmental abnormalities in the offspring even in cases where fertilisation takes place.

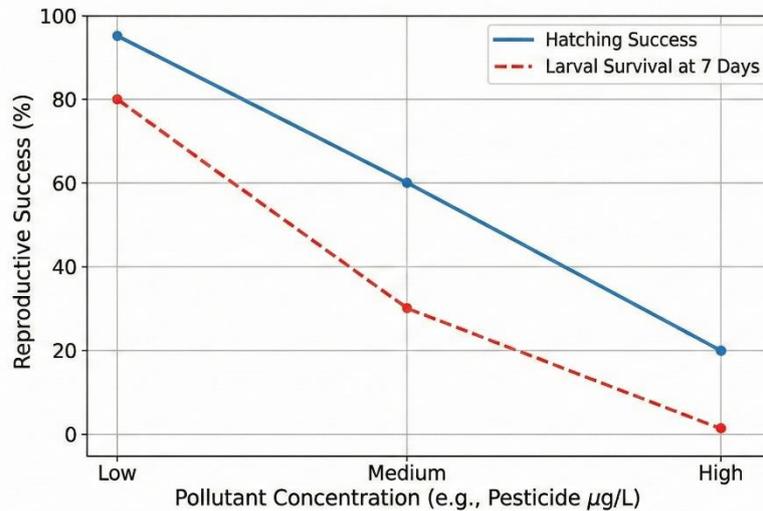
##### 4.3 Transgenerational Effects

Recent studies have shown that the effects of the pollution are not limited to the generation exposed to it. The exposure of pollutants leads to epigenetic alterations, which are modifications in the expression of genes without affecting the genetic sequence and can be passed down to the children. Therefore, broodstock contaminated by

low doses of pollution may give birth to the less healthy ones with slower growth rates, and with diminished reproductive abilities, which will put the sustainability of aquaculture stocks in peril.

### 5. Implications for Agriculture and Aquaculture Management

The physiological and reproductive impairments caused by aquatic pollution have direct economic and practical implications for the agricultural sector.



**Figure 2. Impact of increasing aquatic pollutant concentration on fish reproductive metrics.**

The graph illustrates a dose-response relationship where increasing pollutant concentrations lead to a significant decline in critical reproductive endpoints. Note that larval survival (dashed red line) shows a more precipitous drop compared to hatching success (solid blue line), indicating higher sensitivity at later developmental stages.

- Aquaculture Productivity:** For fish farmers, chronic low-level pollution means reduced feed conversion ratios (due to metabolic stress), higher disease susceptibility, and erratic spawning success in hatcheries. This directly translates to financial losses and production inefficiency.
- Integrated Farming Risks:** Integrated agriculture-aquaculture systems (e.g., rice-fish farming) must be managed carefully. Pesticides used on crops can easily contaminate the adjacent aquaculture units, negating the benefits of integration.
- Wild Fisheries & Food Security:** The decline in reproductive efficiency in wild fish populations due to agricultural runoff threatens capture fisheries, which many rural communities rely on for protein and income.

#### Mitigation Strategies:

Ensuring reproductive efficiency requires a proactive approach to water quality. This includes investing in robust water filtration systems for hatcheries to remove heavy metals and some organic contaminants. Implementing strict biosecurity and regular monitoring of water sources for common agricultural pollutants is essential. Furthermore, the adoption of Best Management Practices (BMPs) in agriculture, such as buffer zones, precision pesticide application, and improved manure management, is critical to reducing the load of pollutants entering aquatic ecosystems in the first place.

### 6. Conclusion

The influence of aquatic pollution on fish physiology represents a multifaceted challenge that extends far beyond the immediate risks of acute toxicity. By chronically activating the Hypothalamic-Pituitary-Interrenal (HPI) axis and overwhelming cellular antioxidant defences, pollutants force fish into a maladaptive state of continuous energy drain. This physiological cost is paid by diverting metabolic resources away from somatic growth and, most critically, from reproduction. The insidious nature of pollutants, particularly Endocrine Disrupting Chemicals (EDCs), further exacerbates this crisis by chemically hijacking the hormonal pathways essential for

gametogenesis. This often renders fish sterile or results in the production of non-viable offspring without manifesting visible external signs of distress, making these sub-lethal effects a silent killer of population stability. For the agricultural and aquaculture sectors, these physiological realities underscore the urgent need for a paradigm shift in water resource management. Sustainable fishery production cannot be achieved in isolation; it requires the integration of rigorous pollution control measures, such as the adoption of bio-mitigation techniques and the minimization of agrochemical runoff from adjacent terrestrial farming. Protecting the reproductive efficiency of fish stocks is not merely an environmental concern but a critical economic imperative for global food security. Moving forward, stakeholders must prioritize the development of sensitive biomarkers for early stress detection and implement holistic watershed management strategies to ensure that aquatic ecosystems remain biologically viable for future generations.

#### References

- Aluru, N., & Vijayan, M. M. (2009). Stress transcriptomics in fish: A role for cortisol signaling. *General and Comparative Endocrinology*, 164(2–3), 142–150. <https://doi.org/10.1016/j.ygcen.2009.03.020>
- Jobling, S., & Tyler, C. R. (2003). Endocrine disruption, parasites and pollutants in wild freshwater fish. *Parasitology*, 126(S1), S103–S122. <https://doi.org/10.1017/s0031182003004862>
- Kumar, N., Krishnani, K. K., & Gupta, S. K. (2016). Impact of agricultural pollution on aquatic ecosystems and fish health. In *Agriculture and Environment* (pp. 153–174). Springer.
- Lushchak, V. I. (2011). Environmentally induced oxidative stress in aquatic animals. *Aquatic Toxicology*, 101(1), 13–30. <https://doi.org/10.1016/j.aquatox.2010.10.006>
- Schreck, C. B., & Tort, L. (2016). The concept of stress in fish. In C. B. Schreck, L. Tort, A. P. Farrell, & C. J. Brauner (Eds.), *Biology of Stress in Fish* (pp. 1–34). Academic Press. <https://doi.org/10.1016/B978-0-12-802728-8.00001-1>
- Sumpter, J. P. (2005). Endocrine disrupters in the aquatic environment: An overview. *Acta hydrochimica et hydrobiologica*, 33(1), 9–16. <https://doi.org/10.1002/aheh.200400555>
- Tierney, K. B., Baldwin, D. H., Hara, T. J., Ross, P. S., Scholz, N. L., & Kennedy, C. J. (2010). Olfactory toxicity in fishes. *Aquatic Toxicology*, 99(1), 14–26. <https://doi.org/10.1016/j.aquatox.2010.03.006>

## Organic Farming Approaches for Sustainable Crop Production



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### 1. Introduction

The Green Revolution, which was in the middle of the twentieth century, managed to prevent global famine by introducing high-yielding varieties (HYVs), artificial fertilizers, and agricultural chemicals. However, the externality of this type of production is now posing a life and death threat to the resource base on which agriculture relies. The vast dependence on fossil-based inputs has broken natural ecological cycles, triggering a sharp reduction in soil organic matter (SOM), the development of pesticide-resistant insects, and significant additions to anthropogenic sources of greenhouse gases.

The shift in paradigm of sustainable crop production needs to be towards the regeneration of natural resources in the form of systems, as opposed to their depletion. A codified framework of this transition is provided by organic agriculture, as defined by the International Federation of Organic Agriculture Movements (IFOAM) on the foundations of the principles of health, ecology, fairness and care. Against popular belief, organic farming does not simply mean the lack of synthetic inputs; it is a proactive approach of management that utilizes ecological processes, biodiversity and local adaptations to the cycles to keep the system healthy.

### 2. The Theoretical Framework: Agroecology and Soil Centrality

Sustainable organic production is based on the understanding of the farm as an agroecosystem that is living and complex. Organic agriculture considers soil to be an active living system as opposed to other systems that tend to use soil as a lifeless medium. Management of organic soils is mainly aimed at increasing the biological activity of the soil. A healthy soil microbiome that consists of bacteria, fungi, protozoa, and nematodes is critical in nutrient cycling, disease prevention, and the development of stable soil aggregates. This philosophy is summarized by the aphorism, feed the soil to feed the plant. Through high SOM, farmers ensure a gradual, synchronized release of nutrients, enhance water-retention ability and intensify resistance to climatic shocks like drought.

In addition, organic soil management is an important climate-change mitigation instrument. Organic systems often have a reduced carbon footprint per hectare compared to their conventional counterparts, through avoiding synthetic nitrogen fertilizers which release nitrous oxide, a strong greenhouse gas, and actively capturing carbon in the form of humus.

### 3. Core Organic Agroecological Approaches

Sustainable yields of organic systems are attained by a combination of practices that are integrated to maximize the ecological functions.

#### 3.1. Nutrient Management: Closing the Loop

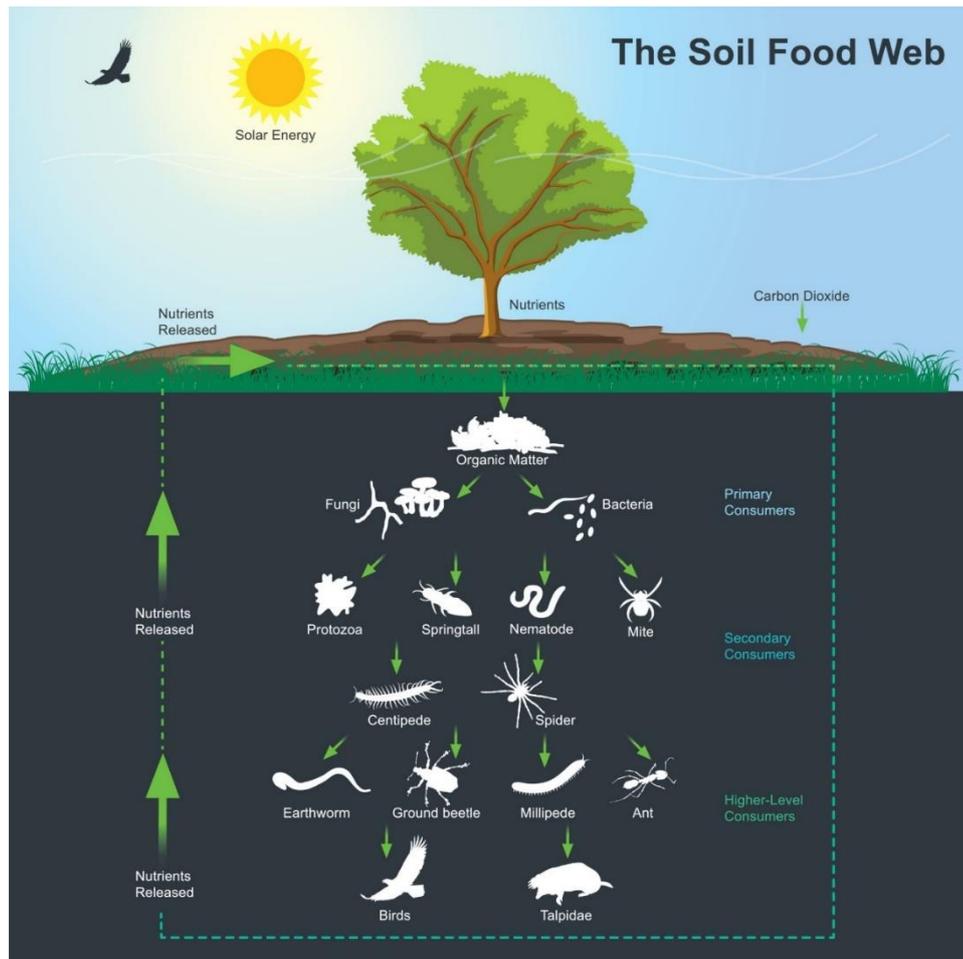
Traditional farming systems rely on soluble mineral nutrients (urea and DAP) as their main components of fertilizer since they provide direct plant nutritional value, but often bypass the microbial cycle and are vulnerable to leaching. Organic methods focus on the focus of reverse nutrient loops and the use of biological fixing of nitrogen.

- a) **Green Manures and Cover Crops:** It is essential to incorporate legumes (e.g. Sesbania, clover, cowpea) into crop rotations. These plants fix nitrogen in organic forms into the atmosphere through symbiosis with the bacteria, *Rhizobium*. Cover crop rye and oats (non-leguminous) act as scavenger crops that absorb remnant soil nitrates and inhibit winter leaching.
- b) **Composting and Farm Yard Manure (FYM):** Application of composted animal manures and crop residues forms the main mechanism of supplying phosphorus, potassium and micronutrients in the soil.

Effective composting stabilises volatile nutrients, minimises loads of pathogens and creates humus precursors.

c) **Biofertilizers:** Microorganisms that are of benefit to the soil or seed are inoculated in the modern organic systems.

- i. *Nitrogen Fixers: Rhizobium, Azotobacter, and Azospirillum.*
- ii. *Phosphate Solubilizers:* Phosphate-Solubilizing Bacteria (PSB) like *Pseudomonas* species, which convert insoluble soil phosphorus into plant-available forms.
- iii. *Mobilizers:* Arbuscular Mycorrhizal Fungi (AMF) extend the root system's reach, accessing water and phosphorus otherwise unavailable.



**Figure 1. The Organic Soil Health Feedback Loop. Organic inputs feed the soil microbiome, which in turn enhances nutrient cycling and structure, leading to improved plant health and crop resilience.**

### 3.2. Ecological Pest and Disease Management

Organic farming does not believe in the calendar spraying. Instead, it employs a multi-level approach that puts a focus on prevention by manipulating habitats, and botanical or permitted mineral pesticides are used as a final option. This is normally made in the form of bio intensive integrated pest management.

**Cultural Controls:** Crop rotation is crucial for breaking the life cycles of soil-borne pathogens and host-specific pests. Sanitation and timing planting dates to avoid peak pest populations are essential proactive measures.

- a) **Biological Control and Habitat Management:** Organic farms purposely ornament landscape to favour natural predators of pests. Planting beetle banks, hedges and flowering insectary strips will offer nectar and pollen to the parasitoid wasps and hoverflies.

- b) **Trap Cropping:** Host crop (i.e. mustard) planted around the perimeter attracts the pests to other plants instead of the cash crop (e.g. cabbage)
- c) **Biopesticides and Botanicals:** In case cultural and biological methods are not effective, farmers can use special, naturally obtained substances. Bt (*Bacillus thuringiensis*) targeting lepidopteran larvae, neem oil (azadirachtin) as an antifeedant, or mating disruption using pheromone traps can be used.

### 3.3. Integrated Weed Management (IWM)

The use of organic herbicides has been banned and weeds management has continued to be one of the biggest issues in organic production. Organic IWM does not consider weeds as competitors, but as a sign of the deficiency in the management.

- a) **Mechanical and Physical Control:** This entails using the stale seedbed method of tillage in pre-plant and thermal weeding in pre-emergence control.
- b) **Cultural Control and Allelopathy:** Narrow row spacing and high seeding rates enhance canopy coverage of the crop, shading off weeds. There are also organic systems that use allelopathic crops like rye or sorghum to produce the release of natural root exudates to inhibit the germination of the weed.
- c) **Mulching:** Organic mulching and plastic geotextiles reduce the germination of the weed and at the same time, keep the soil moist.

**Table 1. Comparative Analysis of Conventional vs. Organic Production Approaches**

Feature/Activity	Conventional Approach	Organic Approach	Impact on Sustainability Outcomes
<b>Soil Fertility Source</b>	Synthetic soluble fertilizers (N-P-K).	Compost, manure, green manures, mineral rock powders.	<b>Organic:</b> Builds long-term soil carbon; reduces energy use in fertilizer production; minimizes nitrate leaching into groundwater.
<b>Nitrogen Supply</b>	Haber-Bosch process (energy intensive).	Biological Nitrogen Fixation (legumes), recycling organic waste.	<b>Organic:</b> Relies on renewable biological processes rather than fossil fuel inputs.
<b>Pest Control Strategy</b>	Reactive; reliance on broad-spectrum synthetic pesticides.	Proactive; reliance on crop rotation, habitat for beneficial insects, biopesticides.	<b>Organic:</b> Protects non-target organisms (pollinators); slows development of pest resistance; reduces chemical residues in food.
<b>Weed Management</b>	Primary reliance on synthetic herbicides.	Mechanical cultivation, crop rotation, mulching, thermal methods.	<b>Organic:</b> Prevents herbicide-resistant superweeds; higher labor requirement but lower chemical ecotoxicity.
<b>Biodiversity (On-farm)</b>	Low; often monocultures with minimal non-crop habitat.	High; diverse crop rotations, hedgerows, intercropping encouraged.	<b>Organic:</b> Increases ecosystem resilience; provides ecosystem services

## 4. Global Adoption and Growth Trends

In order to prove the theoretical benefits of organic methodologies, it is important to research empirical evidence on land-use transformation. Organic agriculture is no longer anecdotal, but a statistically verifiable process of globalization.

### 4.1. Global Growth Trajectory

The area of organic farming across the world has witnessed a strong upward trend as it has grown by an average of about 15 million hectares at the millennium to an approximate of 99 million hectares in 2023. This growth can be seen as a consequence of both a high interest among consumers in food without residue and an attempt to promote this policy via the Farm to Fork strategy of the European Union, according to which at least 25 per cent of land will be managed organically by 2030.

**Table 2. Growth of Global Organic Agricultural Land (2000–2023)**

Year	Total Organic Area (Million Hectares)	Global Share of Agricultural Land	Key Milestone
2000	15.0	< 0.5%	Early adoption in Europe/Oceania
2010	37.0	0.9%	Rapid expansion in Latin America
2018	71.5	1.5%	Mainstream retail integration
2021	76.4	1.6%	Post-pandemic health focus
2023	99.0*	2.1%	Accelerated growth in Asia & Europe

\*Source: Adapted from FiBL & IFOAM – Organics International (2025).

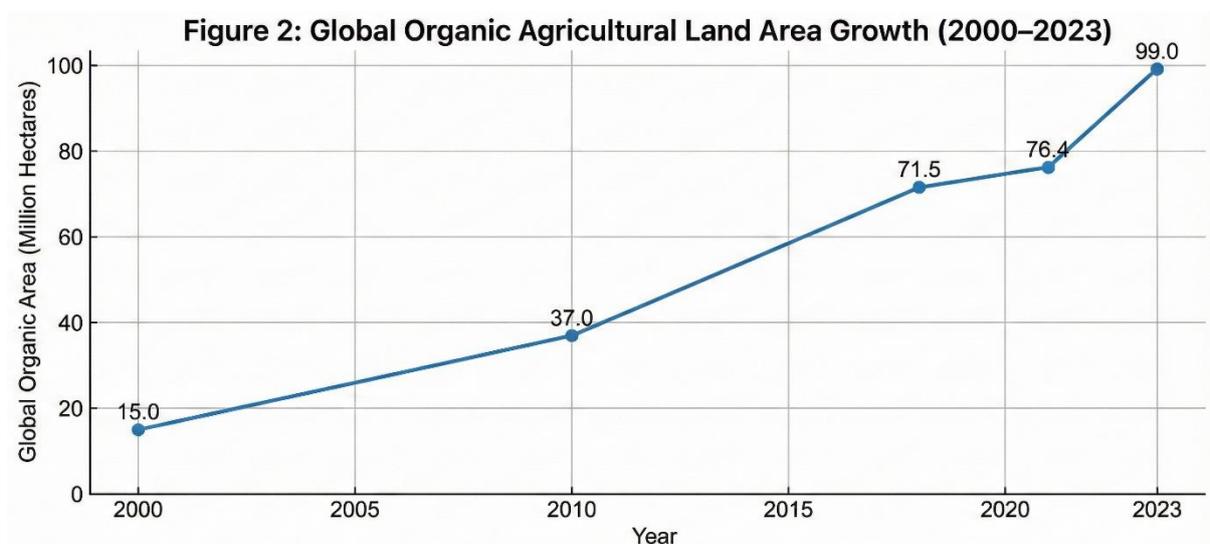


Figure 2. The line graph depicts a consistent positive slope, indicating that organic land conversion is a structural change in global agriculture. The steepening of the curve post-2015 highlights the acceleration driven by climate change mitigation policies.

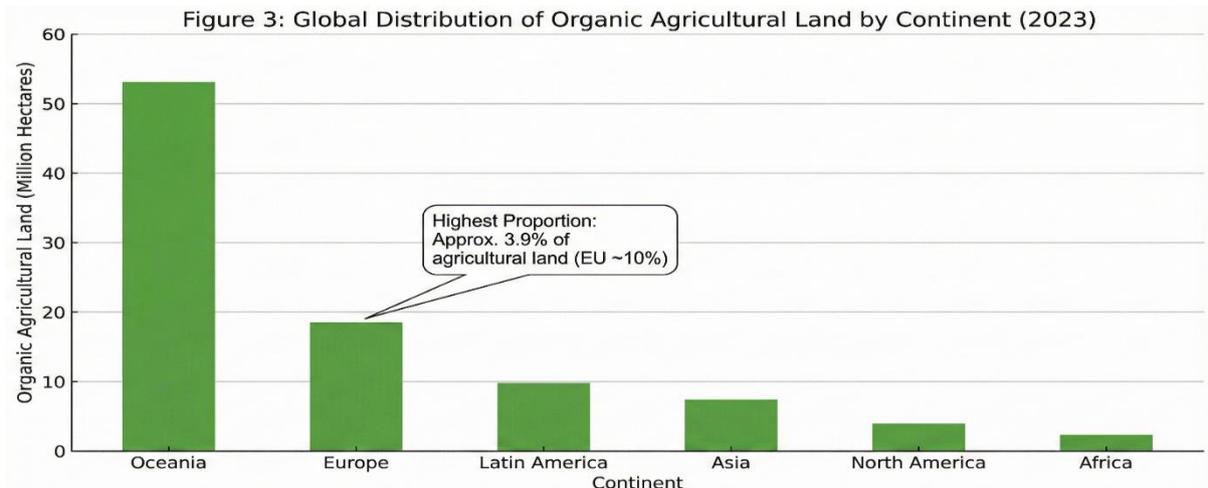
#### 4.2. Regional and National Distribution

As much as it is a global phenomenon, the spread of organic agriculture is clearly skewed. Oceania prevails in the total surface area, which is also because of the large organic grazing areas in Australia. But in looking at the number of producers, Asia, and especially India, come out on top, which highlights a significant difference between prevalent systems of extensiveness and systems that are more intensive.

**Table 3. Top Countries by Organic Agricultural Land Area (2023)**

Rank	Country	Organic Area (Million Hectares)	Primary Sector
1	Australia	53.0	Extensive Grazing/Pasture
2	India	4.5*	Arable Crops, Cotton, Spices
3	Argentina	4.0	Livestock, Cereals
4	China	2.9	Vegetables, Tea, Integrated
5	Spain	2.8	Olives, Vineyards, Fruit

\*Note: India also holds the #1 rank globally for the total number of organic producers (~2.4 million).



**Figure 3.** The bar chart illustrates the dominance of Oceania in terms of hectares.

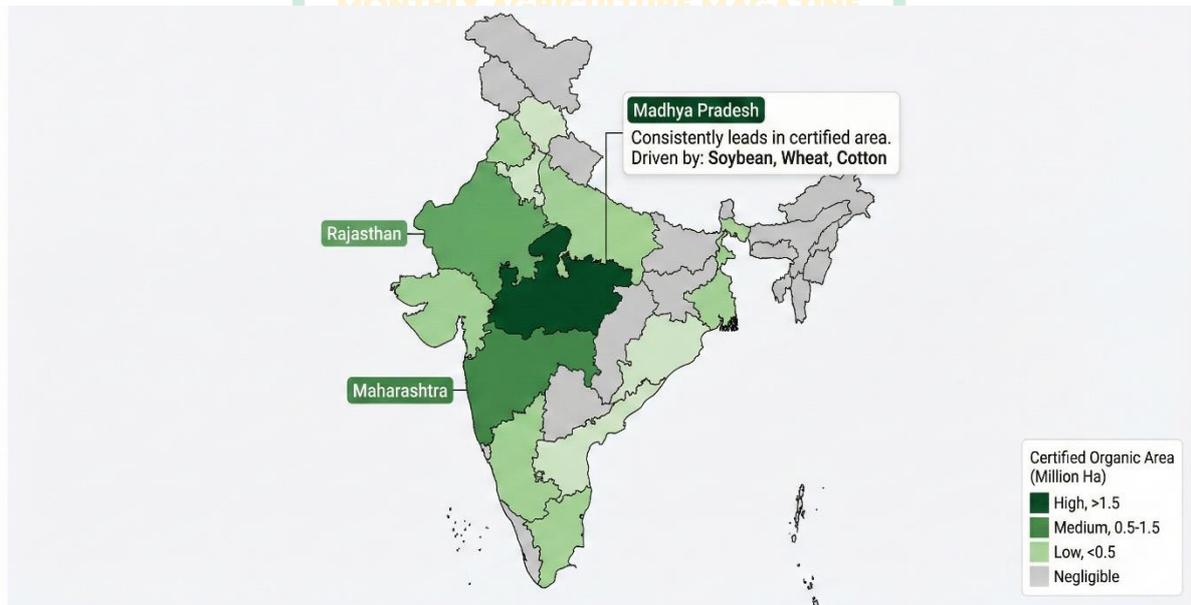
#### 4.3. Case Study: India's Organic Expansion (NPOP Data)

The strategic role played by India as a producer of organic cotton and food supplies makes its development path a crisis in global supply chains. According to the findings provided by the National Programme on Organic Production (NPOP), there is a diversified format of organic activities that goes way beyond the traditional crop production.

**Table 4. Status of Organic Agriculture in India (FY 2023-24)**

Category	Area / Quantity	Leading States
<b>Total Certified Area</b>	7.3 Million Hectares	Madhya Pradesh, Maharashtra, Rajasthan
<b>Cultivated Farm Area</b>	4.5 Million Hectares	Madhya Pradesh (Largest producer)
<b>Wild Harvest Collection</b>	2.8 Million Hectares	Tribal/Forest belts
<b>Total Production</b>	~3.6 Million MT	Oilseeds, Fiber, Sugar crops
<b>Export Value</b>	~\$494 Million USD	USA, EU, Canada (Top importers)

Source: APEDA, Ministry of Commerce & Industry, Govt. of India (2024)



**Figure 4.** Major organic production hubs in India. Madhya Pradesh consistently leads in certified area, largely driven by soybean, wheat, and cotton cultivation. (Based on APEDA, NPOP Data 2024)

## 5. Socio-Economic Dimensions of Sustainable Organic Systems

The concept of sustainability to organic farming can be conceived as a three-legged stool that consists of environmental, economic, and social aspects. Organic technique cannot be considered as a sustainable one when it does not provide economic sustainability to producers and social justice to the communities in question.

- a) **Economic Viability:** Though organic agriculture usually has lower production levels than the intensified conventional production systems, this trade-off is often offset by lower input expenses and high price differentials in the market. Furthermore, organic systems are also expected to be more stable in yield during periods of climate stress and hence economic risk to farmers is reduced.
- b) **Social and Rural Development:** The farming is organic and usually more labour-intensive than the mechanised conventional agriculture. Quite on the contrary, the labour intensity can be used as a driver of rural jobs and hence rejuvenate agricultural communities. Also, the decreased contact with toxic agrochemicals has a direct positive impact on the health of farm-workers.
- c) **Certification Models:** This relates to financial cost to smallholders, whereby there is a tendency of being hampered by financial burden of acquiring third party certification. Participatory Guarantee System (PGS) has been an important innovation in the countries like India and Brazil through which small farmers have been able to enter organic markets at affordable costs without having to cover prohibitive costs.

## 6. Challenges and Future Trajectories

The shift to organic production is marred with enormous challenges. A transitional effect is typically faced by farmers, where there are depressions in yields in the first two to three years as the biological community in the soils reestablishes itself and farmers learn new skills necessary.

Moreover, organic agriculture has a high knowledge intensity. It requires a profound knowledge of local ecology, pest life cycles, and soil dynamics in place of generic chemical solutions with site-specific management. This need is the focus of the strength of extension services and participatory research, which considers and incorporates the indigenous and local knowledge of farmers.

In the future, sustainable organic production will be dependent on the fusion of ancient wisdom with recent technological advancement. Sensors and drones are also potentially used to create precision agricultural instruments, like the mechanical weeders on sensor or drone monitoring to detect pests in the initial stages, which can be applied to organic systems to increase their efficiency without reducing their ecological quality.

## 7. Conclusion

Organic farming as a practice of sustainable crop production is not just a niche market desire, it is essential as a strategy of ensuring a food system on earth operates within the planetary limits. The facts above have shown that organic agriculture is not only scalable but also economically viable and fast growth has been seen in both the developed and the developing economies.

Organic agriculture promotes soil health, biodiversity and long-term resilience through the change of emphasis on treating symptoms with synthetic inputs to control nature, to control the ecological intrinsic conditions. Although issues regarding the gap in yields in the period of transition and labour needs will remain, the ecological and social needs of our modern world suggest the wide implementation of agroecological principles. Investing in organic agriculture as a policy, research and marketing solution is an investment in a regenerative and sustainable food system, as well as a productive one.

## References

- APEDA. (2024). *National Programme for Organic Production (NPOP) status report 2023-24*. Agricultural and Processed Food Products Export Development Authority, Ministry of Commerce and Industry, Government of India. <https://apeda.gov.in>
- Crowder, D. W., & Reganold, J. P. (2015). Financial competitiveness of organic agriculture on a global scale. *Proceedings of the National Academy of Sciences*, 112(24), 7611–7616. <https://doi.org/10.1073/pnas.1423843112>
- European Commission. (2020). *A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system* (COM/2020/381 final). <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0381>

- FAO. (2024). *The state of the world's land and water resources for food and agriculture: Systems at breaking point*. Food and Agriculture Organization of the United Nations. <https://doi.org/10.4060/cb9910en>
- Gomiero, T., Pimentel, D., & Paoletti, M. G. (2011). Environmental impact of different agricultural management practices: Conventional vs. organic agriculture. *Critical Reviews in Plant Sciences*, 30(1–2), 95–124. <https://doi.org/10.1080/07352689.2011.554355>
- IFOAM – Organics International. (2025). *The world of organic agriculture: Statistics and emerging trends 2025* (H. Willer, J. Trávníček, & B. Schlatter, Eds.). Research Institute of Organic Agriculture (FiBL) & IFOAM – Organics International. <https://www.fibl.org/en/shop-en/1354-organic-world-2025>
- Lal, R. (2016). Soil health and carbon management. *Food and Energy Security*, 5(4), 212–222. <https://doi.org/10.1002/fes3.96>
- Mäder, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P., & Niggli, U. (2002). Soil fertility and biodiversity in organic farming. *Science*, 296(5573), 1694–1697. <https://doi.org/10.1126/science.1071148>
- Reganold, J. P., & Wachter, J. M. (2016). Organic agriculture in the twenty-first century. *Nature Plants*, 2(2), 15221. <https://doi.org/10.1038/nplants.2015.221>
- Seufert, V., Ramankutty, N., & Foley, J. A. (2012). Comparing the yields of organic and conventional agriculture. *Nature*, 485(7397), 229–232. <https://doi.org/10.1038/nature11069>
- Tulli, R., & Briones, M. J. I. (2023). Soil biodiversity and organic farming: A global review. *Agronomy*, 13(2), 458. <https://doi.org/10.3390/agronomy13020458>



## Physiological, Nutritional and Medicinal Properties of Custard Apple: A Comprehensive Review



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### 1. Introduction

The genus *Annona* is a genus of more than 120 species of trees and shrubs, mostly of the tropics or the subtropics. Of these, *Annona squamosa* L., which is often repeated as sugar apple, sweetsop, or, in most working agricultural settings, custard apple, has the greatest commercial importance. The custard apple, native to the tropical Americas and widespread throughout India, Southeast Asia and Africa, is praised because of its hardiness and the ability to grow in rocky and marginal soils with very low inputs.

In the past, the cultivation of custard apple has been restricted mostly to smallholder agriculture and backyard gardens. Nevertheless, the growing demand for exotic superfruits and functional foods all over the world has triggered studies into the untapped potential. In addition to this sweet, custard-like pulp, ethno-botanical documents record that the leaves, bark, seeds, and roots have long been used in indigenous medicine systems to treat disease conditions such as dysentery, parasitic infections and so on. Most of these traditional uses are now being validated using modern scientific inquiry, isolating potent phytochemicals. The intended review aims to give a systematic analysis of the physiology of the fruit development, the nutritional scaffolding of the pulp and the proven medicinal qualities of the species, which subsequently gives a basis to the future agricultural and pharmaceutical exploitation.

### 2. Botanical Description and Physiological Characteristics

The *annona squamosa* is a small tree or large shrub that is semi-deciduous and usually grows between 3 and 6 meters. The plant has a high ecological plasticity, especially in the aspect of drought tolerance, although optimum fruit set and development need sufficient soil moisture in the flowering and fruit set stages.

#### 2.1. Floral Biology and Pollination

The species is protogynous; the reproductive organs of the female are receptive earlier than the pollen is viable itself, and this is the physiological adaptation to cross-pollination. Natural fruit set can be low, however, because of the specialized structure of the flower, and the low population of effective nitidulid beetle pollinators often. This has brought about the use of hand-pollination methods in commercial orchard management so that yield and fruit conformity can be realized.

#### 2.2. Fruit Morphology and Development

The apple fruit known as the custard apple is a botanically an aggregate fruit (syncarp), which results as a result of incorporating many pistils and the receptacle into one fleshy fruit. Outwardly this merging can be seen in knobby segments, or carpels, this time, apart at the ripening season.

The custard apple is physiologically a normal climacteric. It shows a characteristic burst in the production and the rate of respiration that coincides with the ripening. This biological characteristic determines its low shelf-life. After harvesting at the mature-green phase, the fruit can be allowed to mature in 3 to 5 days of ambient tropical temperatures, as the fruit becomes soft and the total soluble solids (TSS) and volatile aromatic compounds rise dramatically.

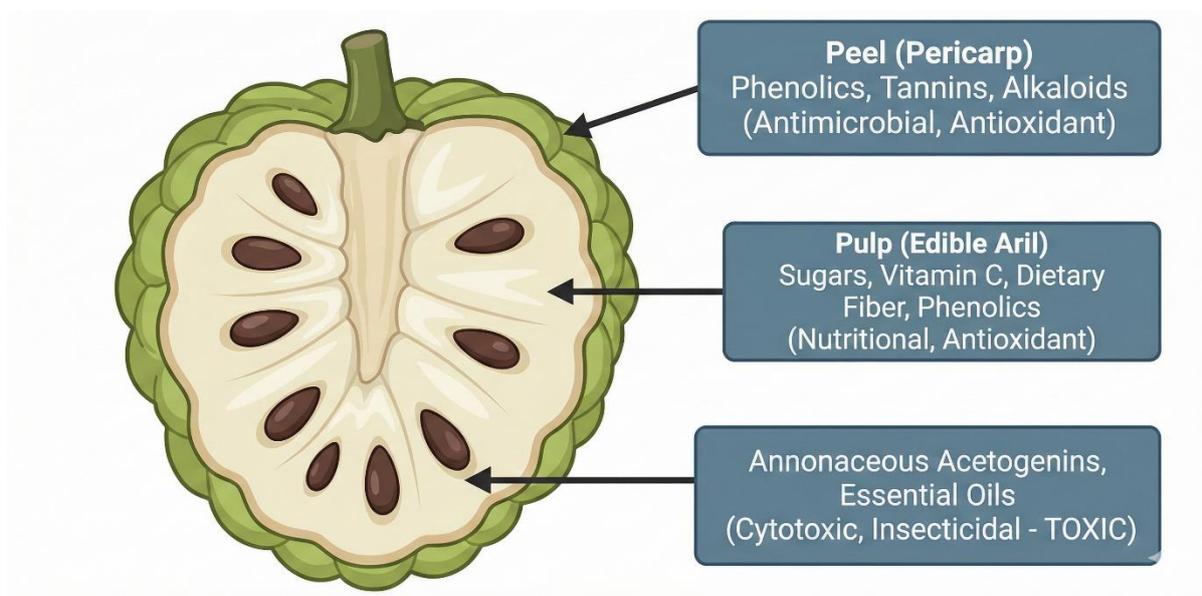


Figure 1. Distribution of key bioactive compounds in custard apple fruit parts

### 3. Nutritional Composition

Custard apple is a concentrated source of energy and essential nutrients especially in the edible part of the fruit (about 50-60 percent of total weight of the fruit). It is classified as high-carbohydrate fruit nutritionally.

#### 3.1. Macronutrients

Pulp contains high amounts of sugars (glucose and fructose), which is why it is extremely sweet, and the Total Soluble Solids usually go above 20° Brix. It is a moderate-level source of protein in comparison with other fruits and a low source of total fat, but the seeds also contain large amounts of oil (which is usually toxic and not eaten). It is worth noting that the pulp is also a good dietary fibre, which renders digestive wellness.

#### 3.2. Micronutrients: Vitamins and Minerals

Custard apple is also a good source of Vitamin C (ascorbic acid), which is also a powerful antioxidant in the diet. It is also a rich source of B-complex vitamins, especially pyridoxine (B6) and thiamine (B1). The mineral analysis shows that there are very high levels of potassium, which are essential in maintaining blood pressure, and a considerable level of magnesium, calcium and phosphorus.

Table 1. Approximate Nutritional Composition of Custard Apple Pulp (*Annona squamosa*) per 100g Edible Portion

Nutrient	Value	Unit	Functional Significance
Water	70 - 75	g	Hydration base
Energy	80 - 100	kcal	High calorific value for immediate energy
Carbohydrates	20 - 25	g	Primary energy source (mostly reducing sugars)
Dietary Fiber	3.0 - 4.5	g	Digestive health, satiety, and blood sugar modulation
Protein	1.5 - 2.0	g	Amino acid supply
Vitamin C	30 - 40	mg	Antioxidant, collagen synthesis, and immune function
Vitamin B6	0.2 - 0.3	mg	Neurotransmitter synthesis, macronutrient metabolism
Potassium	250 - 350	mg	Electrolyte balance, cardiovascular health
Magnesium	18 - 25	mg	Muscle and nerve function, bone integrity
Calcium	15 - 20	mg	Bone and tooth health

### 4. Phytochemistry and Bioactive Compounds

The medicinal possibilities of *Annona squamosa* are due to a wide range of secondary metabolites found in the leaves, bark, seeds, and pulp.

#### 4.1. Annonaceous Acetogenins

Acetogenins are the most crucial and distinctive species of compounds that occur in the genus *Annona*. They are derivatives of fatty acids which are found mostly in the leaves and seeds. Squanocin, annonacin and bullatacin are known compounds that have exhibited strong biological activity. Their mechanisms of action against other pathogens and aberrant cells are nowadays the object of high-intensity pharmaceutical studies.

#### 4.2. Alkaloids and Phenolics

Leaves and bark do possess at least some significant content of isoquinoline alkaloids, such as annonaine and liriodenine which are linked to antimicrobial and antidepressant effects. Moreover, fruit pulp and leaves contain a significant number of phenolic compounds, such as flavonoids (e.g., quercetin, rutin), tannins, which make important contributions to the overall antioxidant capacity (TAC) of the plant.

### 5. Medicinal and Therapeutic Properties

The outlined ethnomedical folklore has given way to scientific investigation of the pharmacological actions of custard apple.

#### 5.1. Antioxidant Activity

Vitamin C and phenolic compounds interact synergistically; hence, custard apple pulp is a good free-radical scavenger. Food consumption helps to counter oxidative stress in the body, which may lead to the decrease in the risk of chronic disease related to cell damage.

#### 5.2. Antimicrobial and Insecticidal Properties

Vitamin C and phenolic compounds interact synergistically; hence, custard apple pulp is a good free-radical scavenger. Food consumption helps to counter oxidative stress in the body, which may lead to the decrease in the risk of chronic disease related to cell damage.

**Table 2. Traditional vs. Scientifically Validated Uses of *A. squamosa* Parts**

Plant Part	Traditional/Ethnomedical Use	Validated Bioactive Compounds	Scientific Findings (Preclinical/Clinical)
<b>Leaf</b>	Vermifuge, treatment of dysentery, antipyretic (fever reduction).	Alkaloids, Flavonoids, Acetogenins.	demonstrated anti-inflammatory and antidiabetic (hypoglycemic) effects in animal models.
<b>Seed</b>	Insecticide (lice), abortifacient (Caution: Toxic).	Concentrated Acetogenins (e.g., Squamocin).	Potent cytotoxicity against tumour cell lines; strong larvicidal activity.
<b>Pulp</b>	Tonic, energy restorative, digestion aid.	Vitamin C, Fibre, Phenolics.	High antioxidant capacity; prebiotic potential due to fibre content.
<b>Bark/Root</b>	Treatment of diarrhea toothache.	Tannins, Alkaloids.	Astringent and antimicrobial properties confirmed.

#### 5.3. Cytotoxic and Anticancer Potential

The research on the cytotoxic effects of acetogenins in the seeds and leaves is, perhaps, the most important field of study. These compounds are very effective in *in vitro* testing with different types of cancer cells, including multi-drug resistant (MDR) cells.

The main physiological process that would be adopted is the inhibition of the mitochondrial complex I (NADH: ubiquinone oxidoreductase) in the electron transport chain of the cells. There is a high energy requirement in cancer cells; acetogenins are known to block the production of ATP by blocking it at the mitochondrial level and therefore by blocking mitochondrial production of ATP, acetogenins effectively starve the cell, triggering apoptosis (programmed cell death).

#### 5.4. Anti-diabetic and Hepatoprotective Effects

Although the pulp of the fruit contains a lot of sugar, counterintuitive evidence indicates that leaf extracts can be hypoglycemic (blood sugar-lowering). Research on diabetic animal models has demonstrated that aqueous leaf extracts can either stimulate insulin secretion or enhance glucose uptake. Also, some extracts have been shown to have hepatoprotective effects, to protect the liver against damage caused by toxins, which is probably connected to the high antioxidant activity of extracts.

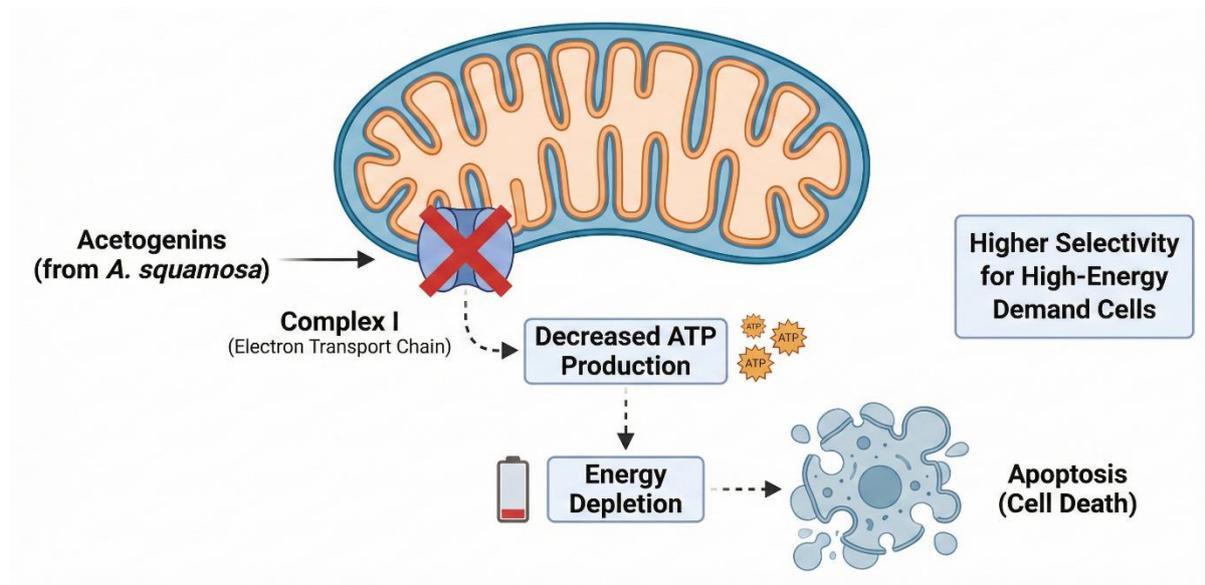


Figure 2. Mechanism of action of *Annonaceous acetogenins* in cancer cells

#### 6. Postharvest Physiology and Processing Challenges

The postharvest physiology of custard apple is a serious impediment to its commercial exploitation regardless of its nutritional riches.

Being a climacteric fruit and having the high respiration rate, the time span of marketing fresh fruit is very narrow (3-5 days at 25degC). Storage at low temperatures is not easy; temperatures that are under 15degC may be followed by chilling injury which involves darkening of the skin of the fruit, inability to ripen and hardening of the pulp.

Also, the fact that the fruit should be processed into value-added products (juices, puree) is complicated by two factors:

1. **Enzymatic Browning:** The polyphenol oxidase (PPO) is present in high levels in the pulp. When cut or pulped, the product will turn brownish very quickly when exposed to oxygen, which makes the product not appealing to the eyes.
2. **Physical Structure:** It is physical, and it is hard to separate the many hard seeds and the soft pulp, and it is hard to mechanize effectively, ensuring that the seeds are not damaged to release toxic compounds into the pulp.

#### 7. Conclusion and Future Perspectives

Custard apple (*Annona squamosa L.*) is a versatile crop which holds a great potential in the fields of agriculture, nutrition and medicine. It is physiologically acclimatized to marginal environments and is nutritionally enriched as well as possessing distinctive bioactive compounds especially the potent acetogenins.

Nonetheless, to overcome the distance between its potential and its present use, the concerted effort of research is needed. Future outlook must be based on:

- a) **Breeding programs** that focus on the production of breeds with reduced seed content, splitting-resistance, and increased shelf-life using modified climacteric responses.
- b) **Standardization of protocols** to extract bioactive compounds to use in pharmaceutical applications, which is safe and has a stable dosage.

- c) **Innovative postharvest technologies**, that are innovative like modified atmosphere packaging or safe enzyme inhibitors, to curb the high perishability rate of the fresh fruit.

These physiological and technical challenges can be dealt with, and the agriculture industry will be able to realize the full potential of the custard apple, which will no longer be a subsistence crop, but a significant source of functional food markets around the world.

#### References

- Ahirwar, S., Jain, S., & Nisha, P. (2023). *Annona squamosa* L.: A brief review on biological activities and their phytochemicals. *Asian Journal of Pharmacy and Pharmacology*, 9(1), 13–19. <https://doi.org/10.31024/ajpp.2023.9.1.3>
- Alkhalidy, H., Al-Nabulsi, A., Mhawish, R., & Liu, D. (2023). Low-dose of phenolic rich extract from *Annona squamosa* Linn leaves ameliorates insulin sensitivity and reduces body weight gain in HF diet-induced obesity. *Frontiers in Nutrition*, 10, 1146021. <https://doi.org/10.3389/fnut.2023.1146021>
- Ansari, P., Flatt, P. R., Harriott, P., & Abdel-Wahab, Y. H. A. (2020). Evaluation of the antidiabetic and insulin releasing effects of *A. squamosa*, including isolation and characterization of active phytochemicals. *Plants*, 9(10), 1348. <https://doi.org/10.3390/plants9101348>
- Gawade, J. A. (2025). A comprehensive review: Exploring the anti-arthritis anti-inflammatory potential of *Annona squamosa* (custard apple) leaves. *International Journal of Therapeutic Innovation*, 3(1), 283–292. <https://doi.org/10.55522/ijti.v3i1.0062>
- Jacobo-Herrera, N., Pérez-Plasencia, C., Castro-Torres, V. A., Martínez-Vázquez, M., González-Esquinca, A. R., & Zentella-Dehesa, A. (2019). Selective acetogenins and their potential as anticancer agents. *Frontiers in Pharmacology*, 10, 783. <https://doi.org/10.3389/fphar.2019.00783>
- Kumari, N., Prakash, S., Kumar, M., Radha, Zhang, B., Sheri, V., Rais, N., Chandran, D., Dey, A., Sarkar, T., Dhumal, S., Kumar, S., Mahato, D. K., Vishvanathan, M., Mohankumar, P., Pateiro, M., & Lorenzo, J. M. (2022). Seed waste from custard apple (*Annona squamosa* L.): A comprehensive insight on bioactive compounds, health promoting activity and safety profile. *Processes*, 10(10), 2119. <https://doi.org/10.3390/pr10102119>
- Patil, R. A., Sudhakar Rao, D. V., & Manasa, B. (2013). Effect of modified atmospheric packaging on chilling injury and shelf-life of custard apple fruits. *Journal of Applied Horticulture*, 15(02), 100–105. <https://doi.org/10.37855/jah.2013.v15i02.18>

## Probiotic Applications in Aquaculture: Enhancing Immunity and Health of Cultured Fish



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### 1. Introduction

Aquaculture has become the fastest-growing branch of the world's food production, and it provides more than half of the fish consumed by humans. By way of meeting the increasing demand, more intensive production systems have been stepped up to meet the increased demand, which generally leads to high stocking densities and poor water quality. These environmental factors contribute to the development of pathogens and cost a lot of financial resources in the form of disease outbreaks. Traditionally, the dependence on sub-therapeutic and therapeutic antibiotics in society was the norm of controlling the disease. However, such dependence has caused dire consequences, the most notable being the rise of antibiotic-resistant bacterial populations in water bodies, thus posing a threat to animal and human lives. Besides, antibiotic residues in aquacultural products have been met with increased regulation and opposition by consumers. This is leading to a paradigmatic change in the industry, whereby preventive health management is taking over. Probiotics have become a possible alternative that is sustainable. Probiotics, as construed by the Food and Agriculture Organisation (FAO) and the World Health Organization (WHO), are live microorganisms that, when delivered in sufficient quantities, have a health benefit to the host. Probiotics are used in aquaculture to manipulate the microbial environment in the rearing environment strategically and the host gastrointestinal tracts to enhance health conditions and disease resistance.

### 2. Mechanisms of Action

Strict knowledge of probiotic activity is necessary to maximise their use. Unlike antibiotics that seek to kill pathogens directly, probiotics act as a result of numerous, and frequently synergistic, mechanisms that support the host's innate defence and out-compete pathogenic microorganisms.

#### 2.1. Competitive Exclusion

Fish have a poor surface area and nutrient pool available to microbial colonisation. Plausibly, probiotic bacteria can colonise these niches, having an edge over potential pathogens. The process operates via:

- a) **Competition for Adhesion Sites:** Probiotics bind to intestinal mucosal epithelium, preventing pathogens from attaching and colonizing.
- b) **Competition for Nutrients:** Probiotics utilize available nutrients, starving pathogenic populations.

#### 2.2. Production of Inhibitory Substances

Many probiotics produce antimicrobial substances that hinder the development of other bacteria. These agents include:

- a) **Bacteriocins:** Toxins that are produced by bacteria and are proteinaceous in nature, and are used to neutralise or infect other bacteria that are closely related or even identical.
- b) **Organic Acids:** the lactic and acetic acid production lowers the gut pH, which is unfavourable to most of the pathogenic agents, especially *Vibrio* spp.
- c) **Hydrogen Peroxide:** Produced by some *Lactobacilli*, acting as a potent antimicrobial agent.

### 2.3. Enhancement of the Epithelial Barrier

Intestinal barrier is the primary barrier to defence against invading microbes. The effects of probiotics on the gut structure are the stimulation of the production of mucus and strengthening tight junctions between epithelial cells, reducing the permeability to toxins and pathogens.

### 2.4. Immunomodulation

Probably the most important long-term probiotic effect in fish is the effect of stimulating immunity. Innate (non-specific) immunity is important to fish. Probiotics also react with gut-associated lymphoid tissue (GALT) and lead to immune responses such as an increase in phagocytic activity of macrophage in the gut, an increase in the activities of the enzyme, lysozyme and complement in the blood serum, and the stimulation of the production of cytokines (signalling proteins) which control immune responses.

### 3. Common Probiotic Microorganisms in Aquaculture

While the human probiotic market is dominated by *Lactobacillus* and *Bifidobacterium*, aquaculture utilizes a wider array of microorganisms adapted to aquatic environments and specific host species.

**Table 1: Common Probiotic Genera Used in Aquaculture and Their Primary Functions**

Microorganism Genus	Type	Examples of Species used	Primary Mechanisms of Action	Key Characteristics
<b>Bacillus</b>	Bacterium (Gram-positive)	<i>B. subtilis</i> , <i>B. licheniformis</i> , <i>B. coagulans</i>	Enzyme production (aids digestion), competitive exclusion, immune stimulation.	Spore-formers; highly stable during feed processing and storage; can survive in the water column.
<b>Lactobacillus</b>	Bacterium (Gram-positive)	<i>L. plantarum</i> , <i>L. acidophilus</i> , <i>L. rhamnosus</i>	Production of lactic acid (lowers pH), bacteriocin production, adhesion to gut mucosa.	Common inhabitants of healthy gut microbiota; sensitive to high heat.
<b>Carnobacterium</b>	Bacterium (Gram-positive)	<i>C. divergens</i> , <i>C. maltaromaticum</i>	Bacteriocin production active against specific fish pathogens (e.g., <i>Listeria</i> ).	Adapted to cold environments; useful in cold-water salmonid culture.
<b>Vibrio</b>	Bacterium (Gram-negative)	<i>V. alginolyticus</i> (non-pathogenic strains)	Competitive exclusion against pathogenic <i>Vibrio</i> spp. through siderophore production (iron competition).	Marine origin; effectively used in shrimp and marine finfish hatcheries.
<b>Saccharomyces</b>	Yeast (Fungus)	<i>S. cerevisiae</i> (Baker's Yeast)	Source of Beta-glucans (immunostimulants), nutrient competition, enzymatic contribution.	Robust; acts as both a nutrient source and an immune modulator.

### 4. Methods of Administration

Probiotics in their delivery method are in charge of the probiotics viability and its capacity to reach the target site (which in most cases is the gut) in sufficient numbers.

- In-Feed Incorporation:** It is the most popular one when it comes to subsequent grow-out stages. Probiotics may be incorporated as feed additives before pelletizing or, more commonly, sprayed onto pellets that have already been produced in finished form, with oil or a pellet binding agent. The main problem is explained by the fact that heat is sensitive to most of the vegetative bacteria, including *Lactobacillus*, which may be destroyed when extruding the pellets during manufacture. A better alternative is often the spore forming *Bacillus* spp. this is because it is thermostable.
- Water Additives (Bioaugmentation):** Directly added to rearing water are pro-biotics. It is especially effective in hatcheries in larval and fry stages when the digestive system is not yet fully developed and fish take huge amounts of water. Probiotics also enhance the water quality because they also decompose organic materials and settle on the skin and gills of the larvae.

c) **Live Food Enrichment (Bioencapsulation):** The live feed organisms, like *Artemia* (brine shrimp) or rotifers, are allowed to graze on probiotic suspensions. These enhanced organisms are then introduced to fish larval whereby they serve as a vector to introduce the bacteria to the larval gut.

**5. Effects on Immunity and Disease Resistance**

The end product of probiotic use is to convert manipulation of microbes to real health gains in cultured stock. These effects empirically have been shown in many studies of different types of fish.

**5.1. Boosting Innate Immune Parameters**

Probiotics always lead to high parametric levels of non-specific immune in fish. An example is the case of Nile tilapia (*Oreochromis niloticus*) fed diets that are enriched with *Bacillus subtilis* which have reported high serum lysozyme activity and respiratory burst activity in phagocytes compared to control groups. These measurements are the pointers of the short-term ability of the fish to counter attacking bacteria.

**5.2. Improved Survival in Challenge Tests**

The conclusive demonstration of probiotic effectiveness is the challenge tests, whereby, there is the deliberate exposure of both the treated and untreated fish to a pathogenic agent.

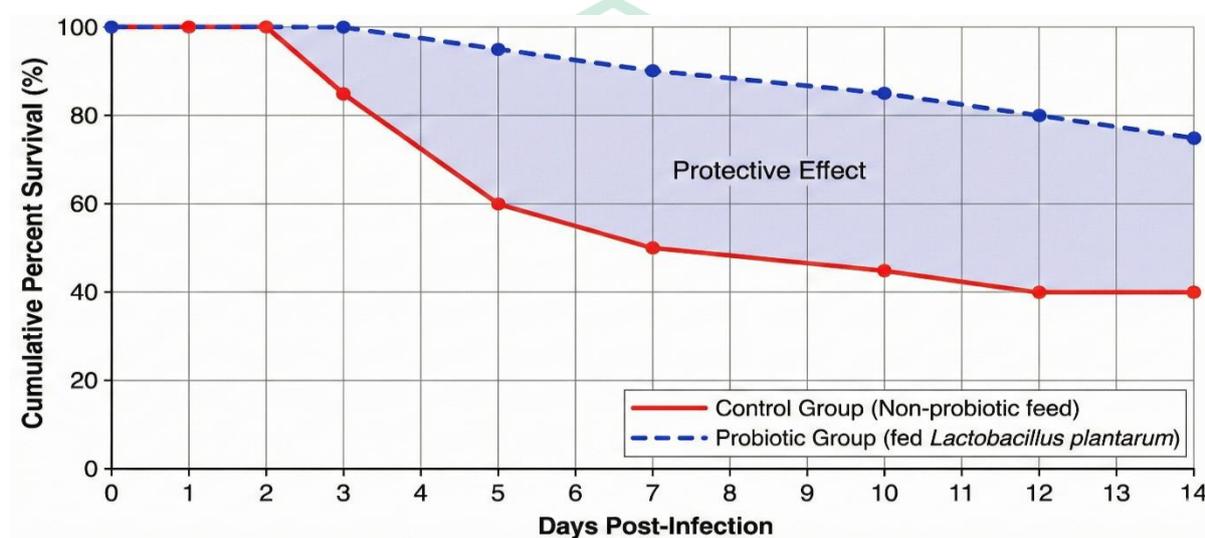


Figure 1. Hypothetical Survival Rates of Rainbow Trout Following Challenge with *Aeromonas salmonicida*

Table 2: Summary of Select Studies Demonstrating Probiotic Efficacy in Fish

Fish Species	Probiotic Used	Pathogen Challenged	Key Findings
Atlantic Salmon ( <i>Salmo salar</i> )	<i>Carnobacterium divergens</i>	<i>Yersinia ruckeri</i> (Enteric Redmouth Disease)	Increased survival rate by 35% compared to controls; enhanced leukocyte activity.
Nile Tilapia ( <i>Oreochromis niloticus</i> )	<i>Bacillus</i> spp. mixture	<i>Streptococcus agalactiae</i>	Significant reduction in mortality; improved feed conversion ratio (FCR) in non-challenged fish.
European Sea Bass ( <i>Dicentrarchus labrax</i> )	<i>Lactobacillus plantarum</i>	<i>Vibrio anguillarum</i>	Upregulation of pro-inflammatory cytokine genes (IL-1 $\beta$ , TNF- $\alpha$ ) indicating primed immune response.

**5.3. Growth Performance and Feed Utilization**

In addition to the boosting of immunity, probiotics often enhance growth. These could be attributed to the production of extraintestinal digestive enzymes (amylases, proteases) by probiotic bacteria to increase feed utilisation; synthesis of essential B-vitamins; and reduction of physiological stress, which causes more energy to be allocated to growth and not maintenance.

## 6. Challenges and Limitations in Commercial Application

In spite of the reported benefits, the translation of probiotic research into the success of commercial farm results on a regular basis is facing many challenges:

- Strain Specificity:** A strain of probiotic that is used successfully in tilapia with *Streptococcus* might not be effective in salmon with *Vibrio*. The strain selection should depend on the host species, the environment in which the rearing is conducted (freshwater or marine) and the desired pathogen.
- Viability and Storage:** It is challenging to store commercial feed with high viable bacteria counts (Colony-forming Units -CFUs) all through the shelf life. The presence of oxygen, moisture and changes in temperature during processing and storage may have an adverse effect on probiotic potency.
- Regulatory Frameworks:** The regulatory landscape for aquacultural probiotics is fragmented Globally. In some regions, they are designated as feed additives, while in others, they approach veterinary medicinal status, complicating international trade and standardization of claims.
- The Black Box of the Gut:** While mechanisms are understood broadly, the complex interactions within the indigenous gut microbiota of fish are still not fully mapped. Introducing a new species can have unpredictable effects on existing microbial community dynamics.

## 7. Future Perspectives

The future of microbial management in aquaculture lies in refining these tools.

- Synbiotics:** This approach combines probiotics with *prebiotics*. Prebiotics are non-digestible fibers (like fructooligosaccharides - FOS, or mannanoligosaccharides - MOS) that selectively feed beneficial bacteria already present in the gut or the administered probiotic. The synbiotic combination ensures the probiotic has an immediate fuel source upon arrival in the gut, enhancing its colonization success.
- Paraprobiotics (Ghost Probiotics):** Recent research suggests that live bacteria act not always necessary. Inactivated (dead) probiotic cells or their cell wall components can still trigger immune responses via specific receptors in the fish gut. This solves the issue of storage viability and shelf-life.
- Host-Derived Probiotics (Autochthonous):** Isolating beneficial bacteria from the gut of healthy wild or cultured fish of the target species, rather than using generic terrestrial strains. These autochthonous strains are already adapted to the host's mucosal environment, theoretically offering better colonization potential.

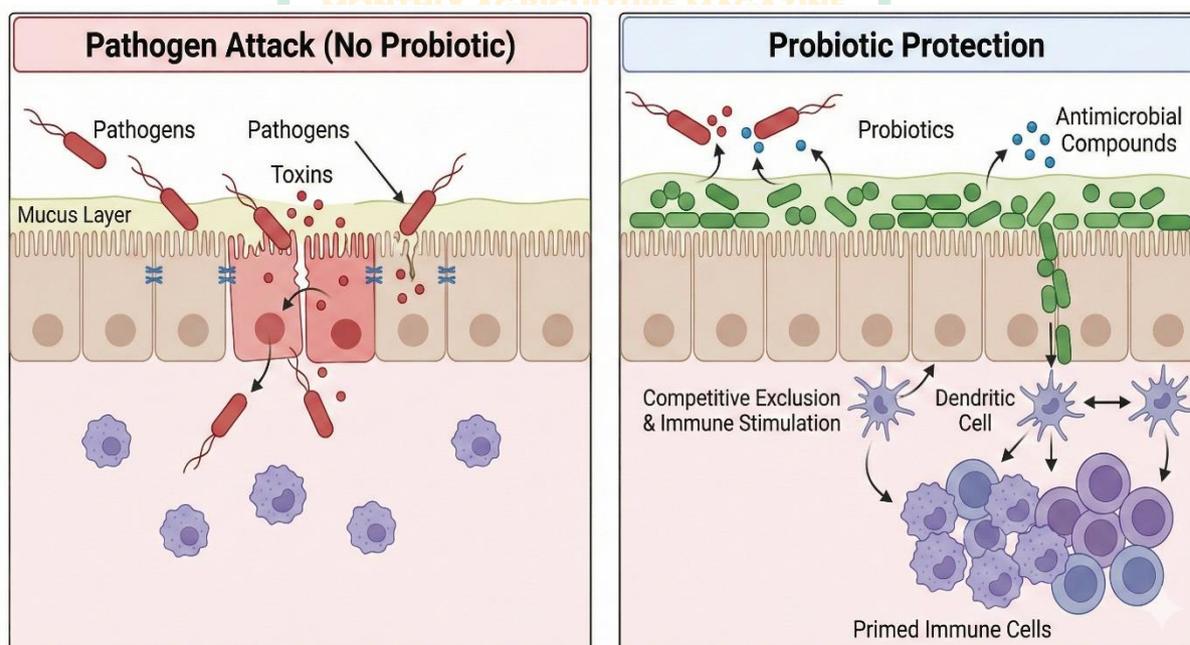


Figure 2. Mechanism of probiotic action in the fish gut

## 8. Conclusion

The integration of probiotics into aquaculture protocols represents a crucial maturation of the industry toward sustainable, environmentally responsible practices. By leveraging the natural synergistic relationships between beneficial microbes and aquatic hosts, farmers can enhance innate immunity, improve disease resistance against bacterial pathogens, and optimize growth performance without relying on antibiotics.

While challenges remain regarding strain selection, formulation stability, and regulatory standardization, the body of scientific evidence supporting probiotic efficacy is robust. Continued research into synbiotics and host-derived strains will further refine these tools, securing probiotics as a cornerstone of modern, resilient aquaculture health management.

## References

- Balcázar, J. L., de Blas, I., Ruiz-Zarzuela, I., Cunningham, D., Vendrell, D., & Múzquiz, J. L. (2006). The role of probiotics in aquaculture. *Veterinary Microbiology*, *114*(3–4), 173–186. <https://doi.org/10.1016/j.vetmic.2006.01.009>
- Gatesoupe, F. J. (1999). The use of probiotics in aquaculture. *Aquaculture*, *180*(1–2), 147–165. [https://doi.org/10.1016/S0044-8486\(99\)00187-8](https://doi.org/10.1016/S0044-8486(99)00187-8)
- Merrifield, D. L., Dimitroglou, A., Foey, A., Davies, S. J., Baker, R. T. M., & Bøgwald, J. (2010). The current status and future focus of probiotic and prebiotic applications for salmonids. *Aquaculture*, *302*(1–2), 1–18. <https://doi.org/10.1016/j.aquaculture.2010.02.007>
- Merrifield, D. L., Bradley, G., Baker, R. T. M., & Davies, S. J. (2010). Probiotic applications for rainbow trout (*Oncorhynchus mykiss* Walbaum) II. Effects on growth performance, feed utilization, intestinal microbiota and related health criteria. *Aquaculture Nutrition*, *16*(5), 504–510. <https://doi.org/10.1111/j.1365-2095.2009.00689.x>
- Nayak, S. K. (2010). Role of gastrointestinal microbiota in fish. *Aquaculture Research*, *41*(11), 1553–1573. <https://doi.org/10.1111/j.1365-2109.2010.02546.x>
- Newaj-Fyzul, A., & Austin, B. (2015). Probiotics, immunostimulants, plant products and oral vaccines, and their role as feed supplements in the control of bacterial fish diseases. *Journal of Fish Diseases*, *38*(11), 937–955. <https://doi.org/10.1111/jfd.12313>
- Zorriehzahra, M. J., Delshad, S. T., Adel, M., Tiwari, R., Karthik, K., Dhama, K., & Lazado, C. C. (2016). Probiotics as beneficial microbes in aquaculture: An update on their multiple modes of action: A review. *Veterinary Quarterly*, *36*(4), 228–241. <https://doi.org/10.1080/01652176.2016.1172132>

## Role of Soil-Organic Carbon in Sustaining Soil Fertility and Crop Productivity



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### 1. Introduction

The need to nourish an ever-swelling world population of around 10 billion by 2050, makes untold demands on farmlands. In the past, increased agricultural production is usually done at the expense of soil degradation. The current agronomic science appreciates the fact that sustainable intensification cannot be attained without the conservation and development of soil health. Soil Organic Carbon (SOC) is the convergence of soil health. SOC represents about 58 percent of Soil Organic Matter (SOM), which consists of decomposing plant and animal remnants, root exudates, living microbial biomass and stable humus. SOC plays a disproportionately large role in soil functioning, although it only constitutes a small portion of the total soil volume (usually 1-5% in mineral soils). It is also known as the key to soil fertility due to its regulation of the complex interaction between the physical building and the chemistry of the soil and its biology.

### 2. The Multidimensional Influence of SOC on Soil Fertility

Fertility of the soil is mostly considered in the perspective of chemical availability of nutrients (NPK). Nevertheless, the real fertility depends upon the physical structure, chemical buffering ability, and the biological activity of soil all of which are controlled by SOC.

#### 2.1 Physical Properties: Structure and Water Dynamics

SOC plays a key role in the formation of the structure of the soil the way in which soil particles are organized into aggregates. The organic molecules, especially the polysaccharides resulting from microbial decay of organic material, are acting as binding agents, holding the mineral particles (sand, silt, and clay) into consistent micro- and macro-aggregates.

Highly aggregated soil is very porous, allowing the important penetration of roots and also exchange of gases (aeration). More importantly, SOC has a significant impact on the water-holding capacity (WHC) of soil. The behaviour of organic matter resembles that of a sponge; organic matter is capable of retaining 20 times its mass.

- a) **Hydraulic Conductivity:** The water infiltration is better due to improved aggregation; this removes surface crusting and erosion during heavy rain.
- b) **Drought Resilience:** High-SOC soils use up more of the available water in the root zone, which shields crops against the immediate drought stress, which is vital in the face of more erratic weather patterns.

#### 2.2 Chemical Properties: Nutrient Cycling and Retention

The soil ecosystem relies on SOC as their main source of energy and one giant anything that the soil ecosystem keeps of nutrients in a twofold way- both as a source and as a regulator.

- a) **Nutrient Reservoir and Mineralization:** SOM has a large amount of organic nitrogen, phosphorus and sulphur. These are nutrients that are never directly available as plants, but are liberated through the process of mineralization, microbial degradation of organic matter. The presence of a stable SOC pool guarantees slow, protracted discharge of these macronutrients during the growing season.

- b) **Cation Exchange Capacity (CEC):** CEC is a characteristic of the soil that is the capacity to retain positively charged ions (cations) like calcium ( $\text{Ca}^{++}$ ), magnesium ( $\text{Mg}^{++}$ ), and potassium ( $\text{K}^+$ ), so that they cannot be washed out. Stable SOC Humic substances contain a high specific surface area and negative charge density, which causes the total CEC of the soil to rise greatly, particularly in sandy soils with intrinsic low clay content.
- c) **pH Buffering:** SOC helps buffer soil against rapid changes in pH, maintaining an optimal range for nutrient availability and microbial function.

### 2.3 Biological Properties: The Engine of Fertility

Soil is a living ecosystem. The numerous soil microorganisms (bacteria, fungi, actinomycetes) and mesofauna (earthworms, nematodes) use SOC as their main source of food.

The presence of a varied and dynamic soil food web with proper carbon input promotes nutrient cycling, competes with soil-borne pathogens, and antagonizes, as well as, secretes and generates plant growth-promoting hormones. The percentage of fungi/bacteria, which is frequently used as a marker of maturity of soil ecosystems, is greatly affected by the quality and amount of carbon inputs.

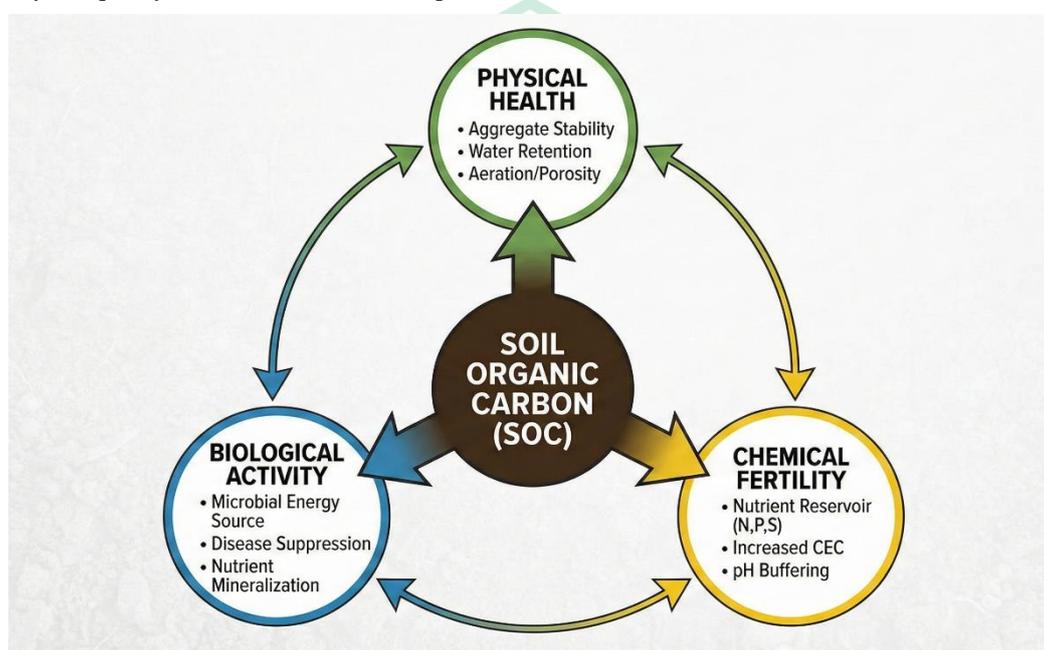


Figure 1. The Central Role of SOC in Soil Function Interactions

### 3. Linkages Between SOC Dynamics and Crop Productivity

The relationship between SOC concentration and the crop yield is well-reported, but complicated. It tends to be asymptotic; the higher the SOC, the higher gradually the yield, but above a critical point, further addition of carbon will lead to decreasing payoffs on yield, but environmental payoffs will continue to accrue.

These productivity gains that are associated with SOC tend to be the most noticeable in stressed or degraded soils. In intensive agricultural systems, the synthetic fertilizers are able to conceal the lack of biological health in the soil at the moment. Nonetheless, there is some long-term evidence that soils whose SOC is depleted need more and more fertilizer to sustain yield, decreasing profitability and increasing environmental burden.

The major mechanisms that connect SOC and productivity are:

- a) **Improved Rooting Zone:** Deep, extensive root systems on the basis of improved soil structure enable the maximum exploration of soil volume in search of water and nutrients.
- b) **Nutrient Use Efficiency (NUE):** SOC decreases the leaching wastage and increases the uptake efficiency of the applied synthetic fertilizers because of retention of nutrients in the root zone (high CEC) and because of biological recycling of nutrients (immobilization).

- c) **Yield Stability:** Aside from the maximum yield within any given year, perhaps the more important thing is yielding stability over a period. The soil has a high level of SOC which is more resistant to climatic extremes, which serves as a buffer to perpetuate yields when weather conditions are unfavourable.

#### 4. The Anthropogenic Decline of SOC

Despite its importance, global agricultural soils have lost a significant portion of their antecedent carbon pools, with estimates ranging from 25% to 75%, depending on the ecosystem and management history. This condition is sometimes referred to as soil fatigue.

The primary drivers of this decline include:

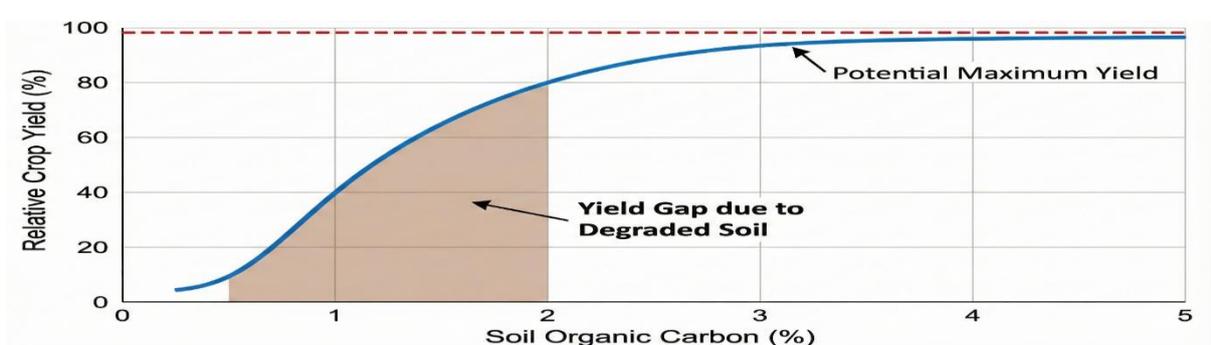
- a) **Intensive Tillage:** The normal ploughing breaks soil aggregates exposing the formerly covered organic matter to oxygen. This increases the rate at which microbes decompose and produce carbon in the form of CO<sub>2</sub>.
- b) **Monocropping and Fallow Periods:** With annual crops of low residue, continued cultivation of the soil prevents fresh carbon additions. Fallow periods cause soil to be left bare exposing it to high temperatures and erosion.
- c) **Erosion:** The uppermost layer of soil is the one that is rich in SOC. Literally, water and wind erosion remove this important resource, and they carry it away elsewhere.
- d) **Overuse of Synthetic Nitrogen:** Although required to bring on a crop, excessive application of nitrogen fertilizers may sometimes increase the rate at which the available carbon pool of soil is decomposed by the microbes unless supplemented by a fresh pool of carbon.

#### 5. Management Strategies for Enhancing SOC Sequestration

A reversal of the SOC depletion process needs to be put into a shift towards regenerative or conservation farming practices that are consistent with two core principles: augmenting carbon inputs and reducing carbon losses.

**Table 1. Comparative Analysis of Agricultural Management Practices on SOC Sequestration**

Management Practice	Mechanism of SOC Enhancement	Impact on SOC Turnover	Additional Co-benefits
<b>No-Till/Reduced Tillage</b>	Reduced physical disruption; protection of aggregates; lower oxidation rate.	Slows turnover rate; increases recalcitrant pool.	Reduced fuel costs; improved water infiltration; reduced erosion.
<b>Cover Cropping</b>	Continuous supply of root exudates; additional biomass input during the offseason.	Increases active (labile) carbon pool initially.	Reduced nitrate leaching; weed suppression; nitrogen fixation (if legumes).
<b>Manure/Compost Application</b>	Direct addition of large quantities of pre-processed organic matter and nutrients.	Increases both active and slow pools depending on maturity.	Improved nutrient supply; enhanced microbial diversity.
<b>Crop Residue Retention</b>	Return of photosynthetic biomass to the soil surface.	Provides substrate for microbes; protects surface.	Moderates soil temperature; conserves soil moisture.
<b>Biochar Application</b>	Addition of highly recalcitrant (stable) pyrolyzed carbon.	Very slow turnover; long-term sequestration.	Increased CEC; potential remediation of toxins; improved aeration in heavy soils.



**Figure 2. Theoretical Relationship Between SOC Levels and Crop Yield**

### 5.1 Reducing Losses: Conservation Tillage

Minimizing soil disturbance is paramount. No-till or reduced-tillage systems leave crop residues on the soil surface. This protects the soil from erosion, moderates soil temperature, and allows soil aggregates to rebuild, physically protecting organic matter from rapid microbial oxidation.

### 5.2 Increasing Inputs: Crop Diversity and Residue Management

Maximizing photosynthesis year-round is key to feeding the soil.

- a) **Cover Crops:** Planting crops during fallow periods provides continuous root exudates (liquid carbon) into the soil profile and generates biomass that is returned to the soil. Leguminous cover crops add nitrogen, while grasses contribute high-biomass carbon.
- b) **Crop Rotation:** Diverse rotations stimulate diverse soil microbial communities.
- c) **Residue Retention:** Leaving crop stubble in the field rather than burning or removing it is the most immediate method of returning carbon to the system.

### 5.3 Organic Amendments

Direct application of external carbon sources can rapidly boost SOC levels. These include animal manures, composted municipal wastes, and biosolids. These amendments provide both readily decomposable carbon for immediate microbial activity and more recalcitrant carbon for long-term sequestration.

### 5.4 Biochar Application

An emerging strategy is the application of biochar, organic matter pyrolyzed under low-oxygen conditions. Biochar is highly resistant to decomposition and can remain stable in the soil for centuries, offering a long-term mechanism for carbon storage while also improving CEC and water retention.

## 6. Challenges and Future Perspectives

While the benefits of SOC are clear, widespread adoption of sequestering practices faces hurdles.

- a) **Time Lags:** Building stable soil carbon is a slow process, often taking 5 to 10 years to manifest measurable changes, while the economic costs of transition (e.g., purchasing no-till equipment) are immediate.
- b) **Measurement Verification:** accurately measuring small changes in SOC pools over vast landscapes remains technically challenging and expensive, complicating carbon credit markets.
- c) **Finite Capacity:** Soils have a carbon saturation point, determined by texture and climate. Once saturated, sequestration rates decline.

Future research must focus on unravelling the complexities of deep-soil carbon storage (below the plough layer), refining the relationship between microbial community composition and carbon stability, and developing policy frameworks that financially incentivize farmers to provide the ecosystem service of carbon sequestration.

## 7. Conclusion

Soil Organic Carbon is not merely a component of the soil; it is the vital currency of agricultural ecosystems. Its role in sustaining soil fertility is foundational, dictating the physical resilience, chemical buffering, and biological vitality necessary for robust crop production. The historical degradation of SOC pools represents a critical threat to global food security. However, it also presents a tremendous opportunity. By adopting management strategies that prioritize the rebuilding of soil carbon, agriculture can transition from a net source of greenhouse gases to a significant sink, simultaneously securing long-term productivity and resilience against an uncertain climate future. Investing in soil carbon is, ultimately, an investment in the sustenance of civilization.

## References

- Brady, N. C., & Weil, R. R. (2017). *The nature and properties of soils* (15th ed.). Pearson.
- Food and Agriculture Organization of the United Nations. (2017). *Voluntary guidelines for sustainable soil management*. FAO. <https://www.fao.org/3/a-bl13e.pdf>
- Lal, R. (2016). Soil health and carbon management. *Food and Energy Security*, 5(4), 212–222. <https://doi.org/10.1002/fes3.96>
- Lal, R. (2020). Soil organic matter content and crop yield. *Journal of Soil and Water Conservation*, 75(2), 27A–32A. <https://doi.org/10.2489/jswc.75.2.27A>

- Lehmann, J., & Kleber, M. (2015). The contentious nature of soil organic matter. *Nature*, 528(7580), 60–68. <https://doi.org/10.1038/nature16069>
- Oldfield, E. E., Bradford, M. A., & Wood, S. A. (2019). Global meta-analysis of the relationship between soil organic matter and crop yields. *Soil*, 5(1), 15–32. <https://doi.org/10.5194/soil-5-15-2019>
- Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G. P., & Smith, P. (2016). Climate-smart soils. *Nature*, 532(7597), 49–57. <https://doi.org/10.1038/nature17174>
- Six, J., Bossuyt, H., Degryze, S., & Deneff, K. (2004). A history of research on the link between (macro)aggregates, soil biota, and soil organic matter dynamics. *Soil and Tillage Research*, 79(1), 7–31. <https://doi.org/10.1016/j.still.2004.03.008>
- Smith, P., Soussana, J. F., Angers, D., Schipper, L., Chenu, C., Rasse, D. P., ... & Klumpp, K. (2020). How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. *Global Change Biology*, 26(1), 219–241. <https://doi.org/10.1111/gcb.14815>



## Soil Carbon Sequestration under Diverse Cropping Systems



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### 1. Introduction

The need to reduce climate change caused by the world and the need to feed the rising population have put agriculture at a crossroads. Soils form the most substantial terrestrial organic carbon repository, with about three times more carbon than the atmosphere and four times more carbon than biotic vegetation. The loss of antecedent soil organic carbon (SOC) stocks by 30 to 75 per cent of native ecosystem conversion to agricultural lands, most notably under intensive tillage regimes, is a historical fact. This drain not only causes emission of greenhouse gases (GHGs) into the atmosphere but also destroys soil structure, water retention, and nutrient cycling efficiency.

The soil capture of CO<sub>2</sub> into the ground of dryland ecosystems in the form of vegetable remains and other organic materials is known as soil carbon sequestration (SCS) or the transfer of atmospheric CO<sub>2</sub> into the soil. In agricultural settings, SCS is accomplished through adding the input of organic material to the soil and/or reducing the soil organic matter (SOM) decomposition rate.

There is a paradigm shift in favour of climate-smart agriculture, which focuses on restoring SOC practices. The key to this change is the abandonment of simplified monocultures in favour of various cropping systems. This paper examines the scientific literature supporting the contribution of cropping system diversity to accruing soil carbon, the biological processes of how this happens, and outlines statistics on comparative system effectiveness.

### 2. Mechanisms of Soil Carbon Stabilization

To complete the knowledge on the ways different systems, store carbon, it is necessary to discuss the underlying processes of SOC formation and stabilization. Carbon penetrates the earth mainly by the process of photosynthesis, in which plants take the CO<sub>2</sub> in the atmosphere and convert it into biomass. This carbon gets to the soil pool in two major ways:

1. **Aboveground litter decomposition:** Crop residues left on the surface.
2. **Belowground inputs:** Root biomass decay and rhizodeposition (root exudates).

Recent studies have shown that belowground inputs play a disproportionately significant role in long term storage of carbon than the aboveground biomass. Root inputs would be more stabilized due to the fact that they are deposited directly into the soil matrix and it is also more likely to be deeper in the profile and therefore they decompose more slowly.

SOC can be found in a continuum of different levels of stability, which are usually divided into two functional pools:

- a) **Particulate Organic Matter (POM):** This is mostly a mixture of plant remains that have been partially decomposed. It is fairly easy to decompose (easily broken down by microbes) and has a quick (years to decades) turnover. It is extraordinarily sensitive to such management practices as tillage.
- b) **Mineral-Associated Organic Matter (MAOM):** This is a category of microscopic microbial products that are chemically bonded to soil mineral particles (clay and silt). This pool is far more stable, with turnover time spanning between decades and millennia.

Cropping systems also increase SCS not only by increasing the biomass, but also by improving the qualities of biomass and activating particular microbial pathways that favor the development of stable MAOM. The diverse plant communities offer a diverse diet to the microbiome living in the soil, which promotes a stronger microbial community that is in charge of the carbon transformation into stable forms.

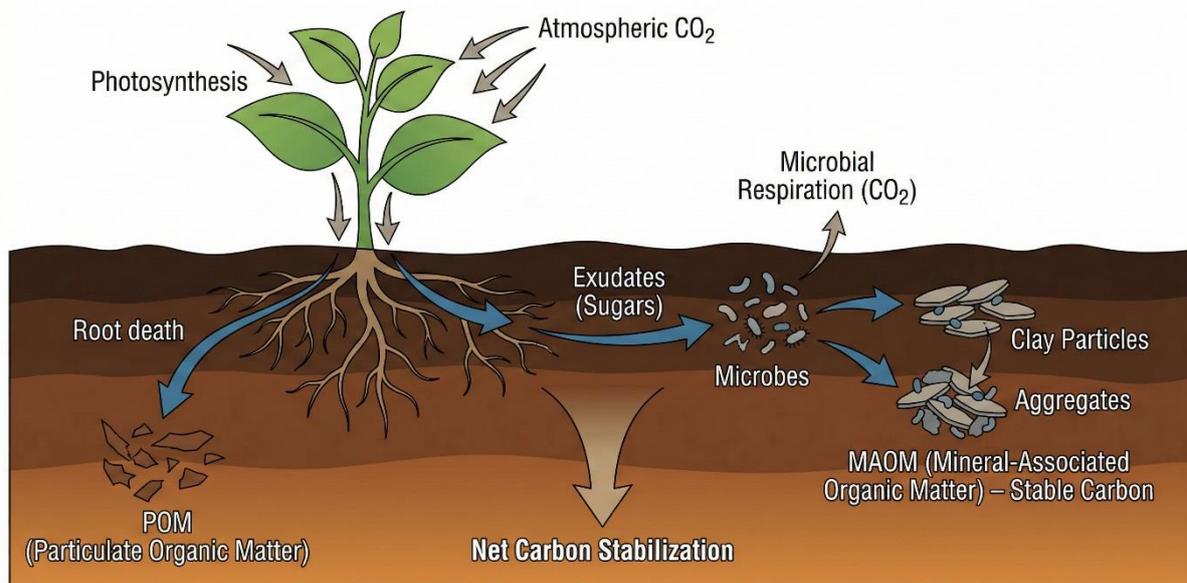


Figure 1. Conceptual Model of Soil Carbon Pathways

### 3. Diverse Cropping Systems and SOC Dynamics

Agricultural landscapes that have undergone simplification (into continuous monocultures, e.g. continuous maize or continuous wheat) are likely to cause a carbon deficit. Varied systems add time and space to the soil that reinstates the carbon balance in the soil.

#### 3.1. Complex Crop Rotations

Crops should be rotated and not planted in the same order to break any cycle of pests and enhance the use of nutrients. Carbon-wise, rotations with high-residue crops (such as maize) together with high-root-biomass crops (such as perennial grasses or legumes) are very efficient.

It is continually demonstrated that the incorporation of forage legumes (e.g., alfalfa, clover) into the rotation with annual grains enhances the soil SOC. Legumes are known to fix nitrogen in the atmosphere, so synthetic nitrogen fertilizer will not be required, and therefore, the production of synthetic N fertilizer is energy consuming. Moreover, the cereal roots contain a different ratio between carbon and nitrogen (C: N) than legume roots, which affects the rate at which microbes are processed. A reduced C:N ratio has the potential to speed up early decomposition, but might eventually result in increased microbial growth performance and increased stable MAOM.

The results of a meta-analysis in *Agriculture, Ecosystems and Environment* concluded that monoculture of one or more crops after baseline added to the soil carbon by an average of 3.6%, with much larger increases in the case of the introduction of perennials in the rotation phase.

#### 3.2. Cover Cropping and Continuous Living Roots

Continuous living roots in the soil throughout the year, perhaps, is the most important principle of SCS. In several traditional systems, soil is exposed to a period of 4-7 months between cash crop periods. In this fallow period, photosynthesis does not contribute to adding new carbon to the soil, but all microbes keep on respiring the existing SOC to produce CO<sub>2</sub>.

This carbon gap is filled with cover crops. They provide feedback to the carbon pump by expanding during the off-season.

- a) **Biomass Input:** They provide additional aboveground and belowground biomass.
- b) **Rhizosphere Priming:** Living roots release carbohydrates that help to increase the activity of the microbes even in the colder seasons.
- c) **Erosion Control:** On the surface of the soil, they prevent physical loss of the topsoil which harbours the highest concentration of SOC.

Cover crops have different levels of efficacy depending on the species and the climate. Deep-rooted crops such as cereal rye or tillage radishes are able to store carbon further down the soil profile, below the plough layer, and it becomes less vulnerable to oxidative losses.

### 3.3. Integrated Crop-Livestock Systems (ICLS)

Returning livestock to the cropland, which was typical historically but is now largely abandoned in modern industrial farming, is a synergistic solution to SOC with deep synergies. ICLS is generally a rotation of cash and pasture or grazing cover crop.

The processes of improved sequestration in ICLS are:

1. **Perennial Phases:** The pasture phases (e.g. 3 years of grass/legume mixture) enable the formation of deep root systems and extensive roots without disturbing the soil on an annual basis.
2. **Manure Inputs:** The grazing animals replenish the carbon and nutrients by depositing them directly on the soil in forms easily picked up by the soil microbes, leading to the creation of soil aggregates, which physically shield SOC against decomposition.
3. **Stimulated Root Growth:** The moderate pressure of grazing can provoke the plants to shed root biomass, injecting carbon into the soil, as the plant grows over the tissue on the soil.

Research shows that ICLS has the ability to produce much higher rates of sequestration than a purely cropping system, and may be up to 0.5 Mg C ha<sup>-1</sup>yr<sup>-1</sup>.

### 3.4. Agroforestry and Woody Perennials

The most promising SCS per unit area of agricultural systems is agroforestry, the deliberate incorporation of trees and shrubs into the systems of crop and animal farming. Trees serve the role of long-term storage of carbon by:

- a) **Deep Rooting:** Tree roots penetrate far deeper than annual crops, depositing carbon in deep soil horizons that are rarely disturbed.
- b) **Recalcitrant Carbon:** Woody biomass contains higher levels of lignin and other compounds that are resistant to decomposition, contributing to longer residence times in the soil.

Systems like alley cropping or silvopasture not only increase SOC but also sequester significant amounts of carbon in aboveground woody biomass.

## 4. Comparative Analysis and Synergies

It is crucial to recognize that cropping diversity does not operate in a vacuum. Its effectiveness is heavily moderated by tillage practices.<sup>17</sup> Intensive tillage fractures soil aggregates, exposing protected SOC to microbial attack and rapid oxidation. Therefore, diverse cropping systems yield the highest sequestration rates when combined with no-till (NT) or reduced-tillage management.

Table 1 presents a generalized comparison of potential SOC sequestration rates under different management scenarios based on meta-analyses across various temperate climatic zones.

**Table 1. Potential Annual Soil Organic Carbon Sequestration Rates by System**

Management System	System Description	Relative C Input	Soil Disturbance Level	Estimated SOC Sequestration Rate (Mg C ha <sup>-1</sup> yr <sup>-1</sup> )
<b>Baseline Conventional</b>	Continuous monoculture (e.g., Maize), intensive tillage, winter fallow.	Low	High	-0.2 to 0.1 (Net loss or static)
<b>Improved Rotation</b>	Corn-Soy-Wheat rotation, conventional tillage.	Medium	High	0.1 to 0.3
<b>Conservation Cropping</b>	Diversified rotation + No-Till (NT).	Medium	Low	0.3 to 0.6
<b>Cover Cropping System</b>	Annual crops + Winter cover crops + Reduced Till.	High	Medium/Low	0.4 to 0.8
<b>Integrated Crop-Livestock (ICLS)</b>	Rotation including perennial pasture phase + grazing + NT.	Very High	Very Low (during pasture phase)	0.6 to 1.2+
<b>Agroforestry</b>	Alley cropping or silvopasture.	Very High	Low	0.8 to 1.5+ (excluding aboveground biomass)

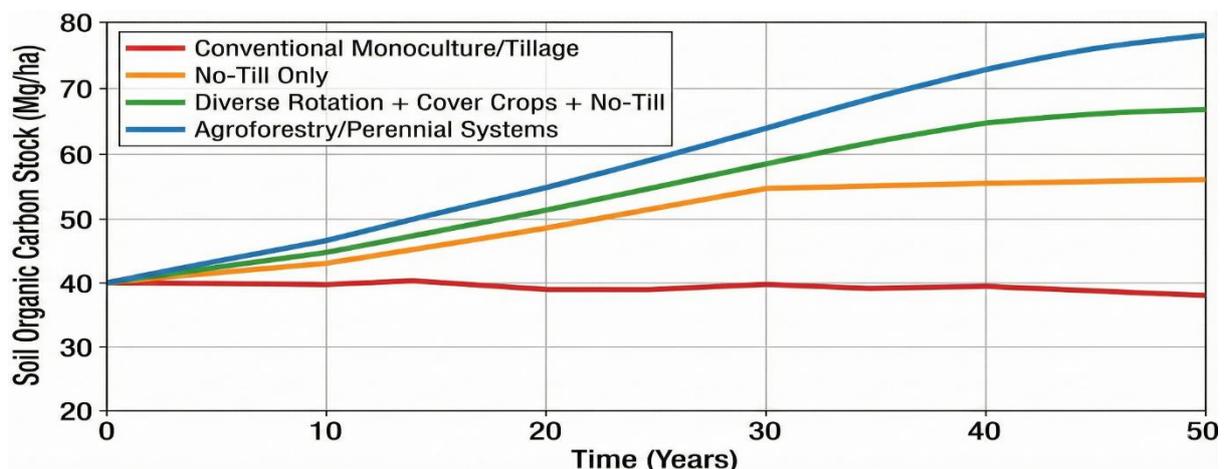


Figure 2. Long-term SOC Accumulation Trajectories

## 5. Challenges and Future Directions

While the scientific consensus supports diverse cropping systems for SCS, several challenges hinder widespread adoption and accurate verification.

- Verification and Measurement Protocols:** Accurately measuring changes in SOC is notoriously difficult due to high spatial variability within fields.<sup>18</sup> Furthermore, many protocols only measure the top 30 cm of soil, potentially missing significant sequestration (or losses) occurring in deeper profiles, particularly in agroforestry or deep-rooted perennial systems. Standardized, cost-effective monitoring, reporting, and verification (MRV) platforms are essential for emerging carbon markets.
- Saturation Limits:** Soils have a finite capacity to store carbon, determined by texture (clay soils store more than sandy soils) and climate. Sequestration rates are highest when soils are depleted and slow down as they approach saturation equilibrium. Therefore, SCS is a long-term strategy, and rates achieved in the first decade of transition will not be sustained indefinitely.
- Economic and Operational Barriers:** Transitioning from conventional monocultures to diverse systems is knowledge-intensive and often requires new equipment (e.g., no-till drills) or infrastructure (e.g., fencing for livestock). The immediate economic benefits may not offset transition costs, emphasizing the need for policy support or ecosystem service payments to bridge the gap until soil health improvements translate into agronomic financial gains.

## 6. Conclusion

The adoption of diverse cropping systems is a fundamental strategy for transitioning global agriculture from a net source to a net sink of atmospheric carbon. By mimicking natural ecosystem processes, ensuring continuous living roots, maximizing biomass inputs through varied plant functional groups, and minimizing soil disturbance farmers can enhance the formation of stable mineral-associated organic matter.

The evidence is clear: combinations of practices, such as integrating cover crops and livestock into no-till rotations, yield synergistic benefits that exceed individual interventions. While challenges in measurement and economic implementation remain, prioritizing soil carbon sequestration through crop diversity offers a no-regrets strategy. It mitigates climate change while simultaneously enhancing agricultural resilience, water quality, and long-term food security. The future of sustainable agriculture lies in embracing the complexity of the soil system, using diversity as the primary tool for regeneration.

## References

- Bai, X., Huang, Y., Ren, W., Coyne, M., Jacinthe, P.-A., Tao, B., Hui, D., Yang, J., & Matocha, C. (2019). Responses of soil carbon sequestration to climate-smart agriculture practices: A meta-analysis. *Global Change Biology*, 25(8), 2591–2606. <https://doi.org/10.1111/gcb.14658>
- Lal, R. (2020). Soil organic matter content and crop yield. *Journal of Soil and Water Conservation*, 75(2), 27A–32A. <https://doi.org/10.2489/jswc.75.2.27a>

- McDaniel, M. D., Tiemann, L. K., & Grandy, A. S. (2014). Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. *Ecological Applications*, 24(3), 560–570. <https://doi.org/10.1890/13-0616.1>
- Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G. P., & Smith, P. (2016). Climate-smart soils. *Nature*, 532(7597), 49–57. <https://doi.org/10.1038/nature17174>
- Sanderman, J., Hengl, T., & Fiske, G. J. (2017). Soil carbon debt of 12,000 years of human land use. *Proceedings of the National Academy of Sciences*, 114(36), 9575–9580. <https://doi.org/10.1073/pnas.1706103114>
- Tiemann, L. K., Grandy, A. S., Atkinson, E. E., Marin-Spiotta, E., & McDaniel, M. D. (2015). Crop rotational diversity enhances belowground communities and functions in an agroecosystem. *Ecology Letters*, 18(8), 761–771. <https://doi.org/10.1111/ele.12453>



## Traditional Versus Modern Fishing Systems: A Comparative Assessment of Efficiency and Sustainability



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### 1. Introduction

In the Anthropocene, the world oceans have moved beyond being perceived as an apparently boundless frontier to one of a resource system that is very limited and heavily utilized. As per the Food and Agriculture Organization (FAO), aquatic foods contribute a significant percentage of animal protein to billions of people all over the world. However, the ways of extracting this resource are very different. The world fishing industry is divided into two separates, yet not independent spheres the traditional (which is often called the small-scale or artisanal) and the modern one.

In the past, the policies governing the development of fisheries adopted in the post-Second World War were led by modernisation of the fleet, where producers were urged to adopt capital intensive technology such as maximising the biomass harvest by the use of technology that was capital intensive. This paradigm based on industrial agriculture equated technological sophistication to progress. Nonetheless, the empirical evidence of the past decades on the stock collapses, the loss of habitat, and even social displacement has forced the critical re-assessment of this paradigm.

### 2. Defining the Dichotomy

In order to bring about analytical rigour, it is necessary to put the operational parameters of the systems under examination into focus. Although there is a continuum, there are definable characteristics between the modal types.

- a) **Traditional Fishing Systems:** They are mostly characterised by low input of capital, high labour intensity, and dependence on various and typically passive forms of gear (e.g., traps, hooks, gillnets). As a rule, operations are close (littoral areas), and boats are of various sizes, starting with unmotorised canoes and boats with outboard motors (<12 m). The catch is mainly to be sold in local or household consumption, which has direct household food security.
- b) **Modern Fishing Systems:** They are also capital-intensive, and employ mechanised boats (>12m, often much larger e.g. supertrawler) with state-of-the-art electronic navigation, fish-finding systems (sonar, satellite positioning) and active, non-selective equipment (e.g. bottom trawls, purse seiners). They are deployed in remote waters and high oceans to access single-species biomass to provide to the global supply chains or reduce by-catch fisheries (fishmeal and oil).

Table 1 summarizes these structural differences, providing a baseline for the subsequent comparative analysis.

**Table 1. Structural Characteristics of Traditional vs. Modern Fishing Systems**

Feature	Traditional (Artisanal) System	Modern (Industrial) System
<b>Capital Intensity</b>	Low (local materials, small engines)	High (mechanized vessels, electronics)
<b>Labor Intensity</b>	High (manual labour dominant)	Low (mechanized/automated processes)
<b>Vessel Size</b>	Typically, <12m; often undecked	Typically, >12m to >100m; decked factory ships
<b>Fishing Zone</b>	Coastal, littoral, near-shore	Offshore, Exclusive Economic Zones (EEZ), High Seas
<b>Gear Type</b>	Diverse, often passive and selective (traps, hook-and-line, small nets)	Monoculture, active and non-selective (bottom trawls, purse seines, longlines)
<b>Market Orientation</b>	Subsistence, local markets, domestic	Global export markets, industrial processing (fishmeal)
<b>Ownership</b>	Household or community-based	Corporate or state enterprise

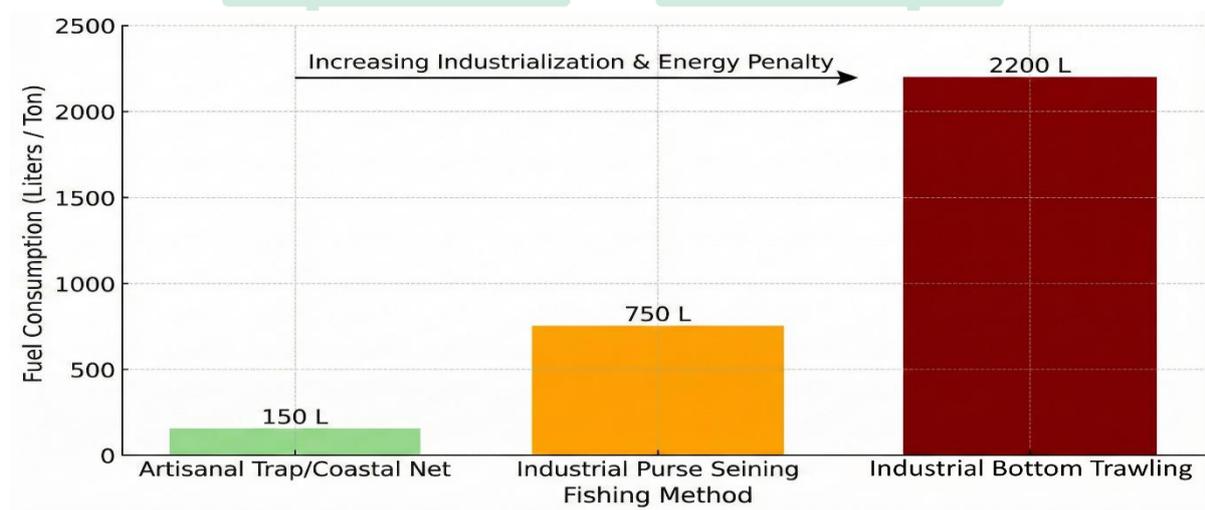
### 3. Comparative Assessment: The Efficiency Paradox

The efficiency of fisheries is a multi-dimensional construct. When it is stringently defined as gross tonnage extracted per vessel per day, then, by far, industrial systems are excellent. Nevertheless, to examine the issue in more depth, one should speak about the economic efficiency and, above all, the energy efficiency.

#### 3.1 Technological and Economic Efficiency

The contemporary systems use fossil fuels and the latest technology to overcome the natural limits. Industrial fleets can find the locations of biomass concentrations precisely because of the application of sonar, GPS, and seabed mapping, which results in significant increases in Catch Per Unit Effort (CPUE) in the short-term. Even one super-trawler is capable of catching and processing hundreds of tons of fish in a single day, an amount that cannot be achieved by an artisanal fleet over a whole season.

However, this gross output conceals economic weak points. Subsidies that support industrial fishing are estimated at \$35 billion annually across the world, most of which is supporting the overcapacity (Sumaila et al., 2019). Many industrial operations at high seas would be economically unsustainable without capacity-enhancing subsidies especially on the fuel. Conversely, the traditional systems, although with lesser overall revenue, are also characterized by less operating cost and greater local economic multiplier, keeping the value within the coastal communities instead of draining it to the external corporations or debt repayment.



**Figure 1. Fuel consumption (Litres) per ton of fish landed**

#### 3.2 Energy Return on Investment (EROI)

The last but arguably the most important metric is energy efficiency. Fishing is nothing more than the investment of fossil-fuel energy to extract the food energy. On this front, industrial fishing is disastrously inefficient. The trawling of modern society is one of the most energy-consuming ways of food production in the world. The need to carry hefty equipment over the bottom of the ocean, the need to energize the refrigeration and processing

factories on-board, not to mention the distance that is required to cover large distances in the ocean, requires a lot of fuel.

On the other hand, the traditional fisheries, especially the ones that use passive gears or wind/manual power, show significantly higher Energy Return on Investment (EROI). Research has shown that some industrial shrimp trawling activities use tens of thousands of litres of fuel per ton of edible product, but some artisanal fisheries will generate the same protein with a fraction of the fuel.

#### 4. Comparative Assessment: Sustainability Dimensions

The concept of sustainability is examined in this case in both ecological and socio-economic terms and the real costs of industrial efficiency are revealed.

##### 4.1 Ecological Footprint

The ecological impact of fishing systems varies not just in scale, but in kind.

- a) **Bycatch and Discards:** Industrial equipment is infamously indiscriminate. The bottom trawling and extensive longlining processes produce very high bycatch -unintentional catches of non-target organisms, such as endangered sea mammals, seabirds, turtles, and young fish. Even in the present day, when some modern fleets use bycatch -reduction devices (BRDs), the vastness of operations makes the volume of discarded marine life absolutely huge. The lower bycatch rates are usually reported in traditional systems, which use more target-specific equipment (e.g., traps, pole-and-line), have close local ecological understanding, and use more intimate ecological knowledge. Besides, artisanal bycatch is often used in local consumption instead of disposal.
- b) **Habitat Destruction:** This is probably the most drastic differentiator. Industrial bottom trawling, or dragging heavy nets, doors, and chains along the seabed, is effectively a clear-cut of the benthic ecosystems of coral reefs, seagrass beds and sponge gardens. This kills nursery areas that are critical in the replenishment of stocks in the long run. The water column has a huge presence of traditional gears or limited contact with the benthic, thus maintaining the integrity of the habitat.

##### 4.2 Socio-Economic Resilience and Equity

Human aspect of fisheries takes a key position in the discourse of sustainability.

- a) **Employment and Livelihoods:** It is evident that there is an inverse relationship of a deep nature between the capital intensity and the labour intensity. Industrialisation replaces labour with capital (fuel, machinery). Although industrial fisheries contribute most to the tonnes of global capture, the artisanal fishing sector provides over 90 per cent of the total capture fishers and fish workers in the world, almost fifty per cent of whom are women significantly engaged in processing and marketing (FAO, 2022). The transfer of quotas in the hands of industries always results in the loss of a huge number of jobs and the destruction of the community of the coast.
- b) **Food Security:** The conventional fisheries are the main staple of hundreds of millions of inhabitants of developing countries concerning protein in their diet. Their catch is delivered straight into local food systems. In comparison, a good deal of industrial catch usually goes to non-food applications (fishmeal to agriculture/aquaculture) or to high-value export markets accessible by local inhabitants. Industrial fishing thus increases the world supply but it may not necessarily bring increased security to the local area.

Table 2 summarizes the sustainability trade-offs.

**Table 2. Comparative Sustainability Metrics**

Metric	Traditional (Artisanal) System	Modern (Industrial) System
<b>Selectivity (Targeting)</b>	High (species and size specific)	Low (high volumes of non-target biomass)
<b>Discard Rates</b>	Low (most catch utilized locally)	High (regulatory or economic discards)
<b>Benthic Impact</b>	Minimal to Negligible	Severe (especially bottom trawling)
<b>CO2 Emissions per kg catch</b>	Low	High to Very High
<b>Jobs per landed ton</b>	Very High	Very Low
<b>Contribution to local food security</b>	Direct and Critical	Indirect (often diverted to exports/feed)

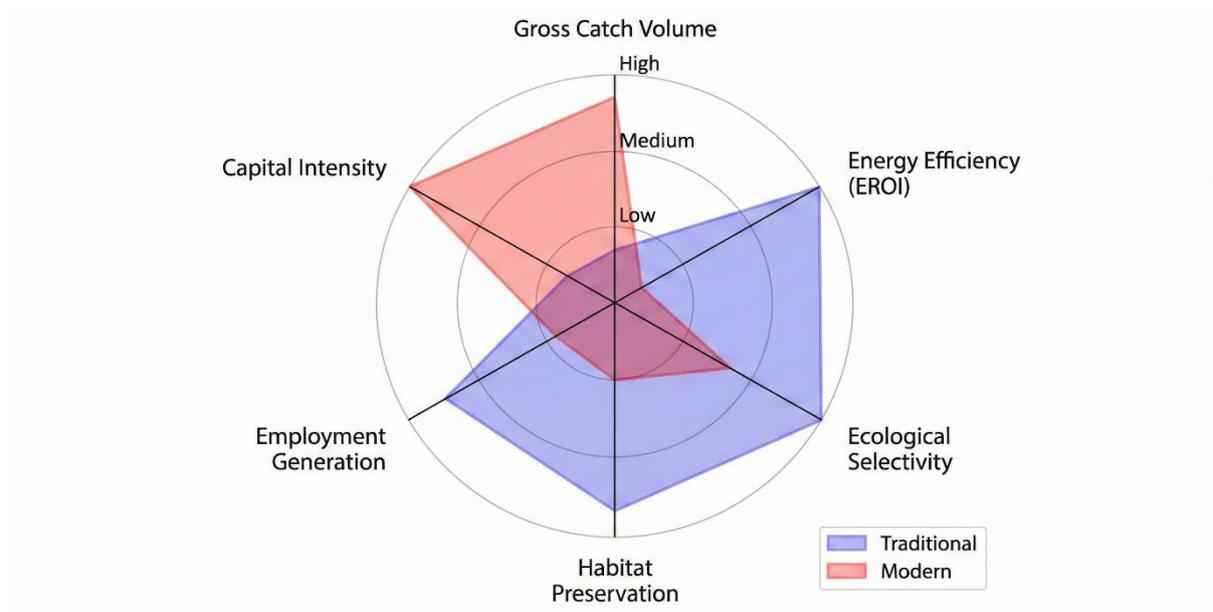


Figure 2. Multidimensional trade-offs in fishing system

## 5. Discussion: The Fallacy of Unilinear Modernization

The comparative evidence suggests a critical misalignment in global fisheries policy. For decades, the implicit goal has been the modernization of artisanal fleets, viewing them as backward vestiges waiting to be industrialized. This analysis suggests this view is fundamentally flawed.

The industrial model achieves high productive efficiency through ecological deficit spending drawing down natural capital (stocks and habitats) and relying on subsidized fossil energy. It is a system designed for rapid depletion. It faces a Red Queen scenario: as stocks decline due to overfishing, fleets must expend more energy and utilize increasingly sophisticated technology just to maintain the same catch levels, further accelerating collapse.

The traditional model, conversely, represents a system of ecological adaptation. Its limitations in power and range have historically acted as de facto conservation mechanisms, preventing the complete annihilation of offshore stocks or deep-sea habitats. While artisanal fisheries are not immune to overfishing particularly given population pressures and creeping technological improvements their fundamental operational structure is more aligned with long-term ecological cycles.

Therefore, the challenge facing agricultural and marine policy is not how to replace traditional systems with modern ones, but rather:

- a) How to restrain the destructive excesses of the industrial sector.
- b) How to enhance the viability of the artisanal sector without replicating the ecological failures of industrialization.

This points toward a hybrid pathway. This might involve equipping artisanal fishers with modern safety equipment, GPS for navigation, and cold-storage facilities to reduce post-harvest losses, while strictly maintaining bans on destructive gear types and protecting exclusive coastal zones from industrial incursion.

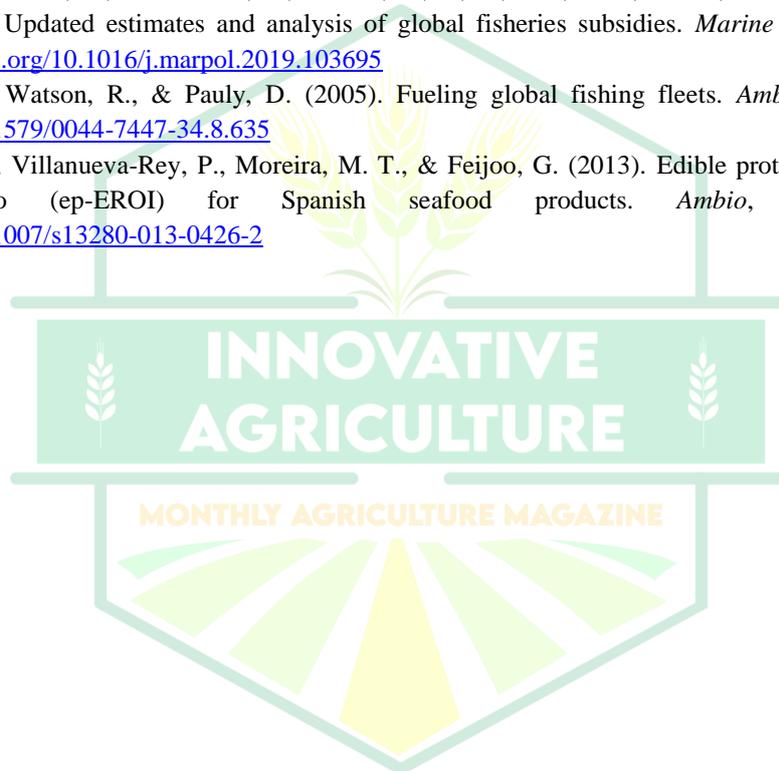
## 6. Conclusion

The comparative assessment of traditional versus modern fishing systems reveals a stark choice between immediate, high-volume extraction and long-term socio-ecological resilience. The industrial system, while a technological marvel of production, is energetically inefficient, ecologically destructive, and socially concentrating. The traditional system, while producing less gross tonnage, is the backbone of global coastal employment, a pillar of local food security, and operates with a significantly lighter ecological footprint.

Achieving sustainable development goals requires a paradigm shift that stops viewing industrialization as the inevitable end-state of fisheries development. Policy frameworks must recognize the superior sustainability metrics of artisanal systems and prioritize their protection through secure tenure rights and the elimination of harmful industrial subsidies. Future global food security depends not on building larger trawlers, but on nurturing the resilient, energy-efficient systems that have sustained coastal populations for millennia.

#### References

- Amoroso, R. O., Pitcher, C. R., Rijnsdorp, A. D., McConnaughey, ... Góngora, M. E. (2018). Bottom trawl fishing footprints on the world's continental shelves. *Proceedings of the National Academy of Sciences*, 115(43), E10275–E10282. <https://doi.org/10.1073/pnas.1802379115>
- FAO. (2022). *The state of world fisheries and aquaculture 2022: Towards blue transformation*. Food and Agriculture Organization of the United Nations. <https://doi.org/10.4060/cc0461en>
- Pauly, D., & Zeller, D. (2016). Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nature Communications*, 7(1), Article 10244. <https://doi.org/10.1038/ncomms10244>
- Sumaila, U. R., Ebrahim, N., Schuhbauer, A., Skerritt, D., Li, Y., Kim, H. S., Mallin, T. G., Lam, V. W. Y., & Pauly, D. (2019). Updated estimates and analysis of global fisheries subsidies. *Marine Policy*, 109, Article 103695. <https://doi.org/10.1016/j.marpol.2019.103695>
- Tyedmers, P. H., Watson, R., & Pauly, D. (2005). Fueling global fishing fleets. *Ambio*, 34(8), 635–638. <https://doi.org/10.1579/0044-7447-34.8.635>
- Vázquez-Rowe, I., Villanueva-Rey, P., Moreira, M. T., & Feijoo, G. (2013). Edible protein energy return on investment ratio (ep-EROI) for Spanish seafood products. *Ambio*, 43(3), 381–394. <https://doi.org/10.1007/s13280-013-0426-2>



## Soil Health Card Scheme – Strengthening India’s Agricultural Foundation



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### Introduction

The Soil Health Card (SHC) Scheme is one of the flagship agricultural initiatives of the Government of India aimed at improving soil quality and enhancing crop productivity by providing farmers with detailed information on the health of their soil and tailored nutrient recommendations. It was officially launched on 19 February 2015 by Prime Minister Narendra Modi in Suratgarh, Rajasthan under the Ministry of Agriculture & Farmers Welfare with the slogan “Swasth Dharaa, Khet Haraa” (Healthy Earth, Green Farm). The scheme represents a significant step toward scientific and sustainable agricultural practices by enabling data-driven decisions for fertilizer use and soil nutrient management.

### Objectives of the Soil Health Card Scheme

The primary goals of the SHC scheme, as outlined by the Government of India, are:

1. Issue Soil Health Cards to all farmers periodically (every three years) to help them understand nutrient deficiencies in their soil and improve fertiliser practices.
2. Strengthen Soil Testing Laboratories (STLs) by improving infrastructure, building capacity, and involving agriculture students and research organisations
3. Diagnose soil fertility constraints through standardised sampling and testing procedures across all states.
4. Promote soil test-based nutrient management to enhance efficient use of fertilisers.
5. Provide financial and technical support to farmers for corrective measures to address soil nutrient imbalances.
6. Build capacity of agricultural officials and progressive farmers to promote nutrient management practices at the grassroots level.

### What Is a Soil Health Card?

A Soil Health Card is a document issued to farmers that provides a detailed assessment of soil health based on scientific testing. It includes the soil’s status with respect to twelve key parameters including macro-nutrients (Nitrogen, Phosphorus, Potassium), secondary nutrients (Sulphur), micro-nutrients (Zinc, Iron, Copper, Manganese, Boron), and physical parameters (pH, Electrical Conductivity, Organic Carbon).

Based on this assessment, the card also contains crop-wise fertilizer recommendations and soil amendment suggestions to help farmers enhance soil fertility and crop performance.

### How the Scheme Works

The implementation of the SHC Scheme follows a structured and technology-enabled process:

1. **Sample Collection:** Soil samples are systematically collected from farmers’ fields using standard grid-based sampling methods.
2. **Laboratory Testing:** Samples are analysed in accredited Soil Testing Laboratories—static, mobile, or mini labs.
3. **Data Recording & Portal Upload:** Test results are uploaded to the national Soil Health Card portal developed by the National Informatics Centre (NIC), providing uniform reporting and access.
4. **Card Generation & Distribution:** Based on the test results, personalised Soil Health Cards are generated in local languages and issued to farmers.
5. **Advisory Services:** Farmers are guided on optimal fertilizer use and soil management practices to maintain long-term soil health.

## Key Features of the Scheme

The SHC Scheme is characterised by the following key features:

- **Uniform Reporting:** A standardised Soil Health Card format is used across the country, available in multiple languages.
- **Digital Connectivity:** The portal allows tracking of soil tests and card status online.
- **Technology Integration:** GIS mapping is used to geo-tag soil samples and create soil fertility maps for districts/regions.
- **Periodic Updates:** Cards are updated in each cycle to monitor changes in soil health over time.

## Benefits for Farmers and Agriculture

The Soil Health Card Scheme offers wide-ranging benefits:

### 1. Balanced Fertilizer Use

Farmers receive scientific recommendations on the exact type and quantity of fertilizers to use, minimising excess application and input costs.

### 2. Increased Productivity

Using soil nutrient data and tailored advice helps in boosting crop yields and improving farm profitability.

### 3. Cost Reduction

Optimised fertilizer use leads to reduction in unnecessary expenditure on inputs.

### 4. Sustainable Soil Health

Encourages adoption of balanced and integrated nutrient management practices key to long-term soil fertility and ecological sustainability.

### 5. Better Agricultural Decisions

Farmers get clarity on what crops are best suited for their soil type and growing conditions, improving planning and outcomes.

## Achievements and Progress

Since its launch, the SHC Scheme has made significant progress:

- Distribution of over 25 crore Soil Health Cards based on the testing of hundreds of millions of soil samples.
- Establishment and strengthening of thousands of soil testing laboratories across the country.
- Extensive capacity building efforts including farmer training programmes and agricultural demonstrations.

The SHC Scheme has also been recently integrated as a component under the Rashtriya Krishi Vikas Yojana (RKVY) from 2022-23 to ensure broader support and holistic agricultural development.

## Challenges and Future Directions

While the Soil Health Card Scheme has been widely beneficial, some challenges continue:

- Limited awareness among farmers in some regions about the full potential of SHCs.
- Uneven laboratory infrastructure, especially in remote areas.
- Need for comprehensive soil quality indicators beyond chemical parameters to include biological and physical assessments for holistic soil health.

Addressing these challenges through enhanced outreach, improved technology, and broader soil science integration can further strengthen the scheme's impact.

## Conclusion

The Soil Health Card Scheme, spearheaded by the Government of India, has become a pivotal programme in transforming agricultural practices by empowering farmers with critical soil nutrition data and actionable insights. By promoting judicious use of fertilizers, improving soil fertility, and enabling sustainable farming, the SHC Scheme continues to support rural livelihoods and contribute to the nation's food security goals.

## Making Women Farmers Visible: Development of an Integrated National Information System for Women in Agriculture “A Review with Special Reference to Maharashtra and AICRP-Women”



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### Abstract

Women play a pivotal yet inadequately recognized role in Indian agriculture, contributing significantly to crop production, livestock management, allied enterprises, and household food security. Despite their growing participation, women remain largely invisible in official agricultural statistics due to fragmented, gender-neutral data systems. Recent evidence indicates a steady feminisation of agriculture, particularly in states like Maharashtra, where male out-migration and agrarian distress have intensified women’s engagement in farming. This review critically examines the need for an Integrated National Information System for Women in Agriculture (INIS–WIA) as a strategic intervention to address data gaps, strengthen gender-responsive policymaking, and enhance women’s empowerment. Drawing upon recent national data, policy documents, and research outputs particularly from AICRP-Women in Agriculture (AICRP-WIA) and Vasantrao Naik Marathwada Krushi Vidyapeeth (VNMKV), Parbhani the article synthesizes existing evidence, identifies systemic challenges, and proposes a comprehensive framework for an integrated information system. The review concludes that a robust, gender-disaggregated digital information system is essential for inclusive, sustainable, and equitable agricultural development in India.

**Keywords:** Women in Agriculture, Gender-disaggregated data, Information systems, AICRP–WIA, Maharashtra, Digital agriculture

### 1. Introduction

Indian agriculture has historically depended on women’s labour, knowledge, and managerial skills, yet their contributions have remained largely unacknowledged in formal policy and planning processes. Women are actively involved in almost all agricultural operations, including sowing, transplanting, weeding, harvesting, post-harvest processing, livestock care, and value addition activities. According to the Periodic Labour Force Survey (PLFS 2023-24), women constitute approximately 64.4 per cent of the agricultural workforce in India, with rural women’s participation in agriculture reaching nearly 76.9 per cent (MoSPI, 2024). These figures highlight a significant structural shift in the agricultural labour economy.



The increasing feminisation of agriculture is particularly evident in rainfed and drought-prone regions such as Marathwada in Maharashtra, where male migration to urban centres has intensified women’s responsibility for farm management (Deshpande & Kulkarni, 2022). However, increased participation has not translated into

proportional gains in access to land, credit, technology, or institutional support. Women continue to face systemic disadvantages, including limited land ownership, lower access to extension services, and minimal representation in farmer institutions (Agarwal, 2019).

A critical reason for this persistent inequity is the absence of a comprehensive, integrated, and gender-disaggregated information system that captures women’s actual roles, contributions, and constraints. Existing datasets remain fragmented, sector-specific, and often gender-neutral, leading to policy blind spots. This review argues that the development of an Integrated National Information System for Women in Agriculture (INIS-WIA) is a policy imperative, particularly for states like Maharashtra, where women’s agricultural participation is high and institutional mechanisms such as AICRP-WIA and SAUs like VNMKV, Parbhani, are well positioned to operationalize such a system.

**2. Feminisation of Agriculture: Evidence and Implications**

The feminisation of agriculture refers to the increasing participation of women in agricultural labour and decision-making due to socio-economic transformations such as male out-migration, declining profitability of farming, and limited rural employment opportunities (Lastarria-Cornhiel, 2006). Recent national data show a consistent rise in female labour force participation in agriculture, while male participation has declined (MoSPI, 2024).

In Maharashtra, studies indicate that women contribute between 60-70 per cent of total agricultural labour, particularly in subsistence farming, horticulture, and livestock-based livelihoods (Patil et al., 2021). Despite this, women’s ownership of operational landholdings remains below 15 per cent at the national level and is even lower in certain regions of Maharashtra (Agricultural Census, 2015-16).

The implications of feminisation without empowerment are profound. Women farmers often remain unpaid family workers, lack access to institutional credit due to absence of land titles, and are excluded from decision-making platforms such as cooperatives and FPOs (Agarwal, 2019). These structural barriers necessitate a data-driven approach to recognize and address gender disparities in agriculture.

**3. Status of Data Systems Related to Women in Agriculture**

India has several large-scale data systems related to agriculture and labour, including the Agricultural Census, PLFS, e-Shram portal, and scheme-level Management Information Systems. While these datasets provide valuable insights, they suffer from critical limitations. First, most systems do not adequately integrate gender-disaggregated variables across sectors. Second, data are often collected in silos, making cross-sectoral analysis difficult (Rao & Kelleher, 2020).



For instance, the Agricultural Census focuses primarily on landholdings and operational holdings but does not capture unpaid labour or intra-household decision-making. The PLFS provides labour participation data but lacks information on productivity, technology use, or access to services. The e-Shram portal has registered over 8 crore women workers, but its integration with agricultural development schemes remains limited (Ministry of Labour & Employment, 2024).

At the state level, Maharashtra has implemented several women-centric programmes under agriculture and rural development, yet the absence of an integrated monitoring framework hampers impact assessment. This fragmentation underscores the need for an integrated national and state-level information system focused specifically on women in agriculture.

#### 4. Conceptual Framework of an Integrated National Information System for Women in Agriculture

An Integrated National Information System for Women in Agriculture should be conceptualized as a multi-dimensional, digital platform that consolidates data from diverse sources into a unified framework. The system should encompass demographic, socio-economic, institutional, technological, and spatial dimensions of women's agricultural engagement.

The core objective of INIS-WIA would be to generate reliable, gender-disaggregated evidence to support policy formulation, programme implementation, monitoring, and evaluation. Such a system should be designed to capture not only participation but also access, control, outcomes, and impacts related to women in agriculture (Kabeer, 1999).

#### 5. Key Components of INIS-WIA

##### 5.1 Gender-Disaggregated Farmer Database

The foundation of the system should be a comprehensive database capturing women farmers' demographic characteristics, educational status, caste, land ownership, type of agricultural engagement, and livelihood diversification. This would allow identification of region-specific challenges, particularly in agro-climatic zones such as Marathwada and Vidarbha.

##### 5.2 Scheme and Policy Integration

The system should integrate data from women-centric schemes such as MKSP, DAY-NRLM, PMFBY, SMAM, and state-level initiatives. Linking beneficiary data with outcomes would enable assessment of scheme effectiveness and resource allocation efficiency (Government of India, 2022).

##### 5.3 Technology and Extension Module

Research indicates that women have lower access to extension services and mechanization due to socio-cultural and economic constraints (Meena et al., 2020). Documenting women's access to training, demonstrations, and women-friendly tools would strengthen extension planning and technology refinement.

##### 5.4 Research, Impact, and Knowledge Repository

A national repository of research outputs, success stories, and impact assessments generated by ICAR institutes, AICRP-WIA centres, and SAUs would enhance knowledge dissemination. VNMKV, Parbhani, with its long-standing involvement in AICRP-WIA, can play a pivotal role in documenting women-led innovations and livelihood models in Maharashtra.



#### 6. Role of AICRP-Women in Agriculture

The All India Coordinated Research Project on Women in Agriculture has generated extensive empirical evidence on women's roles, drudgery reduction technologies, and empowerment outcomes. However, much of this knowledge remains underutilized due to limited digital integration (ICAR, 2021).

AICRP–WIA centres, including VNMKV, Parbhani, are uniquely positioned to serve as nodal agencies for data collection, validation, and dissemination under INIS-WIA. Standardized indicators, formats, and reporting mechanisms developed under AICRP–WIA can form the backbone of the national information system.

### 7. Maharashtra-Specific Context and Relevance

Maharashtra presents a compelling case for localized implementation of INIS–WIA. The state is characterized by diverse agro-ecological zones, high incidence of drought, and significant male migration. Women play a central role in farming systems, particularly in rainfed agriculture, livestock, and allied enterprises (Patil et al., 2021).

Institutions such as VNMKV, Parbhani, with strong extension networks and research capacity, can facilitate state-level integration of women-specific agricultural data. Linking SHGs, FPOs, KVKs, and AICRP–WIA activities into a unified digital platform would significantly enhance planning and impact assessment.

### 8. Technological Architecture and Governance

The INIS-WIA should be web-based, mobile-enabled, and multilingual to ensure accessibility. GIS-enabled dashboards would facilitate spatial analysis of women’s participation and scheme coverage. Interoperability with existing platforms such as e-Shram and agricultural census databases is essential to avoid duplication and ensure data consistency.

Data governance frameworks must prioritize privacy, consent, and ethical use of information, in line with emerging data protection norms (OECD, 2021).

### 9. Challenges and Way Forward

Key challenges include data standardization, inter-departmental coordination, digital literacy gaps among women, and institutional capacity constraints. Addressing these challenges requires sustained investment in capacity building, institutional collaboration, and participatory approaches involving women farmers themselves.

### 10. Conclusion

The development of an Integrated National Information System for Women in Agriculture is a transformative step towards inclusive and gender-responsive agricultural development. By making women visible in data and policy frameworks, the system can strengthen women’s empowerment, improve programme effectiveness, and contribute to sustainable agricultural growth. For Maharashtra, and particularly for institutions like AICRP-WIA and VNMKV, Parbhani, INIS-WIA offers a strategic opportunity to lead nationally in evidence-based gender mainstreaming in agriculture.



**References:**

1. Agarwal, B. (2019). *Gender equality, food security and the sustainable development goals*. *Current Opinion in Environmental Sustainability*, 34, 26–32.
2. Deshpande, S., & Kulkarni, P. (2022). Feminisation of agriculture in Maharashtra. *Indian Journal of Gender Studies*, 29(2), 213–229.
3. Government of India. (2022). *Guidelines on Mahila Kisan Sashaktikaran Pariyojana*. Ministry of Rural Development.
4. ICAR. (2021). *AICRP–Women in Agriculture: Progress Report*. New Delhi.
5. Kabeer, N. (1999). Resources, agency, achievements. *Development and Change*, 30(3), 435–464.
6. Meena, M. S., et al. (2020). Gender issues in agricultural extension. *Agricultural Extension Review*, 32(4), 15–22.
7. MoSPI. (2024). *Periodic Labour Force Survey Annual Report*. Government of India.
8. Patil, B. L., et al. (2021). Women’s role in rainfed agriculture in Maharashtra. *Indian Journal of Agricultural Economics*, 76(3), 345–360.



# Vermicomposting for Sustainable Indian Agriculture: Scientific Principles and Field Applications



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## 1. Introduction

Indian agriculture is facing multiple challenges such as declining soil organic carbon, nutrient imbalances, reduced factor productivity, increased cost of cultivation, and environmental concerns arising from indiscriminate use of chemical fertilizers. ICAR has consistently emphasized the need for Integrated Nutrient Management (INM) and recycling of on-farm organic resources to restore soil fertility and ensure long-term sustainability.



Vermicomposting represents a low-cost, decentralized, and eco-friendly technology for converting biodegradable organic waste into a nutrient-rich organic manure using earthworms.

## 2. Scientific Basis of Vermicomposting

### 2.1 Role of Earthworms

Earthworms are described as ecosystem engineers that improve soil biological activity and nutrient cycling. In vermicomposting, earthworms ingest organic substrates and fragment them mechanically in their gizzard. The material then undergoes biochemical transformation through enzymes and gut microflora before being excreted as casts.

### 2.2 Microbial Interactions

Vermicomposting is a synergistic process involving earthworms and microorganisms such as bacteria, fungi, and actinomycetes. Earthworm activity enhances microbial colonization, accelerates mineralization, and increases the availability of nutrients in plant-usable forms.

### 2.3 Difference Between Compost and Vermicompost

Unlike conventional composting, which is thermophilic, vermicomposting is a mesophilic process resulting in:

- Faster stabilization of organic matter
- Higher microbial activity
- Better humification
- Superior nutrient availability

## 3. Earthworm Species Recommended by ICAR

ICAR recommends epigeic earthworms due to their surface-feeding habit and rapid reproduction.

### 3.1 *Eisenia fetida*

- High tolerance to organic waste
- Suitable for controlled conditions
- Widely used in institutional units

### 3.2 *Eudrilus eugeniae*

- High biomass production

- Efficient waste conversion
- Performs well in warm climates

### 3.3 *Perionyx excavatus*

- Indigenous species
- Highly adapted to Indian conditions
- Faster multiplication rate

ICAR strongly advises avoiding deep-burrowing (anecic) species for vermicomposting.

## 4. Raw Materials and Substrate Preparation

### 4.1 Suitable Organic Wastes

- Crop residues (paddy straw, wheat straw, maize stover)
- Weed biomass and green manure crops
- Cattle dung (most preferred)
- Sheep, goat, and poultry manure (after pre-treatment)
- Sugar industry waste (press mud after partial composting)
- Fruit and vegetable market waste

### 4.2 Pre-Decomposition (Pre-Composting)

It recommends partial decomposition for 10–15 days to:

- Reduce heat
- Eliminate toxic gases
- Improve palatability for worms

## 5. Vermicomposting Methodology

### 5.1 Site and Infrastructure

- Cool, shaded, and ventilated location
- Cemented pits, brick-lined tanks, or raised beds
- Protection from rain, direct sun, and predators

### 5.2 Bed Preparation

- Base layer: Brick pieces/sand for drainage
- Middle layer: Partially decomposed organic waste mixed with dung (3:1)
- Top layer: Thin dung slurry

### 5.3 Earthworm Inoculation

- Rate: 1–1.5 kg worms per 100 kg waste
- Even distribution on bed surface

### 5.4 Moisture and Temperature Regulation

- Moisture: 60–70%
- Temperature: 20–30°C
- Watering through gentle sprinkling

### 5.5 Maintenance

- Avoid turning
- Control ants using lime or ash
- Prevent water stagnation

### 5.6 Harvesting and Storage

- Harvest after 60–70 days
- Separate worms using heap or light method
- Store vermicompost in cool, shaded conditions

## 6. Nutrient Composition and Quality Parameters

Various laboratory analysis reports the following average composition:

- Nitrogen: 1.5–2.0%
- Phosphorus ( $P_2O_5$ ): 0.5–0.9%

- Potassium ( $K_2O$ ): 0.8–1.2%
- Organic Carbon: 15–25%
- C:N ratio: 12–18:1

Additionally, vermicompost contains:

- Micronutrients (Zn, Fe, Cu, Mn)
- Enzymes and vitamins
- Humic substances

#### 7. Impact of Vermicompost on Soil Health

- Improves soil aggregation and porosity
- Enhances microbial biomass carbon
- Increases enzymatic activity
- Improves water infiltration and retention

#### 8. Crop Response and Yield Enhancement

- 10–25% yield increase in cereals and pulses
- Improved vegetable quality and shelf life
- Enhanced flowering and fruit set in horticultural crops

#### 9. Crop-Wise Application Rates (ICAR Recommendations)

- Cereals and pulses: 2–5 t/ha
- Vegetables: 5–10 t/ha
- Orchards: 5–25 kg/tree
- Nurseries: 10–20% potting mixture

#### 10. Conclusion

ICAR research clearly establishes vermicomposting as a scientifically robust, economically viable, and environmentally sustainable technology for Indian agriculture. Its integration into farming systems can significantly contribute to soil health restoration, reduced chemical dependency, and sustainable rural livelihoods.

## Agricultural by products an alternative approach for weed management



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### Introduction:

Agricultural by-products offer a sustainable, alternative approach to weed management through mulching (residues block sunlight), creating natural bioherbicides (like corn gluten meal, mustard seed meal, plant extracts with allelopathic effects), and fostering competitive cover crops (rye, buckwheat) that suppress weeds, reducing reliance on synthetic herbicides and combating resistance. These methods integrate into sustainable systems by utilizing crop residues and natural compounds to inhibit weed growth, often via shading, soil cooling, or releasing weed-inhibiting chemicals (allelochemicals).

The use of agricultural byproducts for weed management dates back to ancient agricultural practices, long before synthetic chemicals, and has seen resurgence as a key component of modern sustainable and organic farming systems.

### Historical Overview:

**Ancient Agriculture (pre-20th century):** Early farmers utilized natural products and mechanical methods to control weeds. Practices included repeated tillage, manual weeding, and crop rotation. Specific byproducts were also used, notably olive oil lees (amurca) in Roman times, which was described in manuals like Cato the Elder's *De Agri Cultura* (c. 150 BC) for preventing weed growth on threshing floors and protecting crops. Salt, another natural product/byproduct, was also used as a non-selective weed killer in England by the late 16th century.

**Early 20th Century (pre-1940s):** The use of "crude" chemicals like oil wastes, rock salts, and sulfuric acid was explored, though often limited by their non-selective nature and adverse effects on the soil. During this time, pioneers of organic agriculture, like Sir Albert Howard, advocated for traditional sustainable farming methods, including the use of animal manures and cover crops, drawing inspiration from practices in India.

**Mid-20th Century ("Chemical Revolution"):** The development of synthetic, selective herbicides like 2,4-D in the 1940s and 1950s led to a dramatic shift, making chemical weed control the dominant practice due to its cost-effectiveness and ease of use. This period saw less focus on traditional or byproduct-based methods in conventional agriculture.

**Late 20th Century to Present (Alternative Approaches):** Growing concerns over the environmental and health impacts of synthetic herbicides (e.g., water contamination, weed resistance) have led researchers and farmers to revisit and improve non-chemical, ecological methods. The use of agricultural byproducts as part of integrated weed management (IWM) strategies has gained prominence in sustainable, organic, and conservation agriculture systems.

### Modern Application of Agricultural Byproducts:

Today, agricultural byproducts are primarily used in two main ways as an alternative, eco-friendly approach to weed management:

**Mulching (Physical Barrier and Allelopathy):** Crop residues (straw, stubble, etc.) are applied to the soil surface as a mulch. This physical barrier suppresses weed emergence by blocking light and creating an unfavorable environment for germination. Additionally, some residues release natural chemical compounds (allelochemicals) that inhibit the growth of specific weed species.

**Examples of effective mulches:**

Sorghum, mustard, and barley residues have shown significant weed-suppressing ability, especially against broadleaf weeds.

Rice and wheat straw are commonly used in rotation systems to manage weeds in subsequent crops like turmeric and maize.

Cover Crops/Green Manures: Growing specific crops during fallow periods, and then incorporating their residues into the soil, helps suppress weeds while also improving soil health and nutrient availability.

Examples:

Hairy vetch and cereal rye provide dense ground cover and allelopathic effects.

Incorporating mungbean residues has proven effective in managing weeds in zero-till direct-seeded rice systems.

These practices, often combined with other cultural methods like crop rotation and adjusting planting dates, offer a sustainable alternative to heavy reliance on synthetic chemicals.

**Key By-Product Approaches:**

Mulching with Residues: Spreading crop residues (straw, stalks) creates a physical barrier, blocks sunlight, cools soil, and can release allelochemicals, preventing weed germination and growth.

**Bioherbicides from Seed Meals:**

Corn Gluten Meal (CGM): A pre-emergent herbicide, excellent for seeded crops like beans, lettuce, and carrots, controlling weeds like pigweed and purslane.

Mustard Seed Meal (MSM): Controls annual grasses and broadleaf weeds like chickweed and annual bluegrass.

Plant Extracts: Extracts from neem, cinnamon, clove, or even other crops like sorghum possess natural herbicidal properties that disrupt weed metabolism.

Cover Crops: Planting dense, fast-growing crops (clover, rye) between cash crops shades out weeds and leaves behind residues that further suppress them.

Allelopathic By-products: Residues from certain plants release chemicals (allelochemicals) that harm neighboring weed seeds, inhibiting their growth.

**Benefits:**

- Reduces Herbicide Resistance: Offers alternatives to chemicals that weeds can evolve resistance to.
- Enhances Soil Health: Returns organic matter, improving soil structure.
- Cost-Effective: Utilizes waste materials, reducing input costs.

Sustainable: Aligns with integrated weed management (IWM) and sustainable agriculture goals.

Many studies have revealed that the alternative methods such as the use of allelopathy phenomenon, cover crops and living mulches, competitive crop cultivars, suitable nutrient management, etc. can be proposed as the low cost, effective and eco-friendly practices for sustainable weed management in cropping systems. In this chapter, the most important alternative weed control methods are discussed.



Figure No.1. SOURCE: CURRENT Research in Microbial Sciences

### **Allelopathy:**

The term allelopathy was first introduced by Hans Molisch in 1937 and refers to chemical interactions among plants, including those mediated by microorganisms. Rice (1984) defined allelopathy as the effects of one plant (including microorganisms) on another plant through the release of a chemical compounds into the environment. Allelopathy can play a beneficial role in various cropping systems such as mixed cropping, multiple cropping, cover cropping, crop rotations, and minimum and no-tillage systems. The exploitation of allelopathy in agricultural practices as a tool for weed control has shown weed reduction, pathogen prevention and soil enrichment (Kohli et al., 1998). Allelopathy is the direct or indirect chemical effect of one plant on the germination, growth or development of neighboring plants. It is now commonly regarded as component of biological control. Species of both crops and weeds exhibit this ability. Allelopathic crops include barley, rye, annual ryegrass, buckwheat, oats, sorghum, sudan sorghum hybrids, alfalfa, wheat, red clover, and sunflower. Vegetables, such as horseradish, carrot and radish, release particularly powerful allelopathic chemicals from their roots. Suggestions have been made that allelochemicals and other natural products or their derivatives could form the basis of bioherbicides. However, it is unclear whether the application of natural weed killing chemicals would be acceptable to the organic standard authorities.

The allelopathic effect can be used to an advantage when oats are sown with a new planting of alfalfa. Allelopathy from both the alfalfa and the oats will prevent the planting from being choked with weeds in the first year. Buckwheat is also well known for its particularly strong weed suppressive ability. Planting buckwheat on weed problem, fields can be an effective cleanup technique. Some farmers allow the buckwheat to grow for only about six weeks before plowing under. This not only suppress and physically destroys, weeds; it also releases phosphorus and conditions the soil.

### **Ways by which allelopathy can be used to control weeds in cropping systems:**

In general, the use of allelopathy as a tool to control weeds can be achieved in different ways:

Use of crop cultivars with allelopathic properties.

Application of residues and straw of allelopathic crops as mulches or incorporated into the soil.

Use of an allelopathic crop in a rotational sequence.

Application of allelochemicals or modified allelochemicals as herbicides (Kruse et al. 2000).

Modification of crops to enhance their allelopathic effects.

How can a cover crop or living mulch affect weed growth?

The effects of a cover crop or living mulch are achieved by a rapid occupation of the open space between the rows of the main crop or generally, the niches that would normally be filled by weeds (Teasdale 1998). This prevents germination of weed seeds and reduces the growth and development of weed seedlings. Generally, the weed suppressing ability of these systems is thought to be based on allelopathic properties, physical impedance of germination and seedling growth, and competition for light, water, and nutrients (Teasdale, 1993; Teasdale and Mohler, 1993).

Agricultural byproducts provide environmentally friendly alternatives for weed management through methods such as mulching, incorporation into the soil, use as cover crops, and extraction for bioherbicides. These approaches suppress weeds by physical barriers, resource competition, and the release of natural chemical compounds (allelopathy).

### **Methods Using Agricultural Byproducts**

**Mulching (Surface Application):** Applying a layer of crop residues, such as straw, wood chips, or corn cobs, onto the soil surface helps control weeds by blocking sunlight, which prevents weed seed germination and inhibits the growth of emerging seedlings. Mulch also helps conserve soil moisture and regulate soil temperature, benefiting the main crop.



Figure 2: Source eOrganic

**Soil Incorporation:** Byproducts like *Vicia faba* (broad bean) pods or *Sorghum* residues can be mixed directly into the soil. The decomposition of this organic matter can release natural phytotoxic compounds (allelochemicals) into the soil, which suppress weed growth while simultaneously improving soil fertility and organic matter content.

**Cover Crops:** Growing specific crops, such as rye, barley, or certain legumes (*Mucuna pruriens*), during fallow periods or alongside cash crops (intercropping) can suppress weeds. These cover crops out compete weeds for resources like light, water, and nutrients and often release allelochemicals into the soil. Once the cover crop is terminated, its residue can serve as a green mulch, providing further weed suppression. Rapid development and dense ground covering by the crop will suppress weeds. The inclusion of cover crops such as rye, red, clover, buckwheat and oilseed radish or over wintering crops like winter wheat or forages in the cropping system can suppress weed growth. Highly competitive crops may be grown as short duration 'smother' crops within the rotation. Additionally, cover crop residues on the soil surface will suppress weeds by shading and cooling the soil. When choosing a cover crop, consideration should always be given to how the cover crop will affect the succeeding crop. In addition, decomposing cover crop residues may release allelo chemicals that inhibit the germination and development of weed seeds.

### EFFECTIVE WEED MANAGEMENT

**A weed is known simply as a plant in the wrong place.**

**But in a farmer's crop weeds are just Opportunists in Disguise.**

Some of the best ways to clear a weed patch safely :

<p><b>MULCH</b></p> 	<p>Mulch benefits plants by : Keeping the soil cool and moist and depriving weeds of light.</p>	<p><b>CHOP</b></p> 	<p>When you can't remove weeds, the next big thing is to chop their heads.</p>
<p><b>DIG</b></p> 	<p>Dig when you only need to and immediately salve the disturbed spot with plants or mulch.</p>	<p><b>USE DRIP IRRIGATION</b></p> 	<p>Placing drip hoses beneath mulch efficiently irrigates plants while leaving nearby weeds thirsty. In most climates, depriving weeds of water reduces weed seed segmentation by 50-70%.</p>
<p><b>PULL</b></p> 	<p>For better or worse, you need to pull out most weeds. The trick to pull weeds is the get the root out as well.</p>	<p><b>USING CHEMICAL HERBICIDES</b></p> 	<p>The choice of herbicide will depend on many factors including Safety, Efficacy, cost, storage and application method.</p>

Figure No. 3. Source: Current Research in Microbial Sciences

**Bioherbicides/Plant Extracts:** Specific plant byproducts and extracts are used to develop natural herbicides (bioherbicides). These products contain potent allelochemicals (e.g., juglone from black walnut, sorgoleone from sorghum, essential oils like eucalyptol) that can be extracted and formulated as pre- or post-emergence sprays to target specific weeds. Byproducts like corn gluten meal (CGM) and mustard seed meal also have inherent herbicidal properties and are used in commercial bioherbicide products.

**Mechanism of Action:**

Agricultural byproducts employ several mechanisms to manage weeds:

**Physical Barrier:** Mulches create a physical barrier that prevents light from reaching the soil surface, inhibiting photosynthesis and weed emergence.

**Allelopathy:** Many plant residues and extracts contain allelochemicals that interfere with weed seed germination, root development, and overall growth.

**Competition:** Cover crops and well-managed cash crops use available resources (water, nutrients, light) more efficiently than weeds, outcompeting them for survival.

**Soil Condition Alteration:** Decomposing residues can alter soil properties such as C:N ratio, temperature, and moisture levels, creating an unfavorable environment for certain weed species.

**Implementation:**

These methods work best when combined (Integrated Weed Management) with cultural practices (crop rotation, tillage) and mechanical control, rather than as a single replacement for herbicides, providing a holistic and eco-friendly strategy.

Integrated weed management system to reduce the risk of herbicide resistance, increase crop production, and reduce production rates. To date, there are few bioherbicides that are commercially available; therefore, future research should focus on the development of new bioherbicides, so that they can become mainstream products in the future.

The future prospects of using agricultural byproducts for weed management are promising, driven by the need for sustainable, eco-friendly alternatives to synthetic herbicides which are facing issues like weed resistance and environmental concerns. This approach leverages the natural power of plant-derived compounds (allelopathy) and organic materials to suppress weeds.

**Key Future Prospects and Approaches:**

**Source of Natural Bioherbicides (Allelopathy):** Agricultural byproducts (e.g., corn gluten meal, *Brassicaceae* seed meals, spent coffee grounds, and *Vicia faba* pods) contain natural phytotoxic compounds (allelochemicals) that can inhibit weed germination and growth. Future research will focus on identifying, extracting, and commercializing these specific compounds as effective, biodegradable bioherbicides with shorter environmental half-lives than synthetic alternatives.

**Integrated Weed Management (IWM):** Agri-byproducts are not expected to be a sole solution but a crucial component of integrated weed management (IWM) programs. The future will involve combining these natural methods with other techniques like crop rotation, mulching, and advanced technologies (e.g., precision agriculture, robotics) to provide comprehensive and sustainable weed control.

**Soil Amendment and Mulching:** Incorporating processed agricultural byproducts (compost, biochar, or raw residues) into the soil as organic amendments or mulches will continue to be a primary application method. This practice suppresses weeds while simultaneously improving soil health, organic matter content, and nutrient availability, aligning with circular economy principles.

**Nano-enabled Weed Management:** Research is exploring the use of nanotechnology to enhance the efficacy of natural compounds derived from byproducts. Nano-encapsulated formulations can provide controlled, slow release of active ingredients, ensuring effectiveness while minimizing environmental impact.

**Waste-to-Wealth Approach:** Utilizing abundant agricultural waste for weed management aligns with the "waste-to-wealth" concept, turning disposal problems into valuable resources. This creates economic opportunities, reduces reliance on finite resources, and helps mitigate climate change by reducing greenhouse gas emissions from traditional waste disposal methods like burning.

**Technological Integration:** Future advancements in computer vision and artificial intelligence will enable the precise application of these byproduct-based solutions. Robots and drones equipped with sensors could soon apply targeted applications of natural extracts or mulches exactly where needed, optimizing resource use and efficiency.

**Challenges:** Despite the potential, challenges remain, including varying efficacy depending on environmental conditions, the need for large-scale production methods, and overcoming potential regulatory hurdles for new products. Further research is needed to optimize formulations and application methods to ensure consistent, effective results across different agricultural systems.

**Conclusion:** Alternative approaches for weed control using crop by-products focus on mulching with residues, exploiting allelopathy (natural plant chemicals), using cover crops, and incorporating bioherbicides from fungi, all while promoting soil health, reducing chemical reliance, and fitting into integrated weed management (IWM) systems. These methods leverage crop residues for shading (mulch), release of weed-inhibiting compounds (allelopathy), or growing competitive plants (cover crops) to suppress weeds naturally.

