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ARTICLE ID: 1

Success Story: Management of Root Knot Nematode in Capsicum under Protected Cultivation at Palwal District, Haryana

Introduction

Protected cultivation is increasingly adopted in rural India to optimize land and water use, reduce dependency on rainfall, and provide favorable microclimatic conditions for crop growth. However, this system faces challenges such as soil-borne diseases, mites, and nematode infestations. Among these, root knot nematodes (*Meloidogyne* spp.) are recognized as a major biotic stress, causing severe economic losses in vegetable crops worldwide.

This success story highlights the potential of eco-friendly, integrated strategies for sustainable crop production in India's protected cultivation sector. In the farmer polyhouse at Alawalpur village, Palwal district of Haryana, a significant breakthrough was achieved in the management of root knot nematode, *Meloidogyne incognita*, infesting cucumner under protected cultivation. The study demonstrated that combining soil solarization with the application of bioagents—*Trichoderma viride*, *Pseudomonas fluorescens*, and *Paecilomyces lilacinus*—resulted in near-complete suppression of the nematode population and a dramatic increase in crop yield and profitability.



Soil solarization with 25 microns polythene roll during the month of May June

The study was conducted in a polyhouse severely infested with *M. incognita*, with an initial population of 8 juveniles per gram of soil. Solarization is most suitable to shallow rooted and short season plants particularly useful to organic growers and vegetable growers in poly houses. Solarization in combination with compost, plant residues, green manures and fertilizers will be an effective non chemical way to improve nematicidal efficacy where solarization alone cannot provide the adequate control to target pathogens. Soil solarization was performed in the month of May-June using transparent polythene sheets (25–30 μ m thickness), sealed properly for one month. Bioagents were applied as follows: *Trichoderma viride* and *Pseudomonas fluorescens* at (1×10^8 cfu/gm), and *Paecilomyces lilacinus* at 1.15% WP (1×10^8 cfu/gm) @2 kg per tonne vermicompost, all mixed with vermicompost and were allowed to multiply for two to three weeks under shade conditions and incorporated into the soil before sowing. The farmer was advised to grow Capsicum (cv. Bomby) instead of cucumber, Hence capsicum was grown with standard agronomic practices.



Formation of new plants after solarization and bio agent treatment: Left (non solarized rows) and left (solarized rows)

Results and Impact

- **Nematode Suppression:** Soil solarization reduced the nematode population by 100% compared to the untreated control.
- **Yield Increase:** Capsicum yield increased from 3.5 kg/plant in the control to 6.5 kg/plant in the solarized treatment, representing a 469% increase.
- **Economic Benefit:** The net profit from solarized capsicum was Rs. 3,08,400, compared to only Rs. 17,000 from the untreated crop.
- **Crop Health:** Plants in the solarized plots were healthy, with no visible root galls or nematode damage.

Conclusion

The integration of soil solarization with bioagent application proved highly effective in controlling *M. incognita* under protected cultivation. This approach not only eliminated the need for chemical nematicides but also significantly boosted yield and profitability. The results align with global studies confirming the efficacy of solarization and bioagent combinations in nematode management, especially in organic and vegetable production systems.

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BIOCHAR - AN UNNOTICED HERO IN THE AGRICULTURE FIELD

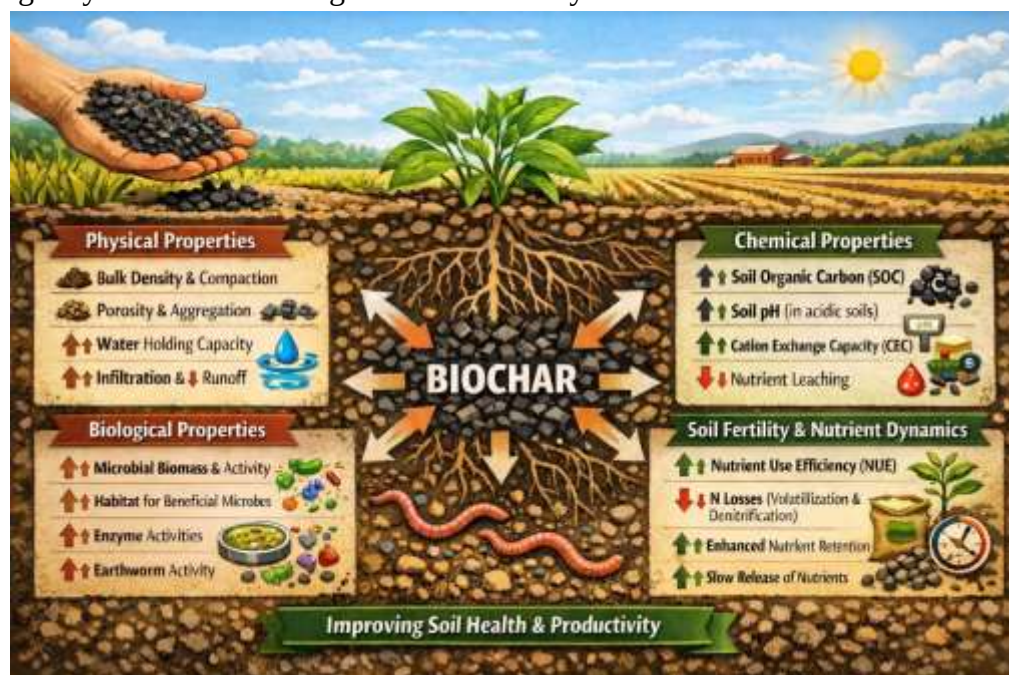
Abstract

Biochar, a carbon-rich material produced through the pyrolysis of biomass, emerges as an unnoticed hero in modern agriculture by transforming soil health, boosting crop productivity and promoting environmental sustainability. When incorporated into soils, it enhances water retention, nutrient availability and microbial activity, leading to improved yields while reducing the need for chemical fertilizers and mitigating greenhouse gas emissions through its stable carbon sequestration potential. Beyond productivity gains, biochar remediates contaminated soils by binding heavy metals and pesticides, fosters resilient farming in drought-prone areas and supports circular economies by valorising agricultural waste. Despite its ancient roots in practices like Amazonian terra preta, biochar remains underutilized due to limited awareness, yet its multifaceted benefits position it as a game-changer for sustainable food systems amid climate challenges.

Keywords: Biochar, Soil health, Crop Productivity, Microbial activity, Carbon sequestration

Introduction

Agriculture faces mounting challenges from soil degradation, climate variability and the overuse of chemical inputs, making sustainable solutions urgently needed to ensure global food security.



Biochar, a stable carbon-rich material produced by pyrolyzing biomass in low-oxygen conditions (Lehmann and Joseph, 2015), stands out as an overlooked powerhouse with ancient precedents like the fertile Amazonian terra preta soils. By enhancing soil structure, water retention and nutrient cycling, biochar boosts crop yields by 10-30% in nutrient-poor soils while sequestering carbon for centuries and reducing greenhouse gas emissions (International Biochar Initiative, 2018). Its ability to bind pollutants and foster microbial life further positions biochar as a versatile amendment for resilient farming systems worldwide (Major *et al.*, 2019).

Soil Health Benefits

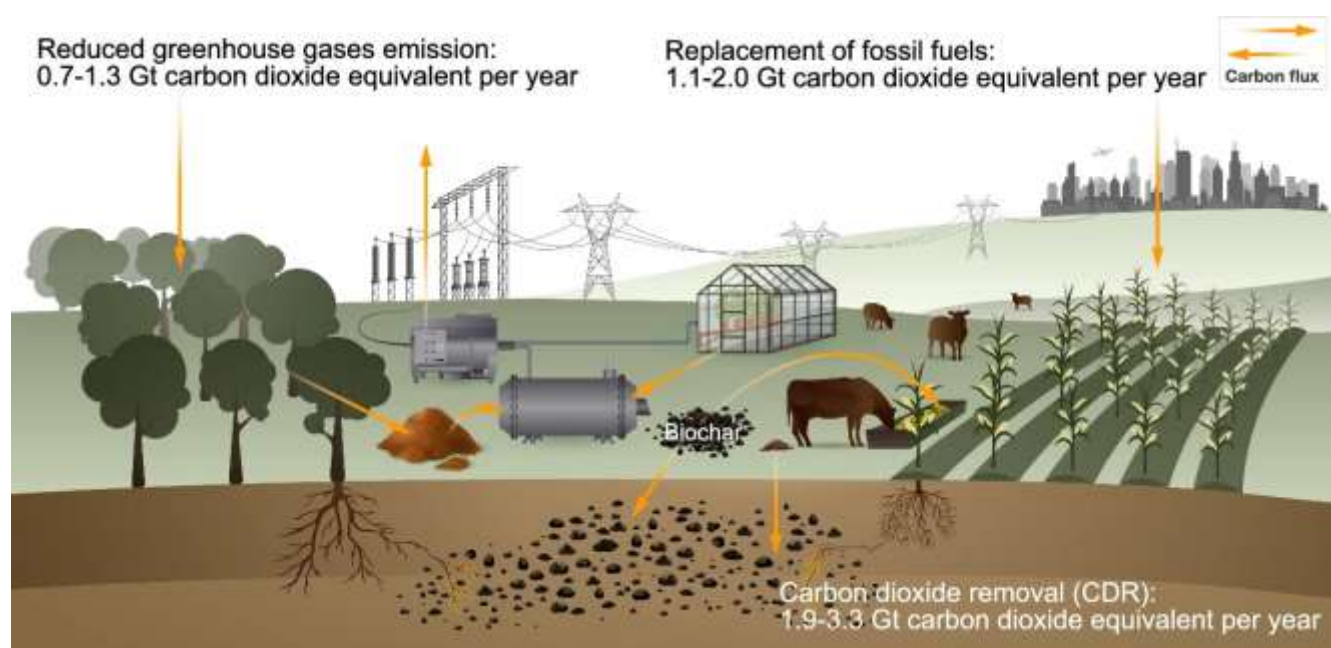
Biochar profoundly impacts soil health by enhancing physical properties such as structure, porosity, and water retention, as demonstrated in studies by Teng *et al.* (2025) and Kabir *et al.* (2023). Its highly porous carbon matrix reduces bulk density by 3-31%, improves aeration and increases water-holding capacity by up to 64% in sandy or compacted soils, enabling better root penetration and drought resilience. These changes also promote aggregate stability, minimizing erosion risks in degraded farmlands.

Chemically and biologically, biochar elevates cation exchange capacity (CEC) by 21-57% at typical application rates, retaining nutrients like potassium and phosphorus while curbing leaching losses, according to research by Pokharel *et al.* (2025) and Ali *et al.* (2025). It raises pH in acidic soils, stimulates microbial diversity and enzyme activity for efficient nutrient cycling, and sequesters carbon to bolster long-term organic matter stability. Overall, these effects foster a resilient soil ecosystem, supporting sustainable crop productivity.

Crop Yield Impacts

Biochar improves crop yields by enhancing soil fertility and water retention, as shown in a 2023 meta-analysis by Wang *et al.*, which reported average yield increases of 14% alongside boosts in nitrogen use efficiency. Similarly, Ye *et al.* (2020) found that biochar with fertilizers amplified yields by up to 48% over controls, with sustained effects over three years due to improved soil organic carbon.

Long-term field trials by Kammann *et al.* (2021) highlight variability, where wood-based biochars raised yields by 31% in sandy soils,



outperforming manure-derived types through greater stability and pH stabilization. These gains, noted in a 2025 global analysis by Zhang *et al.*, are most pronounced at 5-20 tons/ha rates in acidic or nutrient-poor conditions.

Environmental Advantages

Biochar provides key environmental advantages by sequestering carbon in soils for centuries, as noted by researchers like Lehmann and Joseph (2015) in their work on biochar for environmental management, potentially offsetting 1-2 gigatons of CO₂ annually from global biomass waste. It also suppresses potent greenhouse gases, with studies by Shakoor *et al.* (2021) showing up to 54% reductions in nitrous oxide (N₂O) emissions and 37-80% cuts in methane (CH₄) from rice fields and landfills, per findings from Yang *et al.* (2022).

In applications, biochar is incorporated into agricultural soils at 10-50 tons per hectare to enhance water retention and nutrient efficiency, reducing fertilizer runoff as highlighted by Nan *et al.* (2020), who reported sustained CH₄ emission drops over years with annual low-rate additions. It serves in remediation by adsorbing heavy metals and pesticides, with Yargicoglu and Reddy (2017) demonstrating up to 80% CH₄ mitigation in landfill covers, and is fed to livestock to lower enteric emissions by 20%, promoting sustainable land restoration.

Conclusion

Biochar emerges as an unnoticed hero in the agriculture field, revolutionizing soil health by enhancing water retention, nutrient availability and microbial activity while boosting crop yields and resilience against climate challenges. Its ability to sequester carbon for centuries mitigates greenhouse gas emissions, transforms agricultural waste into a valuable resource and promotes sustainable farming practices that ensure long-

term food security. By bridging the gap between productivity and environmental stewardship, biochar holds immense promise for global agriculture, urging farmers, policymakers and researchers to prioritize its widespread adoption for a greener, more prosperous future.

References

- Ali, A., Jabeen, N., Chachar, Z., Chachar, S., Ahmed, S., Ahmed, N., Laghari, A. A, Sahito, Z. A., Farruhbek, R. and Yang, Z. 2025. The role of biochar in enhancing soil health & interactions with rhizosphere properties and enzyme activities in organic fertilizer substitution. *Frontiers in Plant Science* **16**: 1595208.
- International Biochar Initiative. 2018. Biochar carbon stability primer.
- Kabir, E., Kim, K. H. and Kwon, E. E. 2023. Biochar as a tool for the improvement of soil and environment. *Frontiers in Environmental Science* **11**.
- Kammann, C., Ippolito, J., Hagemann, N., Borchard, N., Cayuela, M. L., Estavillo, J. M., Fuertes-Mendizábal, T., Komtanti, D., Novak, J. and Kaser, S. 2021. Impact of biochar on nutrient supply, crop yield and microbial respiration on sandy soils of northern Germany. *European Journal of Soil Science*: **72**(5): 2068-2085.
- Lehmann, J. and Joseph, S. 2015. Biochar for environmental management: Science, technology and implementation (2nd ed.). *Routledge Publication*.
- Major, J., Rondon, M., Molina, D., Riha, S. J. and Lehmann, J. 2019. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Soil Science Society of America Journal* **73**(6): 1950-1959.
- Nan, J., Wang, M., Du, Z. and Ma, L. 2020. Biochar amendment pyrolysed with rice straw increases rice yield and mitigates CH₄ and N₂O emissions from paddy fields in central

- China. *Science of the Total Environment* **762**: 143082.
- Pokharel, U., Neelgund, G., Ray, R. L., Balan, V. and Kumar, S. 2025. Biochar for Soil Amendment: Applications, Benefits, and Environmental Impacts. *Bioengineering (Basel)* **12**(11): 1137.
 - Shakoor, A., Shakoor, A. and Ashraf, M. 2021. Biochar for a sustainable future: Environmentally friendly carbon material for a greener planet. *Journal of Cleaner Production* **312**: 127819.
 - Teng, X., Huang, D., Zhi, Y., Li, Y., Dong, D., Wu, X., Wang, Y., Jiang, Z., Huang, H., Tang, Y., Liu, D. and Xu, W. 2025. Effects of biochar on soil properties as well as available and TCLP-extractable Cu contents: a global meta-analysis. *Nature Scientific Reports*.
 - Wang, J., Zhang, L., Li, Y. and Chen, X. 2023. Effect of biochar addition on crop yield, water and nitrogen use efficiency: A meta-analysis. *Journal of Cleaner Production* **420**: 138583.
 - Yang, Y. L., Sun, K. and Gu, J. F. (2022). Biochar application strategies for sustainable agriculture and environmental remediation. *Frontiers in Environmental Science* **10**: 1324533.
 - Yargicoglu, E. N. and Reddy, K. R. 2017. Effects of biochar and wood pellets amendments added to landfill cover soil on microbial methane oxidation under high moisture contents. *Journal of Environmental Management* **195**: 11-21.
 - Ye, J., Zhang, Q., Wang, H., Liu, Z. and Jin, Z. 2020. Biochar effects on crop yields with and without fertilizer: A meta-analysis. *Soil Use and Management* **36**(1): 2-18.
 - Zhang, X., Liu, M., Wang, S., Zhao, Y. and Guo, R. 2025. Global analysis on potential effects of biochar on crop yields and soil quality. *Soil & Environmental Letters*.

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PREDATORS: THE ENTOMOPHAGOUS BEINGS

Abstract

Biological control has a long history as an ecologically sustainable approach to pest management and relies on natural enemies such as predators, parasitoids, and parasites to regulate pest populations. Among these agents, predators play a crucial role due to their broad prey range and capacity for rapid population response. This paper focuses on the diversity of predatory organisms across different insect orders, as well as non-insect predators, highlighting their taxonomic distribution and prey associations. Particular emphasis is placed on identifying the host or prey specificity of major predator groups and their functional roles in pest suppression. In addition to entomophagous insects, predatory mites represent an important yet often underemphasized group of biological control agents. These mites are effective predators of a wide range of arthropod pests inhabiting both above-ground plant parts and below-ground environments, including soil-dwelling stages. By synthesizing information on insect and mite predators and their target pests, this paper aims to provide an introduction of predator-based biological control and its potential contribution to sustainable pest management strategies.

Keywords: Biological control; Predators; Integrated pest management (IPM); Sustainable agriculture; Lepidopteran predators.

Introduction

DeBach (1964) defined biological control as the use of parasites, predators, and pathogens to regulate pest populations. This concept is based on two fundamental principles: first, natural enemies routinely suppress prey populations in ecosystems, and second, biological control aims to reduce pest densities rather than eradicate them, allowing both pest and natural enemy to persist at low, stable levels within the agro-ecosystem. Biological control programs commonly employ predatory insects and mites, parasitoids, and microbial agents such as bacteria, fungi, and viruses to manage insect and mite pests. The practice has a long history, dating back to around AD 300 with the use of predatory ants in citrus orchards (van Lenteren 2005; van Lenteren & Godfray 2005). However, the successful introduction of the vedalia beetle *Rodolia cardinalis* from Australia to California in 1888 for control of the cottony cushion scale *Icerya purchasi* is regarded as the formal beginning of biological control as a scientific discipline (Doutt 1958). Insect predators are key biocontrol agents that play a vital role in regulating pest populations in agricultural and horticultural systems.

Excessive reliance on chemical pesticides has led to environmental pollution, pest resurgence, and the loss of beneficial organisms. Predatory insects and arthropods contribute significantly to natural pest regulation and are integral components of integrated pest management (IPM). Promoting biological control over chemical-based approaches is therefore

essential for sustainable agriculture and ecological balance.

• Predators across different insect orders

The global distribution of insect predators and parasitoids spans a diversity of ecosystems, each shaped by distinct environmental factors. Similarly, from a taxonomical perspective, these organisms showcase remarkable diversity,

Table – 1. Systematic overview of insect orders containing predatory lineages

Common name	Scientific name	Family	Host	Reference
Order – Odonata				
Dragonfly and damselfly	<i>Aeshna flavifrons</i> <i>Coenagrion kashmirum</i> , <i>Ischnura forcipata</i> , <i>Rhinocypha ignipennis</i> <i>Sympetrum durum</i>	Aeshnidae Coenagrionidae Coenagrionidae Chlorocyphidae Libellulidae	<i>Culex quinquefasciatus</i> maggot	Mandal <i>et al.</i> , 2008
Damselfly and dragonfly	<i>Ceragrion coromandelianum</i> , <i>Brachydiplax chalybea</i>	Coenagrionidae Libellulidae	<i>Culex quinquefasciatus</i>	Saha <i>et al.</i> , 2012
Order – Mantodea				
Praying mantids	<i>Hierodula patellifera</i>	Mantidae	<i>Tessaratoma papillosa</i>	Wang <i>et al.</i> , 2020
Order – Hemiptera				
Assassin bugs	<i>Platymeris laeviocolis</i>	Reduviidae	<i>Oryctes rhinoceros</i>	Abd Karim <i>et al.</i> , 2019
Pirate bugs	<i>Montandoniola indica</i>	Anthocoridae	<i>Gynaikothrips uzeli</i>	Ballal <i>et al.</i> , 2012
Pirate bugs	<i>Orius laevigatus</i>		<i>F. occidentalis</i>	Elimem and Chermitti, 2012 a,b
Order - Thysanoptera				
Thrips	<i>Scolothrips longicornis</i> <i>Scolothrips sexmaculatus</i>	Thripidae	<i>Tetranychus urticae</i>	Simala <i>et al.</i> , 2019
Order – Neuroptera				
Green lacewing	<i>Chrysoperla zastrowi sillemi</i>	Chrysopidae	<i>Myzus persicae</i> <i>Bemesia tabaci</i>	Nair <i>et al.</i> , 2020
brown lacewing	<i>Micromus angulatus</i>	Hemerobiidae	<i>Myzus persicae</i> <i>Chaetosiphon fragaefolii</i>	Pekas <i>et al.</i> , 2023
Order- Coleoptera				
Ladybird beetle	<i>Rodolia cardinalis</i>	Coccinellidae	<i>Icerya purchasi</i>	Kibar <i>et al.</i> , 2017
Seven spotted ladybird beetle	<i>Coccinella septempunctata</i>	Coccinellidae	<i>Lipaphis erysimi</i>	Pal and Bhatt, 2018
Order – Diptera				
Hoverfly	<i>Xanthandrus comtus</i>	Syrphidae	<i>Lobesia botrana</i>	Rojo <i>et al.</i> 2003
Aphid midge	<i>Aphidoletes aphidimyza</i>	Cecidomyiidae	<i>Aphis nerii</i> , <i>Aphis asclepiadis</i>	Boulanger <i>et al.</i> 2019
Order – Lepidoptera				
	<i>Taraka hamada</i> , <i>Oedematopoda semirubra</i>	Lycaenidae	<i>Ceratovacuna japonica</i>	Pierce, 1995
	<i>Ereunetis miniuscula</i>	Tineidae	<i>Icerya purchasi</i>	Leonard, 1932

representing various orders and families. Insect predators are prevalent across diverse orders, encompassing Coleoptera, Diptera, Hemiptera, Mantodea, Neuroptera, Odonata, and Thysanoptera.

- **Non insect predators**

Predatory mites

Predatory mites constitute a major component of commercial augmentative biological control programs. They are predominantly employed in protected vegetable and ornamental production systems for the management of phytophagous mites, thrips, and whiteflies, whereas their application in open-field crops and animal husbandry remains limited. Species belonging to the family Phytoseiidae represent the most important group of commercially available predatory mites. Predatory mites *Amblyseius swirskii* shows effective control over thrips and whiteflies (Knapp *et al.*, 2018) Phytoseiid predatory mites with *Amblyseius swirskii* (Athias-Henriot), *P. persimilis*, *Neoseiulus californicus* (McGregor) and *N. cucumeris* as the major species of predatory mite available commercially. Along with this, predatory soil mites are effective biocontrol agents of soil dwelling pests as well as pests above soil; for example, the laelapid predators *Hypoaspis* (*Geolaelaps*) *aculeifer* (Canestrini) and *Stratiolaelaps* (= *Hypoaspis*) *scimitus* (miles) (Womersley), as well as *Macrocheles robustulus* (Berlese) of the Macrochelidae family are used to control various species of edaphic pests (Beretta *et al.*, 2022).

Conclusion

Agriculture is fundamental to human survival as it provides essential resources such as food and fibre. However, pest incidence remains one of the major biological constraints affecting agro-ecosystems. The prolonged and indiscriminate use of chemical pesticides over

several decades has resulted in adverse effects on crops, soil health, and non-target beneficial flora and fauna. Consequently, there is a growing need to adopt sustainable and environmentally benign pest management alternatives. Biological control represents a key component of integrated pest management, wherein predators serve as important biological agents for insect pest regulation. These naturally occurring predators effectively suppress pest populations below economic threshold levels, thereby significantly reducing reliance on chemical pesticides.

References

- Abd Karim, F.N., Zaini, M.R., Rakibe, I., Sani, S., Hazlee, N.F.H. and Shaikh Mazran, N.S. (2019). Status of pest, *Oryctes rhinoceros* and its natural enemies in the independent smallholder treated with different insecticides. Agriculture, Forestry and Fisheries. 8 (4): 89–94.
- Ballal, C.R., Gupta, T. and Joshi, S. (2012a). Production protocols for and storage efficacy of an anthocorid predator *Cardiastethus exiguus* Poppius. Journal of Environmental Entomology. 34 (1): 50–56.
- Beretta, G. M., Deere, J. A., Messelink, G. J., Muñoz-Cárdenas, K., & Janssen, A. (2022). Predatory soil mites as biocontrol agents of above- and below-ground plant pests. Experimental and Applied Acarology, 87, 143–162.
- Boulanger, F.-X., Jandricic, S., Bolckmans, K., Wäckers, F.L. and Pekas, A. (2019). Optimizing aphid biocontrol with the predator *Aphidoletes aphidimyza*, based on biology and ecology. Pest Management Science. 75 (6): 1479–1493.
- DeBach, P. 1964 Biological control of insect pests and weeds. London, UK: Chapman and Hall.
- Douthett, R. L. 1958 Vice, virtue and the vedalia. Bull. ent. Soc. Am. 4, 119-123.
- Elimem, M. and Chermiti, B. (2012a). Effect

- of *Orius laevigatus* and *Amblyseius swirskii* releases on *Frankliniella occidentalis* populations in pepper crop greenhouses in the Bekalta region of Tunisia. IOBC/WPRS Bulletin. 80: 147.
- Elimem, M. and Chermiti, B. (2012b). Use of the predators *Orius laevigatus* and *Aeolothrips* spp. to control *Frankliniella occidentalis* populations in greenhouse peppers in the region of Monastir, Tunisia. IOBC/WPRS Bulletin. 80: 141–146.
 - Kibar, A.K., Akca, I. and Saruhan, I. (2017). Biological control of *Icerya purchasi* Maskell (Hemiptera: Margarodidae) with *Rodolia cardinalis* Mulsant (Coleoptera: Coccinellidae) in a cherry laurel orchard. International Journal of Agriculture Innovations and Research. 5 (6).
 - Knapp, M., van Houten, Y., van Baal, E., & Groot, T. (2018). *Use of predatory mites in commercial biocontrol: Current status and future prospects*. Acarologia, 58 (Supplement), 72–82.
 - Leonard, M.D. (1932). The cottony cushion scale in Puerto Rico. *Journal of Economic Entomology*. 25: 1103–1107.
 - Mandal, S.K., Ghosh, A., Bhattacharjee, I. and Chandra, G. (2008). Biocontrol efficiency of odonate nymphs against larvae of the mosquito, *Culex quinquefasciatus* Say, 1823. *Acta Tropica*. 106 (2): 109–114.
 - Nair, I.J., Sharma, S. and Kaur, R. (2020). Efficacy of the green lacewing, *Chrysoperla zastrowi sillemi* (Esben-Peterson) (Neuroptera: Chrysopidae), against sucking pests of tomato: an appraisal under protected conditions. *Egyptian Journal of Biological Pest Control*. 30: 74.
 - Pal, S. and Bhatt, J. (2018). Feeding efficiency of six beetle species against mustard aphid, *Lipaphis erysimi* (Kalt.) in Uttarakhand, India. *International Journal of Current Microbiology and Applied Sciences*. 7 (4): 1970-1976.
 - Pekas, A., De Smedt, L., Verachtert, N. and Boonen, S. (2023). The brown lacewing *Micromus angulatus*: A new predator for the augmentative biological control of aphids. *Biological Control*. 186: 105342.
 - Pierce, N.E. (1995). Predatory and parasitic Lepidoptera: Carnivores living on plants. *Journal of the Lepidopterists' Society*. 49 (4): 412–453.
 - Rojo, S., Gilbert, F., Marcos-García, M.A., Nieto, J.M. and Mier, P.M. (2003). A world review of predatory hoverflies (Diptera: Syrphidae: Syrphinae) and their prey. CIBIO Ediciones, Alicante.
 - Saha, N., Aditya, G., Banerjee, S. and Saha, G.K. (2012). Predation potential of odonates on mosquito larvae: Implications for biological control. *Biological Control*. 63 (1): 1–8.
 - Šimala, M., Pintar, M. and Masten Milek, T. (2019). *Scolothrips longicornis* Priesner, 1926 – a new thrips species for Croatia. *Fragmenta Phytomedica*. 33 (3): 1–8.
 - van Lenteren, J. C. & Godfray, H. C. J. 2005 European science in the Enlightenment and the discovery of the insect parasitoid life cycle in The Netherlands and Great Britain. *Biological Control* 32, 12–24.
 - van Lenteren, J. C. 2005 Early entomology and the discovery of insect parasitoids. *Biological Control* 32, 2–7.
 - Wang, S., Wu, J., Zhao, Y. *et al.* (2020). Functional response of adult *Hierodula patellifera* (Serville, 1839) (Mantodea: Mantidae) to *Tessaratoma papillosa* (Drury) (Hemiptera: Tessaratomidae). *International Journal of Tropical Insect Science*. 40 (4): 1053–1058.

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IMPLICATIONS OF BIOCHAR ON SOIL CHARACTERISTICS AND SOCIO-ECONOMICS OF RURAL LIVELIHOOD

Abstract

Global sustainable development is severely hampered by soil erosion, dwindling agricultural production, and rural people's socioeconomic fragility. Biochar, a carbon-rich material produced through the pyrolysis of biomass under oxygen-limited conditions, has emerged as a promising soil amendment with multifunctional benefits. This article critically examines the implications of biochar application on soil characteristics and the socio-economics of rural livelihoods. The benefits of biochar are highlighted and the socioeconomic aspects of biochar adoption are also covered, including employment creation, waste valorization, revenue production, and the resilience of smallholder farming systems. The research concludes that, given suitable production methods, governmental backing, and farmer-centric extension services, biochar is a feasible climate-smart and livelihood-enhancing technology, especially for resource-poor rural populations.

Keywords: Biochar, rural livelihoods, sustainable agriculture, socio-economics

Introduction

Food security, environmental sustainability, and agricultural productivity all depend on healthy soil. However, soil deterioration has intensified in many areas, especially in emerging nations, due to intensive farming methods, overuse of chemical fertilizers, deforestation, and climate variability (Lal, 2015). Low organic matter, poor structure, decreased nutrient availability, and diminishing biological activity are characteristics of degraded soils that have a detrimental impact on crop production and rural livelihoods.

At the same time, growing input costs, crop failures brought on by climate change, and a lack of chances for livelihood diversification placed rural communities—especially smallholder farmers—under increasing socioeconomic strain (FAO, 2021). In this environment, sustainable soil management techniques that boost rural economies and restore soil productivity are gaining popularity.

As a potential remedy that connects environmental sustainability with socioeconomic growth, biochar has drawn attention from all around the world. Ancient agricultural systems, like the Terra Preta soils of the Amazon Basin, which show exceptionally high fertility and carbon content even after centuries, are the source of the historical use of charcoal-like materials in soils (Lehmann et al., 2006). Research on biochar has grown quickly in the modern era, with an emphasis on its use in waste management, soil enhancement, carbon sequestration, and climate-smart agriculture.

The goal of this article is to summarize what is currently known about the effects of biochar on rural livelihoods and soil health. This study aims to give a thorough understanding of how biochar might support sustainable rural development by combining agronomic, environmental, and socioeconomic viewpoints.

Biochar's impact on soil health and nutrients

Remediation because of Biochar's special physicochemical characteristics, such as soil fertility, nitrogen retention, and water-holding capacity. By boosting microbial activity, biochar, a stable carbon-rich substance, encourages plant development and raises agricultural yields. Additionally, it can be utilized as a sorbent to extract nutrients, organic pollutants, and heavy metals from soil and water systems.

Biochar's impact on the characteristics of soil

In terms of chemical properties, biochar significantly influences soil nutrient dynamics and pH regulation. Most biochars are alkaline in nature, and their application can raise soil pH, particularly in acidic soils, thereby reducing aluminum toxicity and increasing nutrient availability. Biochar surfaces contain functional groups capable of adsorbing and retaining essential nutrients such as nitrogen, phosphorus, potassium, calcium, and magnesium, reducing nutrient leaching losses. Several studies report enhanced cation exchange capacity (CEC) following biochar addition, which improves soil fertility and nutrient use efficiency over time (Glaser et al., 2002; Agegnehu et al., 2017).

Biochar also exerts a notable impact on biological soil characteristics by influencing microbial abundance, diversity, and activity. The porous matrix of biochar provides protected microhabitats for soil microorganisms, enhancing microbial colonization and enzymatic activity.

This microbial stimulation supports improved nutrient cycling, organic matter stabilization, and symbiotic interactions such as mycorrhizal associations. Field experiments indicate that biochar amendments can increase microbial biomass carbon and promote beneficial soil fauna, thereby contributing to overall soil health and long-term ecosystem functioning (Thies & Rillig, 2009; Lehmann et al., 2011).

According to Lu et al. (2023), By facilitating the passage of air and water through the soil, biochar has been demonstrated to increase soil porosity, which boosts crop production and nutrient uptake. Blanco-Canqui (2017) claims that permeable soil can absorb and hold pollutants as well as sequester CO₂ from the atmosphere. According to Zhang et al. (2017), conducted Fieldwork on sandy loam alfisol for two years found that biochar increases capillary and overall soil porosity by 23% and 24%, respectively,

Socio-Economic Implications for Rural Livelihoods

Beyond on-farm benefits, biochar production and utilization create new economic opportunities within rural communities. Biochar systems often rely on locally available agricultural residues, forest waste, or livestock manure, encouraging value addition to materials that are otherwise underutilized or discarded. Small-scale biochar enterprises can generate employment in feedstock collection, pyrolysis operations, marketing, and extension services, thereby diversifying rural income sources. In addition, decentralized biochar production technologies are well aligned with community-based models, promoting inclusive participation of women and landless laborers in rural economies (Kammann et al., 2017; Schmidt et al., 2021).

Farm Income and Crop Productivity

Higher and more consistent crop yields are frequently the outcome of improved soil health brought about by the application of biochar. Particularly for smallholder farmers working in poor soil conditions, increased productivity improves farm income and household food security (Jeffery et al., 2017). Over time, decreased production costs due to fewer fertilizer requirements increase net profitability.

Value Addition and Waste Management

Agricultural and forestry leftovers that would otherwise be burned or thrown away can be recycled through the manufacture of biochar. By using local biomass resources to create value-added products, this lessens environmental pollution. (Woolf et al., 2010).

Employment and Rural Businesses

Rural jobs in biomass collection, pyrolysis operations, marketing, and extension services can be created by decentralized biochar production facilities. Cooperatives and community-based biochar businesses provide chances for inclusive rural development and livelihood diversification. (FAO, 2021).

Real-Life Experiences of Biochar Production and Its Socio-Economic Implications: Global and Indian Perspectives

Across the world, practical experiences with biochar production have demonstrated its potential to strengthen rural livelihoods through integrated soil, energy, and waste-management solutions. In East Africa, particularly in Kenya and Senegal, household-level and community-based pyrolysis systems have been introduced using agricultural residues and biomass waste. These initiatives enabled farmers to produce biochar alongside clean cooking energy, reducing fuelwood consumption and indoor air pollution

while generating a soil amendment for crop fields. Field evaluations reported improved soil moisture retention and crop performance when biochar was applied in combination with organic inputs, while local fabrication and maintenance of kilns created employment opportunities within rural communities (Lehmann & Joseph, 2015; Woolf et al., 2010). Such experiences highlight how biochar systems can simultaneously address livelihood diversification, energy access, and environmental sustainability.

In Southeast Asia and Latin America, farmer cooperatives and small enterprises have adopted decentralized biochar production models linked to agro-processing residues such as rice husk, coconut shell, and sugarcane bagasse. These real-world projects show that biochar production can convert low-value waste into marketable products, improving farm economics while reducing open burning of residues. Participatory field trials revealed that farmers using biochar experienced reduced dependence on chemical fertilizers and greater yield stability under drought stress, leading to higher income security. Moreover, community-managed biochar enterprises supported collective action, knowledge sharing, and local value-chain development, reinforcing social capital in rural regions (Kammann et al., 2017; Schmidt et al., 2021).

In India, biochar production has progressed from experimental trials to pilot-scale livelihood interventions across several states. Research institutions and rural development agencies have demonstrated low-cost drum kilns and tractor-mounted pyrolysis units that utilize surplus crop residues such as rice straw, cotton stalks, and coconut shells. Field-level experiences indicate that farmers adopting biochar reported improvements in soil structure, water-holding capacity, and nutrient use efficiency, particularly

in degraded and rainfed soils. Importantly, village-level biochar production has created seasonal employment for residue collection, kiln operation, and biochar application, contributing to supplementary income generation for smallholders and landless laborers (Agegnehu et al., 2017; FAO, 2022).

More recently, market-oriented biochar initiatives in India have linked rural biochar production with emerging carbon-removal and sustainability markets. Pilot projects in states such as Odisha, Maharashtra, and Madhya Pradesh demonstrate that aggregating biochar production through farmer producer organizations can enhance economic viability while maintaining quality standards. These initiatives illustrate how biochar can generate long-term socio-economic benefits by combining soil health improvement, climate mitigation, and rural enterprise development. However, field evidence also emphasizes the need for policy support, extension services, and access to finance to ensure that biochar adoption remains inclusive and economically sustainable for rural communities (Woolf et al., 2010; Schmidt et al., 2021).

Limitations and Difficulties with Adoption

Despite its advantages, adoption of biochar is hampered by factors like low knowledge, a lack of uniform quality standards, high initial investment costs, and site-specific performance variability (Joseph et al., 2021). Integrated policy assistance, farmer training, and ongoing research are necessary to address these issues.

Conclusion

Biochar is a multipurpose technique that concurrently tackles issues related to rural livelihood, climate change, and soil degradation. Its beneficial effects on the physical, chemical,

and biological characteristics of soil result in increased crop yield, revenue generation, and environmental resilience. Biochar has the potential to revolutionize sustainable agriculture and rural development when it is accompanied by suitable policies, inexpensive technology, and participatory extension strategies. Future initiatives should concentrate on socioeconomic evaluations, region-specific optimization, and incorporating biochar into national soil health and climate action initiatives.

References

1. Agegnehu, G., Bass, A. M., Nelson, P. N., & Bird, M. I. (2017). Benefits of biochar, compost and biochar–compost for soil quality, crop yield and greenhouse gas emissions in tropical agricultural soils. *Science of the Total Environment*, 543, 295–306. <https://doi.org/10.1016/j.scitotenv.2015.11.054>
2. Antal, M. J., & Gronli, M. (2003). The art, science, and technology of charcoal production. *Industrial & Engineering Chemistry Research*, 42(8), 1619–1640.
3. Blanco-Canqui, H. (2017). Biochar and soil physical properties. *Soil Science Society of America Journal*, 81(4), 687–711. <https://doi.org/10.2136/sssaj2017.01.0017>
4. Cayuela, M. L., et al. (2014). Biochar's role in mitigating soil nitrous oxide emissions. *Agriculture, Ecosystems & Environment*, 191, 5–16.
5. FAO. (2021). *The state of the world's land and water resources for food and agriculture*. FAO.
6. Food and Agriculture Organization of the United Nations (FAO). (2022). *Biochar for soil health and climate change mitigation*. FAO.
7. Glaser, B., Lehmann, J., & Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal: A review. *Biology and Fertility of Soils*, 35, 219–230. <https://doi.org/10.1007/s00374-002-0466-4>
8. Jeffery, S., et al. (2017). Biochar effects on crop yield. *Agriculture, Ecosystems & Environment*, 144, 175–187.

9. Joseph, S., et al. (2021). Designing biochar systems for agronomic and environmental benefits. *Sustainability*, 13(2), 1–24.
10. Kammann, C. I., Schmidt, H. P., Messerschmidt, N., Linsel, S., Steffens, D., Müller, C., & Koyro, H. W. (2017). Plant growth improvement mediated by nitrate capture in biochar-amended soils. *Scientific Reports*, 7, 11080. <https://doi.org/10.1038/srep11080>
11. Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability*, 7(5), 5875–5895.
12. Lehmann, J., & Joseph, S. (2015). *Biochar for environmental management: Science, technology and implementation* (2nd ed.). Routledge.
13. Lehmann, J., et al. (2006). Biochar sequestration in terrestrial ecosystems. *Mitigation and Adaptation Strategies for Global Change*, 11, 403–427.
14. Lehmann, J., Rillig, M. C., Thies, J., Masiello, C. A., Hockaday, W. C., & Crowley, D. (2011). Biochar effects on soil biota – A review. *Soil Biology and Biochemistry*, 43(9), 1812–1836. <https://doi.org/10.1016/j.soilbio.2011.04.022>
15. Mukherjee, A., & Lal, R. (2013). Biochar impacts on soil properties. *Geoderma*, 193–194, 122–130.
16. Schmidt, H. P., Hagemann, N., Draper, K., & Kammann, C. (2021). The potential of biochar to contribute to climate change mitigation and sustainable agriculture. *GCB Bioenergy*, 13(2), 208–224. <https://doi.org/10.1111/gcbb.12786>
17. Sohi, S. P., et al. (2010). A review of biochar and soil interactions. *Advances in Agronomy*, 105, 47–82.
18. Thies, J. E., & Rillig, M. C. (2009). Biochar effects on soil microbes. *Biology and Fertility of Soils*, 45, 723–738.
19. Van Zwieten, L., et al. (2010). Biochar effects on soil pH and fertility. *Australian Journal of Soil Research*, 48, 569–576.
20. Warnock, D. D., et al. (2007). Mycorrhizal responses to biochar. *Plant and Soil*, 300, 9–20.
21. Woolf, D., Amonette, J. E., Street-Perrott, F. A., Lehmann, J., & Joseph, S. (2010). Sustainable biochar to mitigate global climate change. *Nature Communications*, 1, 56. <https://doi.org/10.1038/ncomms1053>

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AGROFORESTRY AS A CLIMATE ADAPTATION AND INCOME STRATEGY

Introduction:

The increasing effects of climate change are a major limiting factor to the sustainability of agriculture. Increasing temperatures, uneven distribution of rainfall, extended droughts, augmented floods and an augmented frequency of extreme weather condition significantly impede crop development, diminish yield and cut down the overall productivity of farms. The main climatic stressors such as heat and moisture stress, disrupted patterns of rainfall, and increased pressure of pests and diseases negatively affect the crop growth cycle and increase the risk of production, particularly in rainfed and smallholder agricultural systems. It is not only suppressing agricultural production, but also disrupting income streams and livelihoods of the farming communities. This review synthesizes existing literature to evaluate the economic feasibility of agroforestry as a climate mitigation and adaptation approach.

Agroforestry - More Than Just Planting Trees

Agroforestry is a land-management paradigm of deliberate placement of woody perennials, trees and shrubs, in close association with arable plants or livestock in a single piece of land. Unlike the traditional monoculture, agroforestry model develops the synergism between the elements of the system, and therefore, the increase in productivity, sustainability, and ecological integrity is achieved.

The concept of Agroforestry has a number of principles. The first is the concept of integration: trees are not considered as ancillary or segregated elements but are considered as being part of the greater agricultural system, as co-operating parts of an integrated system. The second is that of diversification: it will not be based on reliance on one crop and thus the risk will be spread throughout a heterogeneous portfolio that can contain timber, fruit, fodder, firewood and medicinal flora. The third principle is about the efficiency of resources, because the existence of trees increases nutrient cycling, water holding ability, and soil protection against erosion forces and, consequently, maintains strong ecological processes. Lastly, agroforestry focuses on long-term sustainability, which allows the agronomic production to be sustained and a wise utilization of natural resources. Using these principles, agrarian systems may transform into active ecosystems where biological processes do not weaken but strengthen the agrarian economy.

Type of AFS	Agro-Ecological Adaptation
Agri-silvicultural systems	
Shifting cultivation, Chena, Taungya, Bewat, dhya, dippa, erka, jhum, kumara, peenda, pothur, podu, rep syrti, zabo	In tropical forest areas in North-East India, Sri Lanka
Plantation-based cropping system	Mainly humid tropical countries (India, Bangladesh, Maldives, Sri Lanka)
Scattered trees on farms, parklands	All regions, especially semiarid, and arid regions
Shelterbelts and windbreaks	In wind-prone areas, especially coastal, arid, and alpine regions of India, Bangladesh, Maldives, Sri Lanka
Boundary Planting and live hedges	In all countries of the region
Woodlots for soil conservation	In hilly areas, along sea coast and ravine lands of the region
Industrial plantations with crops	Intensively cropped area having plantation on bunds
Silvi-pastoral systems	
Silvi-pastures	Sub tropics and tropics with bio-edaphic sub- climaxes
Horti- pastoral	In hilly and non-hilly orchards for soil conservation
Tree on rangelands	In all countries of the region
Plantation crops with pastures	Mostly humid and sub-humid regions with less grazing pressure on plantation lands
Seasonal forestry Grazing	Semi- arid and mountainous ecosystems
Agro-silvi-pastoral systems	
Home gardens	In all countries of the region especially Sri Lanka, India, Maldives, Bangladesh
Others	
Aqua forestry	Low lands
Apiculture with trees	In all countries of the region

Figure 1: Traditional agroforestry systems accepted/adopted in South Asia

Source: Dhyani, S.; Murthy, I.K; Kadaverugu, R.; Dasgupta, R.; Kumar, M.; Adesh Gadpayle, K. *Agroforestry to Achieve Global Climate Adaptation and Mitigation Targets: Are South Asian Countries Sufficiently Prepared?* Forests **2021**, 12, 303.
<https://doi.org/10.3390/f12030303>

Stressors in the Climate of the Modern Farming:

The escalating temperatures, changing patterns of precipitation, and the frequency of extreme events are making changes in the parameters of crop production. As a result, farmers are faced with increased uncertainty, risk and a greater pressure on natural resources.

- **Temperature Stress and Crop Productivity:** Global warming cuts phenological phases and disrupts biochemical processes on which plant development is based. This leads to a shrinkage of agricultural production and agronomic quality of the agricultural product, thus compromising food security and livelihoods of agricultural societies.

- **Rainfall Variability and Water Scarcity:** Delayed monsoon, periodic heavy precipitation and prolonged scarcity interfere with the sowing schedules and increase the irrigation costs. Unbalanced rainfall distribution creates waterlogging in some areas and causes precipitation drought in others, creating a harsh limit on freshwater supply and control in the irrigation industry.
- **Extreme Weather Events and Production Risk:** Over the past decades the frequency and intensity of disastrous weather events such as cyclones, flash floods, sustained heat waves and out-of-season storms have increased. These occurrences may destroy crops in hours, destroy important farming infrastructure and increase topsoil erosion,

thus disrupting the sustainability of production regimes.

- **Land Degradation and Soil Fertility Decline:** Anthropogenic climate dynamics, i.e. increased erosion, nutrient loss and loss of soil organic matter, hasten the erosion of arable land. In the long term, all these processes lead to the decrease of soil fertility, decrease of yields, and increase of the marginal lands which cannot be farmed by the traditional methods.

Agroforestry as a Climate Adaptation Strategy

Agroforestry creates a defensive mechanism whereby the integration of arboreal species with arable crops and livestock provide buffers to farms in the face of rising temperatures, hydric stress, soil erosion and ecological imbalance.

- **Microclimate Control and Temperature Dampening:** Trees in agricultural landscapes serve to control the climate. Their canopies reduce the temperature of the ground hence reducing the heat stress on crops and livestock. Agroforestry also provides stable conditions of growth by mitigating the impacts of extreme temperatures even in response to changing weather patterns.
- **Soil Moisture Conservation and Water-Use Efficiency:** Agroforestry is an inherent water-management system in arid or water deficient areas. Large trees improve the soil structure, infiltration rates and reduce surface runoffs during heavy rainfalls.
- **Soil Fertility and Nutrient Cycling:** Agroforestry enhances the quality of soils by providing a constant supply of organic matter in the form of leaf litter, root turnover and biomass decomposition. This is a natural addition that promotes the activities of microbes and increases the availability of nutrients to crops
- **Erosion Control and Land Stabilization:** Roots of trees hold the particles of soil together to strengthen the soil structure and avoid top soil erosion. On the surface, tree tops disperse the kinetic energy of rain falling

to the ground, minimizing erosion by splash, and shelterbelts slow the speed of wind across the fields. Contour based Agroforestry on hilly slopes serves as a natural check on run off.

- **Biodiversity Conservation and Ecosystem Resiliency:** Agroforestry farms are natural ecosystem models that maintain several vegetation layers. This type of diversity provides habitats to pollinators, birds, useful insects, and soil biota. Increased biodiversity increases the natural pest control, pollination services and ecological stability.
- **Crop-Tree-Livestock Interactions in Climate Stress:** Integrated Agroforestry systems produce the strong synergies between crops, trees and livestock. Trees also act as fodder, shades, and shelter to the animals, which alleviate heat stress and enhance productivity. Stock animals provide manure which makes the soils fertile.

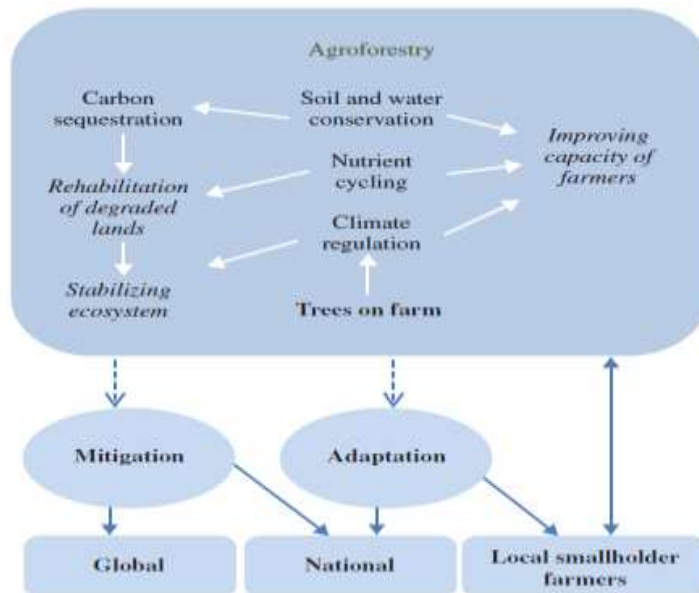


Figure:2 Climate change adaptation and mitigation potential of Agroforestry systems.

Source: Lasco RD, Delfino RJP, Espaldon MLO. Agroforestry systems: helping smallholders adapt to climate risks while mitigating climate change. WIREs Clim Change. 2014. doi: 10.1002/wcc.301

Mechanisms of income diversification:

Agroforestry facilitates income diversification by combining the biological elements such as trees, crops and livestock into the same production platform hence

producing a variety of marketable products. Annual crops provide regular and short-term income whereas trees pay medium- and long-term incomes in form of timber, fruits, fodder, medicinal products and other non-timber forest products. This diversification in time and product enables the farmer not to rely on one commodity and gives the option to take advantage of the various market cycles and price formations. Agroforestry increases financial flexibility at the household level and increases livelihood resilience, especially in the face of production uncertainty caused by the climate change.

Return on investment and Economic Viability:

Economically, agroforestry systems are often shown to be more profitable in the long run compared to monocropping when the planning horizon is long. The initial set up costs might be high because of the need to plant trees and maintain them but the costs are usually compensated through reduced input cost and increased aggregate returns. Improved soil fertility, better moisture retention and better recycling of

nutrients lower the costs incurred in fertilizers and irrigation, and tree products have a high-value output.

Agroforestry, Sustainability, and SDGs:

Agroforestry, in the paradigms of modern agricultural practices, has both direct and indirect impact on a continuum of Sustainable Development Goals (SDGs) by the intentional combination of crop farming with activities that protect the ecological well-being and promote socioeconomic prosperity. This system is indispensable in the war against poverty and the pursuit of food security by richer diversification of income streams, better access to food, and food security even in the face of climatic disturbances. The promotion of responsible production systems the hallmark of which is resource-saving processes, reduced dependence on external resources, and the introduction of sustainable land management, also strengthens the role of agroforestry in enhancing long-term sustainability. Moreover, agroforestry helps in

Table 1: Economic Returns from Different Agroforestry System

AFS Model	Production of Wood (m ³ /ha/year)	Yield of mango (t/ha)	Yield of Mustard (t/ha)	Production of Intercrop (t/ha)	Returns from year (Rs/ha/year)	Return from fruit crops (Mango) (Rs/ha/year)	Returns from mustard crop (Rs/ha/year)	Return from Intercrop (Rs/ha/year)	Gross returns	B:C Ratio
Gamhar + Mango + Cowpea	11.20	7.46	-	3.59	335862.69	223900	-	107750	667512.69	1.05
Gamhar + Mango + Black gram - Mustard	8.98	7.13	0.94	4.34	269484.08	213850	37600	86700.00	607634.08	1.03
Gamhar + Mango + Groundnut - Mustard	13.73	8.05	1.01	2.55	412020.62	241400	40200	152800.00	846420.62	1.82
Gamhar + Mango + Maize -Mustard	9.53	6.67	1.16	4.78	285822.33	200100	46400	286800.00	819122.33	1.73
Gamhar + Mango	6.26	5.79	-	-	187814.84	173750	-	-	361564.84	0.81
Sole Gamhar	4.88	-	-	-	146287.29	-	-	-	146287.29	0.17
Sole Mango	-	5.31	-	-	-	159400	-	-	159400.00	0.59

Source: Murmu, S., Padhi, G. K., Murmu, P., Roy, D., & Dhara, P. K. (2022). *Potential of different fruit-based agroforestry models for improving livelihood in humid and sub-tropical region of India*. Indian Journal of Ecology, 49(5, Special Issue), 1861–1869. <https://doi.org/10.55352/IJE/2022/3748>

the reduction of climate change through sequestration of atmospheric carbon in the arboreal biomass and the soil substratum, hence, reducing the levels of greenhouse gases.

INFERENCE: The return from fruit tree, intercrops and mustard were calculated based on the mean yield and farm gate prices. **Gamhar + Mango + Groundnut + Mustard** based agroforestry model gave the highest returns in terms of income and yield of tree and intercrops i.e., ₹8.46 lakh /ha/yr in Indian Rupee (INR). The sole cropping of mango and Gamhar provides minimal income to the farmers, on the contrary the agroforestry models are enabled to enhance the livelihood of the farmers by combining the complementary effects of the agro-ecosystem.

Agroforestry is a more economically sustainable substitute to a standard monocultural agricultural system, which is more profitable and reduces the income risk in the face of climatic uncertainty at the same time. The volatility of yields inherent in sole-cropping systems lowers the returns of the farm, but agroforestry reduces the effects of economic performance due to diversification of income and reduced dependence on external inputs. Agroforestry strengthens the stability of farm income and ensures the long-term economic sustainability by working as a diversified production system where arboreal parts are built as productive capital assets.

Conclusion:

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ARTICLE ID: 06

APMC REFORM PARAMETERS FOR INCREASE FARMER INCOME

Key Parameters of APMC reform in India

1. Market Liberalization: It means reducing government restrictions on buying, selling, storing leading to reducing APMC monopoly and allowing farmers to sell **outside mandis. current situation of market liberalization in APMC having a e-NAM initiative** that digitally links hundreds of APMC mandis across states to create a unified national market. Currently there are 1522 markets that are linked to the e-NAM network from 23 states and 4 UT's. This platform increases price transparency and provides farmers access to a wider range of buyers, including those in other states. But there is having some constraints like lack of awareness and technical illiteracy, improper dissemination of information, complicated sale process. It is proposed that increasing farmers' knowledge and awareness of e-NAM can encourage and strengthen their usage of this platform for produce marketing.

2. Reduction in Fees and Regulatory Burdens: Multiple market fees like market fee, cess, development fee, entry tax, purchase tax, weighment charges and High commission charges lead to increase farmers' marketing cost and reduce their net returns. The status of Agricultural Produce Market Committee (APMC) market fees in India currently varies by state. Mandi Fees are generally range from 0.8% to 2% of the produce's value, charged to the trader. Commissions can be significant, ranging from 2% to 10% depending on the commodity. For example, last year 2024, Haryana government HSAMB reform labour fee in APMC Market in connection with sale, purchase, storage and processing of agricultural produce, different market functionaries, whether licensed or not, shall not demand or receive remuneration, in excess of the rates specified.

3. Licensing Reforms: The licensing of commission agents in the regulated markets has led to the monopoly of these licensed traders acting as a major entry barrier in existing APMCs for a new entrepreneur thus, preventing competition. The traders, commission agents and other functionaries organize themselves into associations, which generally do not allow easy entry of new persons, stifling the very spirit of competitive functioning. States are encouraged to implement a single, unified trading license valid across the state and a single-point levy of market fees on the first transaction. This reduces transaction costs and barriers to inter-state trade, benefiting both farmers and traders.

4. Private Sector Participation: It offers an appropriate institutional mechanism to attract private investment, technology, and managerial expertise into market infrastructure, logistics, and service delivery. It help to reduce monopoly of APMC Mandis, Improve efficiency in handling, grading, logistics and introduce innovation like e-trading and Blockchain technology. But in current situation, Private sector participation in APMC markets remains low because of a combination of regulatory, structural, and economic barriers.

5. Farmer-Centric Reforms: Farmer-centric reforms aim to empower farmers, increase their income, improve market access, and ensure fair & transparent price discovery.

6. Infrastructure Reforms: Modernization of mandis with Electronic weighbridges, Sorting & grading units, Assaying labs and Cold storage & warehouses, Open auction systems and display of market fees, trader lists, and price information.

Constraints faced by APMC

1. Handling Constraints like Poor Post-Harvest Handling due to follow manual unloading, cleaning, grading and sorting, lack of mechanised conveyors, graders and cleaners increases damage and deteriorate quickly due to slow handling. Farmers forced to use gunny bags, crates of low quality, increasing spoilage. No provision for scientific packaging in most APMCs.

2. Infrastructure Constraints like 40–45% of APMC yards lack shed areas. Less than 10% APMCs have functional cold storage and no pack-houses, ripening chambers and Poor Connectivity & Logistics.

3. Institutional Constraints like due to monopoly of licensed traders, limited number of traders leading to collusive bidding and lower prices for farmers. Due to heavy dependence on commission agents, it creates information asymmetry and reduces farmer bargaining power.

4. Financial Constraints like low Private Sector

Participation and avoid investing due to Regulatory restrictions, structural, and economic barriers leading to underdeveloped markets despite high transaction volumes.

Present Challenges of Agricultural Markets in India

1. Limited Access of Agricultural Produce Markets: There is a huge variation in the density of regulated markets in different parts of the country, which varies from 118 sq km. in Punjab to 11,214 sq km. in Meghalaya, while ideally a regulated market should be available to farmers within a radius of 5 Km.

2. Lack of Market Infrastructure in Agricultural Markets: Studies indicate that covered and open auction platforms exist only in two-thirds of the regulated markets, while only one-fourth of the markets have common drying yards. Cold storage units exist in less than one tenth of the markets and grading facilities in less than one-third of the markets. Electronic weighbridges are available only in a few markets.

3. High Incidence of Market Charges: APMCs are authorized to collect market fee ranging between 0.50 % to 2.0 % of the sale value of the produce. In addition, commission charges vary from 1 % to 2.5 % in foodgrains and 4 % to 8 % in fruits and vegetables. Further, other charges, such as, purchase tax, weighment charges and hamal charges are also required to be paid. In some States, this works out to total charges of about 15 % which is excessive.

4. Less Farmers' Price Realization: The share of farmer in consumer's price is very low particularly in perishables due to a number of intermediaries, lack of infrastructure and poor holding capacity. In order to provide remunerative prices to the farmers, there is a need to reduce intermediation by providing alternative marketing channels like direct marketing, contract

farming, etc. for which reforms in agricultural marketing system are necessary.

Future Prospect to Transforming Agricultural Marketing in India

Agricultural marketing in India is expected to transform with the help of digital and smart technologies. Platforms like e-NAM (National Agriculture Market) will bridge the gap between farmers and buyers, eliminating intermediaries and enhancing price transparency (Aggarwal et al., 2022).

Artificial Intelligence (AI) and the Internet of Things (IoT), help to enable the current status of market demand, pricing trend and weather conditions to make data-driven decisions (Bansal & Singh, 2023). Blockchain technology will help to enhance transparency, ensure traceability, and build consumer trust (Kumar et al., 2023). Infrastructure development will enhance market efficiency, reduce costs, and secure better income opportunities for farmers (Roy, 2023)

Current Status of the Indicators in Agricultural Market

1) Market charge : It include market fees (a levy on the sale/purchase of produce, often ad valorem or percentage-based), cess (additional development or rural funds), commission charges (paid to agents/arhatiyas), and user charges (for infrastructure/services). These vary significantly across states, commodities (e.g., lower for perishables like fruits/vegetables), and market types.

These fees are state specific having a range of most states levy 1-2% market fee; commissions range 1-3.5%

2) Quantity Traded Through APMC vs. Private Markets in India

According to the 2020–21 National

Statistical Office (NSO) data, farmers sold only 15–22% of their agricultural produce through APMC mandis, of which merely 6% of the total APMC trade occurred via the e-NAM platform. This indicates that even within regulated markets, the level of digital integration remains limited. In contrast, a substantial 60–70% of the produce is channelled through local private markets or direct sales to traders, processors, and consumers.

This trend is clearly visible in Uttar Pradesh, India's largest wheat-producing state. Out of a marketable surplus of 16 million metric tonnes (MT) of wheat, only 1 million MT (6.25%) was procured by state agencies through APMC mandis. The remaining 15 million MT (93.75%) was sold to private buyers, including local traders, aggregators, and processing units. This shift underscores the growing dominance of private trade in agricultural marketing, even in states with an established APMC structure.

Status of e-NAM

Principal Market Yards	2591
Sub-Market Yards	4329
Total APMC	6920
Total e-NAM Mandis	1522
%age share of e-NAM	22%

The trade of ₹4,39,941 crores has been recorded on e-NAM platform. The addition of 09 new commodities will further increase this number to 247 for online auction on the e-NAM.(PIB, 2025). To encourage small and marginal farmers, especially from rural areas to actively participate in the e-NAM platform, Government has taken various initiatives. Training programs are conducted at each e-NAM mandi for farmers and stakeholders.

3) Gap between Farm gate price

The gap between farm-gate prices and retail or consumer prices for agricultural produce—commonly referred to as the farmer-to-consumer price spread or marketing margin—remains a significant challenge in India. This disparity is often substantial, resulting in farmers receiving only a small share of the final price paid by consumers.

For example, in Himachal Pradesh, apples are sold at a farm-gate price of ₹30–50 per kg, while the retail price ranges from ₹120–200 per kg. Consequently, farmers receive only 25–35% of the consumer price, with a large markup captured by intermediaries, logistical costs, and market inefficiencies.

Summary

APMC market provide a regulated, transparent auction platform where price is discovered based on Supply and Demand. On the other hand, the licensing of commission agents in the regulated markets has led to the monopoly of these licensed traders acting as a major entry barrier in existing APMCs. It needs Private sector Partnership investment but they don't invest due to Regulatory restrictions, structural, and economic barriers leading to underdeveloped markets despite high transaction volumes. I think market should be Liberalized, because due to this, reducing APMC monopoly and allowing farmers to sell outside mandis and it also attract the Private Sector Participation investment because of removing a combination of regulatory, structural, and economic barriers.

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ARTICLE ID: 07**Biochar: Climate-Smart Amendment for Improving Soil
Properties in Semi-Arid Soils****Abstract**

Soil degradation and low organic matter content are some of the most significant limitations in semi-arid areas. Biochar, a carbon-rich material produced from biomass pyrolysis, has recently been recognized as a climate-smart soil amendment that can improve soil properties and promote sustainable agriculture in water-limited environments. This review aims to compile existing knowledge on biochar production techniques such as pyrolysis, gasification, torrefaction, and electrochemical modification, as well as their impact on the physical, chemical, and biological properties of semi-arid soils. There is evidence that the addition of biochar to soil reduces soil bulk density, increases water-holding capacity, improves soil aggregation, and increases soil organic carbon and microbial biomass. These effects are dependent on the type of biochar feedstock, production conditions, and application rates. The use of biochar in soil management practices not only helps to stabilize soil organic matter but also improves nutrient retention, microbial processes, and overall soil resilience. The use of biochar in soil management practices is therefore a promising approach for mitigating soil degradation, improving carbon sequestration, and increasing crop productivity in semi-arid ecosystems. Future studies should therefore be focused on improving biochar properties and application techniques to fully exploit its potential in different climatic conditions.

Keywords: Biochar, Semi-arid soils, Soil organic carbon, Soil physical properties, Climate-smart agriculture.

1. Introduction

Soil organic matter (SOM) is a critical indicator of soil health, governing nutrient availability, structural stability, water retention, and ecosystem resilience, particularly in semi-arid regions where soils are highly vulnerable to degradation. These regions are characterized by low and erratic rainfall, high temperatures, and limited biomass production, which restrict organic carbon inputs and accelerate SOM mineralization. As a result, semi-arid soils commonly exhibit low SOM stocks, poor aggregation, reduced water-holding capacity, and declining productivity.

In this context, biochar has emerged as a promising soil amendment for building and stabilizing SOM due to its high carbon content, aromatic structure, and resistance to microbial decomposition. Beyond its direct contribution to stable carbon pools, biochar enhances SOM accumulation indirectly by improving soil physical properties, increasing nutrient retention, stimulating microbial activity, and promoting plant biomass production. Consequently, the integration of biochar into semi-arid soil management strategies offers a viable pathway to enhance SOM sequestration, improve soil functionality, and strengthen agricultural resilience under climate-stressed environments.

1. Biochar

Biochar, a solid obtained through the pyrolysis of biomass, has been employed for thousands of years and is generally known as charcoal when obtained from wood biomass. Its uses are diverse, including the production of heat and power, flue gas treatment, metallurgical applications, agricultural and farm use, construction materials, and even medical applications. More recently, biochar has emerged as a promising alternative to fossil carbon materials to reduce greenhouse gas emissions.

During the carbonization process, some biomass is decomposed, while a substantial amount of carbon is conserved, producing a material rich in carbon, which is ideal for different technical purposes. The properties of biochar are determined by the type of biomass as well as the carbonization process. Torrefaction, a low-temperature pyrolysis process up to 300 °C, improves some of the limiting factors of raw biomass, including grindability, which is important for co-firing and co-gasification with coal-handling systems. However, higher treatment temperatures are needed for the

production of biochar with very high carbon content. In addition to the technical applications of biochar in energy conversion, gas and water purification, and metallurgical applications, biochar is also used as a soil conditioner for improving fertility and carbon sequestration. Evidently, different applications demand different properties of biochar.

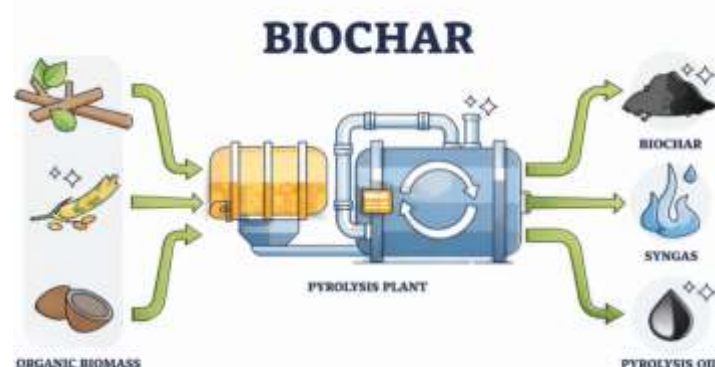


Fig. 1. Conversion of Biomass into Biochar and Byproducts

2. Methods of biochar production

3.1 Pyrolysis

Pyrolysis is a thermo-chemical conversion process in which biomass is heated in the absence of oxygen or with limited oxygen supply to produce biochar and gas/liquid products. Agricultural biomass is primarily composed of cellulose, hemicellulose, lignin, and silica, with cellulose undergoing decomposition at 350 °C and lignin undergoing decomposition at higher temperatures. Therefore, the temperature range for pyrolysis is 300-700 °C. Although pyrolysis is an oxygen-free process, external heat sources like hot gas, solid, or partial oxidation are necessary. Depending on the process parameters of temperature, heating rate, and residence time, there are traditional and new methods of

pyrolysis, namely flash pyrolysis, vacuum pyrolysis, and microwave pyrolysis.

3.2 Gasification

Gasification is a common thermochemical method for the production of syngas from solid fuels, which produces more gas and less emissions than pyrolysis, combustion, and fermentation. Hydrogen is the main product of gasification, but a large amount of biochar is also produced as a byproduct. Gasification biochar, which is often regarded as waste, has several uses: adsorption of pollutants, carbon sequestration, wastewater treatment, and soil conditioning. Gasification is carried out at high temperatures (>700 °C) with controlled oxygen or steam flow, and gas composition depends on the gasification agent used. Steam addition increases hydrogen production and syngas calorific value. Biomass materials undergo decomposition at 400-500 °C to produce biochar, which further reacts at higher temperatures to produce hydrogen-rich syngas. Gasification has been successfully carried out with various feedstocks, such as biomass wastes, sewage sludge, and municipal waste, producing a large amount of hydrogen and biochar that can be recovered.

3.3 Torrefaction

Torrefaction is a low-temperature thermochemical process that involves the heating of biomass at relatively low temperatures (230-300 °C) in low oxygen conditions to improve its physical and chemical properties. Torrefaction is usually employed as a pretreatment process to improve the properties of biomass during combustion, gasification, and co-firing. Hemicellulose undergoes partial decomposition during torrefaction, resulting in a more stable and carbon-rich solid with low moisture sensitivity.

The process is usually carried out in a fixed bed reactor at atmospheric pressure. It has been observed that torrefaction and densification result in the production of high-quality pellets compared to raw biomass. Agricultural and forest residues have been found to undergo hemicellulose decomposition at temperatures around 240 °C, while cellulose decomposition starts at temperatures above 280 °C.

3.4 Electro-modified biochar

Biochar has a high adsorption capacity for the removal of pollutants from soil, water, and air and also has the ability to retain nutrients. To improve the selectivity of biochar towards targeted pollutants, it is often subjected to chemical modification, resulting in the production of so-called modified biochar. This modification involves the use of metals such as Fe, Mg, or Al, which helps to modify the surface functional groups and pore size, resulting in improved efficiency of adsorption. Some of the recent developments in this area include electro-modification, which is a fast and efficient method of modifying biochar using an electric field to enhance the surface area and impregnate metal ions on the biochar. Electrochemically modified biochar, prepared from aluminum or magnesium sources, has been found to possess high phosphate adsorption capacity due to the presence of nano-sized metal oxides and hydroxides on its surface, thus proving its potential for targeted applications in environmental remediation.

3. Effect of biochar on soil physical properties

4.1 Effect of Biochar on Soil Bulk Density

Soil bulk density is a measure of soil compaction and the degree of packing of soil particles, which is defined as the ratio of the oven-dry weight of soil to its total volume. High bulk density values (>1.6 Mg m⁻³) are known to limit water

infiltration and root penetration, thus adversely impacting soil physical properties and plant growth. The effect of biochar addition on soil bulk density has been found to be significant due to its low density and high porosity, which increases the volume of soil pores. The results have indicated a steady decrease in soil bulk density with an increase in biochar application rates.

4.2 Effect of Biochar on Water Holding Capacity

Soil water retention capacity is the maximum water-holding capacity of the soil, which is an important factor in crop growth and water conservation. Soils with higher water-holding capacity need irrigation less frequently and are more favorable for plant growth. Various studies have shown that the application of biochar can greatly improve soil water retention capacity. For instance, biochar application has been shown to increase the available water content by as much as 97% and saturated water content by 56%. Soils treated with biochar have also been shown to have about 15% higher water retention capacity than soils not treated with biochar. The influence of biochar on water retention capacity is highly dependent on soil texture, and significant improvements have been observed in sandy soils, while there are no effects in loamy and clay soils. The improvement in water retention capacity is mainly due to the increased porosity of the soil, the adsorptive properties of biochar, and the presence of hydrophilic functional groups on the surface of biochar.

4.3 Effect of Biochar on Soil Aggregation

Soil aggregation is the process by which soil colloidal particles are bound together by overall attractive forces, resulting in the formation of stable soil aggregates. A well-aggregated soil promotes efficient water and nutrient movement and their subsequent uptake by plants. Microbial participation in aggregate formation is significant,

as microorganisms produce polysaccharides that function as a binding agent for soil particles. The addition of biochar provides ideal microhabitats that shield soil microorganisms from predators and desiccation, thus promoting microbial activity and polysaccharide production, ultimately improving soil aggregation and structure.

4.4 Effects of Biochar Application on SOC

The application of biochar can rapidly enhance the soil carbon pool owing to its high carbon concentration and strong resistance to microbial decomposition. Biochar incorporation has been shown to significantly increase soil organic carbon (SOC) along with water-soluble organic carbon (WSOC) and soil microbial biomass carbon (SMBC), reflecting improved carbon availability and microbial activity in soil. The extent of SOC improvement is strongly influenced by biochar characteristics and application rate, with higher pyrolysis temperatures producing more aromatic and stable carbon forms, and greater application amounts contributing more persistent carbon inputs to the soil system.

Conclusion

The addition of biochar to semi-arid soils greatly improves the physical and chemical properties of the soil, such as bulk density, water-holding capacity, and soil aggregation. The addition of biochar to soil increases the organic carbon content of the soil, thus acting as a carbon sink. The effectiveness of biochar is largely dependent on the type of material used, the process of its production, and the rate at which it is applied to the soil. Therefore, biochar is a climate-smart soil amendment that has the potential to improve soil quality and support sustainable agriculture in semi-arid areas.

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ARTICLE ID: 08

WHEAT GROWTH CYCLE: STAGES FOR OPTIMAL YIELD SUCCESS

Introduction

Wheat (*Triticum aestivum*) remains one of the world's most significant staple crops, cultivated in a variety of climates and regions. Wheat is essential to the global food supply because it is the primary food source for millions of people. Understanding wheat growth stages and their specific physiological changes is critical for achieving consistently high yields and optimal grain quality. From seed germination to grain filling and ripening, each stage presents unique management challenges and opportunities. Making timely, informed decisions about imaging, nutrient application, and crop protection can significantly improve productivity and sustainability. In this comprehensive guide, we will look at the various stages of wheat plant development, the science behind each stage, and practical wheat crop management tips.



Whether you're an individual farmer, agribusiness, researcher, or agricultural service provider, this resource will help you master the timing of interventions to increase yields, improve grain quality, and implement more sustainable farming practices.

1. Germination and Seeding Establishment

Seed germination is the process by which a seed matures into a new plant. It involves the activation of the seed's metabolic machinery, which results in the growth of the embryonic plant within the seed. This process begins when the seed is exposed to the appropriate conditions, such as water, oxygen, and a suitable temperature. During germination, the seed absorbs water, swells, and eventually splits its coat, allowing the embryonic root (radicle) to emerge and grow in the soil. The germination of wheat seeds signifies the start of the growth cycle and has a significant impact on subsequent phases and ultimate yield. Fast, even emergence requires ideal soil temperatures (50-86°F/10-30°C) and sufficient moisture content after careful sowing in fields that have been prepared.

Swelling and Seed Absorption: The germination process starts when wheat seeds absorb water from the soil and swell. Enzymes required for growth are activated by this absorption.

Radicle Emergence: The embryonic root (radicle) emerges first, anchoring the plant and initiating nutrient uptake.

Coleoptile Growth: The coleoptile (a sheath that protects the shoot) pushes through the surface before stopping as the first true wheat leaf emerges. For the best results, ensure even seed coverage, the appropriate depth (2.5-5 cm), and proper irrigation. Rapid and uniform seedling establishment lays the groundwork for strong tillering, healthy leaves, and hardy wheat crops.

2. Wheat tillering stage: Building foundation for high yield

Tillering is a critical wheat growth stage that begins after the plant produces three to four leaves.

During this time, the plant produces multiple tillers (side shoots) from the basal nodes, each of which has the potential to form a wheat head containing grains.

- **Tiller Formation:** The number of productive tillers greatly influences maximum yield potential per unit area.
- **Resource Competition:** Proper Nutrition and Water availability at this stage reduces competition and promotes even development.
- **Management practices:** Maintain weed-free conditions and supplement with nitrogen as needed to increase tiller survival and vigor.

Optimal conditions: Air temperatures ranging from 55°C to 75°F and consistent moisture availability promote robust development.

Timely interventions during the wheat tillering stage have a direct, long-term impact on the number of spikelets per head, fertilizable florets, and final grain count.

3. Stem elongation: establishing wheat canopy and head formation

Plants begin to elongate their stems (jointing) after tillering. The primary shoots and tillers grow taller as the internodes (sections between plant nodes) lengthen, resulting in a strong canopy for energy capture.

Node Appearance: The first node is visible only above the soil, signaling stem elongation begins. Each successive node provides support for new leaves and the developing head.

Photosynthetic Efficiency: A dense canopy Maximizes light interception and energy

conversion, thereby promoting grain and biomass development.

Moisture and nutrient demand: This period a surge in nutrient and moisture requirements; deficiencies can stunt growth or reduce spikelet fertility.

4. Booting: The critical pre-flowering wheat growth stage

The booting stage marks the wheat head's rapid development and the establishment of spikelet and floret numbers. The tiny wheat head (inflorescence) remains within the flag leaf's sheath.

- **Head Development:** The wheat head matures hidden within the sheath, determining the theoretical maximum grain count.
- **Flag Leaf:** This is the highest leaf on the stem and is extremely important. The flag leaf can provide up to 75% of the energy required for future wheat grain filling.
- **Monitoring pests and diseases:** is crucial for protecting developing heads, particularly against armyworms.

Moisture Management: Water deficits at this stage, when the grain number is being determined, can significantly reduce yield. Aim for soil moisture levels of 70-80% field capacity.

5. Wheat heading and flowering period (Anthesis): Grain setting phase

The reproductive climax of the wheat crop occurs during the heading and flowering (anthesis) stages, which determine the number of grains produced on each head.

Heading: The wheat head starts to emerge from the flag leaf sheath. The process is divided into distinct stages (10.1 to 10.5), beginning with awn visibility and ending with full head exposure.

Flowering (Anthesis) begins within a few days of the plant heading. This typically takes 4-5 days, with pollination and fertilization determining grain set.

Temperature Sensitivity: The wheat flowering period is extremely sensitive to temperature (optimal range: 64-75°F/18-24°C) and drought. Any stress experienced during anthesis can have a significant impact on grain quantity and quality.

Best Practices: Provide adequate irrigation, closely monitor for pests and diseases, and ensure that no chemicals are used that could disrupt pollination. Enable wheat growers to securely track and document inputs and harvest quality, thereby improving supply chain transparency.

6. Wheat grain filling and ripening: maximizing kernel weight & quality

Following pollination, wheat enters wheat grain filling, the final growth stage in which kernels accumulate starch and proteins, gaining weight and nutritional value. Efficient wheat grain filling is critical for high yield and superior grain quality.

Kernel Development: Wheat kernels grow, moisture levels fall from around 80% to 20-25% by harvest, and protein/carbohydrate deposition occurs.

Ripening: As ripening progresses, the plant senesces. The leaves yellow and die back, while the kernels harden (approaching physiological maturity).

Water and Temperature Criticality: Drought or heat stress during this period reduced kernel fill and yield. Optimal moisture levels and moderate temperatures result in plumper, heavier grains.

Management: Maintain soil moisture, continue

disease and pest surveillance, and carefully time fertilizer applications so that nutrients are available but not in excess. Using satellite-based verification for crop insurance and loans reduces risks from unpredictable weather and helps to protect harvest value.

7. Wheat maturation and harvest: securing maximum yield

Maturity is the end of the wheat growth cycle, when further grain filling stops and kernels reach harvestable moisture content (usually 12-15% for safe storage).

Physical Signs: The crop turns golden brown, the stems are brittle, and the majority of the leaves are dry.

Kernels: At physiological maturity, kernels are hard, difficult to divide with a thumbnail, and break easily.

Optimal Harvest Timing: Early harvest reduces grain shattering and loss due to storms, pests, or late-season diseases. Delayed harvesting reduces quality and yield.

8. Advanced precision farming platform

the forefront of agricultural innovation, providing advanced satellite-based farm management solutions that are accessible via web, Android, iOS, and API integration. Our mission is to make precision agriculture affordable and accessible to farmers, agribusinesses, and policymakers.

Carbon Foot printing: Real-time carbon accounting and reporting features help to monitor, benchmark, and reduce the environmental impact of wheat cultivation.

Crop Loans and Insurance: Using satellite data, remote verification, and risk assessment can speed up access to agricultural financing.

9. Key environmental factors affecting wheat yield

Specific environmental factors influence each phase of the wheat growth cycle. Understanding and anticipating the following variables is critical for effective management:

1. **Temperature:** Wheat is a cool-season crop, yet different growth stages have unique optimal temperature ranges:

Germination: 50–86°F (10–30°C)

Tillering: 55–75°F (13–24°C)

Heading & Anthesis: 64–75°F (18–24°C)

Grain Filling: 64–86°F (18–30°C)

Frost events during flowering and grain fill can lead to serious yield reduction.

2. **Water Availability:** Proper soil moisture is essential for seedling establishment, tillering, booting, and wheat grain filling. Acute droughts can result in "shriveled heads" or poor kernel development, making irrigation management critical.

3. **Soil Fertility:** Nutrient-rich, well-structured soils (pH 6.0-7.5) promote healthy growth. Address phosphorus and nitrogen deficiencies before and during stem elongation and tillering.

4. **Wheat requires ample sunlight** for efficient photosynthesis, particularly during the flag leaf and stem elongation phases.

5. **Other Factors:** Without targeted wheat crop management, pests, diseases, soil compaction, and weed competition can significantly reduce yield.

10. Wheat crop management: Best practices for each key growth stage

Pre-Sowing:

- ✓ Soil should be tested and amended as needed (for wheat cultivation).

- ✓ Use certified, disease-free seed to ensure even emergence.
- ✓ For optimal wheat growth conditions, plan the variety and sowing date around the local seasons.

Germination/Seedling:

- ✓ Maintain moist, aerated soil during the wheat seed germination process.
- ✓ Pests and diseases that live in the soil should be monitored and controlled.

Tillering:

- ✓ For optimal wheat tillering stage success, use split nitrogen fertilization and weed control.

Stem Elongation & Booting:

- ✓ Timely irrigation promotes head and stem development, which is critical for high yield.
- ✓ Look for signs of fungal and insect attacks and respond quickly with recommended methods.

Heading and Flowering:

- ✓ Avoid pesticide sprays that may harm pollinators and limit field traffic during anthesis.
- ✓ Maintain stable soil moisture levels to ensure kernel set and reduce sterility risk.
- ✓ Heat waves and frost are particularly damaging right now, so keep an eye on the weather.

Grain Filling & Ripening:

- ✓ Maintain irrigation to prevent heat and drought stress until physiological maturity.
- ✓ Continue disease and lodging surveillance.

Maturity/Harvest:

- ✓ Plan to harvest as soon as the moisture content reaches a safe level (12-15%).
- ✓ Protect harvested grain from rain, pests, and mechanical damage to ensure top quality.

11. Conclusion

To achieve optimal wheat growth and consistent high yields, it is critical to understand and precisely manage the various stages of the wheat crop cycle, from seed germination to maturity and harvest. Each phase has different soil, moisture, and temperature requirements and is susceptible to various environmental factors.

Effective wheat crop management requires:

- Monitor plant development using advanced technology.
- Proactively addresses environmental challenges such as drought, pests, and disease outbreaks.
- Verifying inputs and harvest data to ensure transparency and market access.
- Optimizing each stage to maximize yield and grain quality.

Whether you're a farmer, an agribusiness manager, or involved in agricultural policy, understanding the wheat growth stages ensures that every input results in maximum yield, profitability, and sustainability. Embrace advanced agri-technology, educate your practice with stage-specific interventions, and ensure the global food supply for future generations.

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ARTICLE ID: 09

Double-Stranded RNA-Mediated Gene Silencing: A Novel Strategy for Managing Plant Pathogens

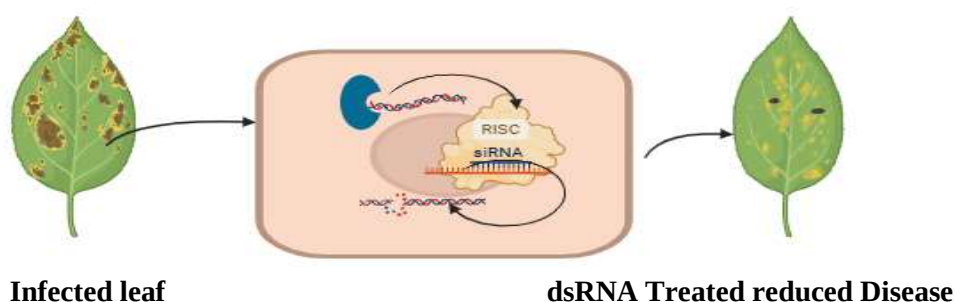
Introduction

Plant diseases caused by fungi, bacteria and viruses significantly reduce crop productivity worldwide, necessitating sustainable alternatives to chemical control methods. RNA interference (RNAi), first discovered by Andrew Fire and Craig mello, 1998, suggesting its role in that double-stranded RNA (dsRNA) induces sequence-specific degradation of homologous messenger RNA, thereby suppressing gene expression. In plants, RNA silencing functions as a fundamental defense mechanism, particularly against viral pathogens, and regulates endogenous gene expression pathways (Baulcombe, 2004). Exploiting this conserved mechanism, Host-Induced Gene Silencing (HIGS) has been shown to confer resistance against fungal pathogens through plant-mediated expression of dsRNA targeting essential pathogen genes (Nowara et al., 2010). Furthermore, Spray-Induced Gene Silencing (SIGS) have shown exogenously applied dsRNA can be taken up by pathogens such as *Fusarium graminearum*, resulting in reduced infection and disease development without the need for transgenic modification (Koch et al., 2016). Collectively, these studies establish that dsRNA-mediated gene silencing provides a sequence-specific and environmentally compatible strategy for controlling plant pathogens by targeting genes critical for their growth and virulence.

Mechanism of dsRNA-Mediated Gene Silencing in Plant Pathogens

Double-stranded RNA (dsRNA)-mediated gene silencing in plant pathogens operates through a conserved RNA interference (RNAi) pathway functioning at the post-transcriptional level. Upon entry into fungal cells, dsRNA molecules are processed by Dicer-like (DCL) enzymes into small interfering RNAs (siRNAs), typically 20–25 nucleotides in length.

Fig 1: Mechanism of dsRNA Mediated Gene Silencing in Plant Pathogenic Fungi



These siRNAs are subsequently incorporated into Argonaute-containing RNA-induced silencing complexes (RISCs), which guide sequence-specific degradation of complementary messenger RNA transcripts, resulting in suppression of target gene expression. In the filamentous fungus *Neurospora crassa*, functional Dicer and Argonaute proteins were shown to be essential components of the RNAi machinery, thereby establishing the molecular basis of dsRNA-triggered gene silencing in fungi (Catalanotto et al., 2004).

The efficiency of dsRNA-mediated silencing in plant pathogenic fungi depends on intact RNAi pathway components. Mutations in Dicer-like genes have been reported to impair gene silencing efficiency and influence fungal development (Dang et al., 2011).

Host-Induced and Spray-Induced Gene Silencing Strategies

Host-Induced Gene Silencing (HIGS) was experimentally demonstrated in the interaction between barley and the obligate biotrophic fungus *Blumeria graminis*. Transgenic barley plants expressing double-stranded RNA constructs targeting fungal genes showed reduced haustorium formation and decreased fungal development, indicating that host-derived dsRNA can induce gene silencing within fungal cells and impair infection (Nowara et al., 2010). This study provided direct evidence that plant-expressed dsRNA can suppress pathogen gene expression during host colonization.

Spray-Induced Gene Silencing (SIGS) represents a non-transgenic alternative in which double-stranded RNA molecules are applied externally. Topical application of double-stranded RNA targeting viral genes was shown to protect plants against virus infection, demonstrating that externally applied RNA molecules can trigger RNA interference and confer disease resistance without genetic modification of the host plant (Mitter et al., 2017). Foliar delivery of dsRNA can be enhanced by incorporating non-ionic surfactants such as Tween-20, Triton X-100, or organosilicone surfactants like Silwet L-77, which reduce surface tension and improve leaf surface penetration and RNA uptake (Numata et al., 2014). This work highlighted the potential of RNA-based crop protection strategies as environmentally adaptable tools for sustainable

disease management. Exogenous dsRNAs can activate RNAi in both plants and pathogens (Dubrovina & Kiselev, 2019). The effectiveness of delivery varies among plant organ. High pressure leaf and bud spraying are more efficient than petiole absorption or trunk injection (fDalakouras et al., 2018).

Together, these experimentally validated studies illustrate two distinct delivery methods host-mediated and external application through which dsRNA can be utilized to suppress pathogen gene expression and reduce disease development.

Table:1 dsRNA in Silencing Genes of Plant Pathogens

Mechanism	Plant	Pathogen	Target Gene	Function	Reference
HIGS	Rice	<i>Magnaporthe oryzae</i> and <i>Xanthomonas oryzae</i>	OsSS12	Fatty acid metabolism	Jiang et al 2009
HIGS	Rice	<i>Magnaporthe oryzae</i>	OsFAD7 and OsFAD8	Omega 3 fatty acid synthesis	Yara et al 2007
HIGS	Barley	<i>Blumeria graminis</i> f. sp. <i>hordei</i>	Avr10 and Avr1	Host cell manipulation	Nowara et al., 2010
SIGS	Tobacco	<i>Tobacco mosaic virus</i>	Viral coat protein gene	Genome encapsidation	Mitter et al., 2017
HIGS	Tomato	<i>Verticillium dahliae</i>	Ave	Host immune modulation	Song & Thomas, 2018
SIGS	Barley	<i>Fusarium graminearum</i>	CYP51A, CYP51b and CYP51C	Ergosterol biosynthesis	Wang et al., 2016

Applications of dsRNA Technology in Plant Disease Management

Environmental RNA interference was examined in *Sclerotinia sclerotiorum*, where externally applied double-stranded RNA targeting Dicer-like genes resulted in reduced transcript accumulation of the targeted genes (Wytinck et al., 2020). The study demonstrated that dsRNA exposure directly influenced gene expression within the fungal pathogen. This finding confirmed that externally supplied RNA molecules can activate endogenous RNA interference pathways in necrotrophic fungi.

In *Fusarium graminearum*, spray application of long dsRNA molecules targeting CYP51 genes significantly reduced fungal infection in barley leaves (Koch et al., 2016). The treated plants showed decreased fungal biomass compared to controls, providing experimental evidence that external dsRNA application can suppress pathogen development under infection conditions.

Similarly, McLoughlin et al. (2018) reported that application of gene-specific dsRNA molecules against *Botrytis cinerea* led to suppression of fungal growth and reduced lesion expansion in treated plant tissues. Their findings supported the feasibility of spray-induced gene silencing as a non-transgenic disease control approach.

Collectively, these studies demonstrate that dsRNA technology can function across different fungal pathogens, directly suppressing gene expression and limiting disease progression under controlled experimental conditions.

CONCLUSION

Double-stranded RNA (dsRNA) mediated gene silencing represents a promising advancement in plant disease management. By exploiting the natural RNA interference pathway, dsRNA technology enables precise suppression of essential pathogen genes, thereby reducing infection and disease severity. Both Host-Induced Gene Silencing (HIGS) and Spray-Induced Gene Silencing (SIGS) have demonstrated practical potential for controlling fungal and viral pathogens through targeted molecular intervention. Unlike conventional chemical

pesticides, dsRNA-based approaches offer specificity and adaptability, aligning with sustainable crop protection strategies. Although challenges related to stability, delivery efficiency, and large-scale application remain, continued research and technological refinement are likely to enhance its field-level applicability. Overall, dsRNA technology holds significant promise as a next generation tool for environmentally responsible and precision-based plant disease management.

References

- Baulcombe, D. (2004). RNA silencing in plants. *Nature*, 431, 356–363. <https://doi.org/10.1038/nature02874>
- Catalanotto, C., Pallotta, M., ReFalo, P., Sachs, M. S., Vayssie, L., Macino, G., & Cogoni, C. (2004). Redundancy of the two Dicer genes in transgene-induced post-transcriptional gene silencing in *Neurospora crassa*. *Molecular and Cellular Biology*, 24(6), 2536–2545. <https://doi.org/10.1128/MCB.24.6.2536-2545.2004>
- Dalakouras, A., Jarausch, W., Buchholz, G., Bassler, A., Braun, M., Manthey, T., ... & Wassenegger, M. (2018). Delivery of hairpin RNAs and small RNAs into woody and herbaceous plants by trunk injection and petiole absorption. *Frontiers in Plant Science*, 9, 1253. <https://doi.org/10.3389/fpls.2018.01253>
- Dang, Y., Yang, Q., Xue, Z., & Liu, Y. (2011). RNA interference in fungi: Pathways, functions, and applications. *Eukaryotic Cell*, 10(9), 1148–1155. <https://doi.org/10.1128/EC.05109-11>
- Dubrovina, A. S., & Kiselev, K. V. (2019). Exogenous RNAs for gene regulation and plant resistance. *International journal of molecular sciences*, 20(9), 2282. <https://doi.org/10.3390/ijms20092282>
- Fire, A., Xu, S., Montgomery, M. K., Kostas, S. A., Driver, S. E., & Mello, C. C. (1998). Potent and specific genetic

- interference by double-stranded RNA in *Caenorhabditis elegans*. *Nature*, 391, 806–811.
<https://doi.org/10.1038/35888>
- Nowara, D., Gay, A., Lacomme, C., Shaw, J., Ridout, C., Douchkov, D., Hensel, G., Kumlehn, J., & Kogel, K. H. (2010). HIGS: Host-induced gene silencing in the obligate biotrophic fungal pathogen *Blumeria graminis*. *The Plant Cell*, 22(9), 3130–3141.
<https://doi.org/10.1105/tpc.110.077040>
- Jiang, C. J., Shimono, M., Maeda, S., Inoue, H., Mori, M., Hasegawa, M., ... & Takatsuji, H. (2009). Suppression of the rice fatty-acid desaturase gene OsSSI2 enhances resistance to blast and leaf blight diseases in rice. *Molecular plant-microbe interactions*, 22(7), 820–829.
<https://doi.org/10.1094/MPMI-22-7-0820>
 - Koch, A., Biedenkopf, D., Furch, A., Weber, L., Rossbach, O., Abdellatif, E., Linicus, L., Johannsmeier, J., Jelonek, L., Goesmann, A., Cardoza, V., McMillan, J., Mentzel, T., & Kogel, K. H. (2016). An RNAi-based control of *Fusarium graminearum* infections through spraying of long dsRNAs involves a plant passage and is controlled by the fungal silencing machinery. *PLoS Pathogens*, 12(10), e1005901.
<https://doi.org/10.1371/journal.ppat.1005901>
 - McLoughlin, A. G., Wytinck, N., Walker, P. L., Girard, I. J., Rashid, K. Y., De Kievit, T., Whyard, S., & Belmonte, M. F. (2018). Identification and application of exogenous dsRNA confers plant protection against *Sclerotinia sclerotiorum* and *Botrytis cinerea*. *Scientific Reports*, 8(1), 7320.
<https://doi.org/10.1038/s41598-018-25434-4>
 - Mitter, N., Worrall, E. A., Robinson, K. E., Li, P., Jain, R. G., Taochy, C., Fletcher, S. J., Carroll, B. J., Lu, G. Q., & Xu, Z. P. (2017). Clay nanosheets for topical delivery of RNAi for sustained protection against plant viruses. *Nature Plants*, 3, 16207.
<https://doi.org/10.1038/nplants.2016.207>
 - Nowara, D., Gay, A., Lacomme, C., Shaw, J., Ridout, C., Douchkov, D., Hensel, G., Kumlehn, J., & Kogel, K. H. (2010). HIGS: Host-induced gene silencing in the obligate biotrophic fungal pathogen *Blumeria graminis*. *The Plant Cell*, 22(9), 3130–3141.
<https://doi.org/10.1105/tpc.110.077040>
 - Numata, K., Ohtani, M., Yoshizumi, T., Demura, T., & Kodama, Y. (2014). Local gene silencing in plants via synthetic dsRNA and carrier peptide. *Plant biotechnology journal*, 12(8), 1027–1034.
<https://doi.org/10.1111/pbi.12208>
 - Song, Y., & Thomma, B. P. H. J. (2016). Host-induced gene silencing compromises Verticillium wilt in tomato and Arabidopsis. *Molecular Plant Pathology*, 19(1), 77–89.
<https://doi.org/10.1111/mpp.12500>
 - Wang, M., Weiberg, A., Lin, F. M., Thomma, B. P., Huang, H. D., & Jin, H. (2016). Bidirectional cross-kingdom RNAi and fungal uptake of external RNAs confer plant protection. *Nature plants*, 2(10), 1–10.
<https://doi.org/10.1038/nplants.2016.151>
 - Wytinck, N., Manchur, C. L., Li, V. H., Whyard, S., & Belmonte, M. F. (2020). dsRNA uptake in plant pests and pathogens: insights into RNAi-based insect and fungal control technology. *Plants*, 9(12), 1780.
<https://doi.org/10.3390/plants9121780>
 - Yara, A., Yaeno, T., Hasegawa, M., Seto, H., Montillet, J. L., Kusumi, K., ... & Iba, K. (2007). Disease resistance against *Magnaporthe grisea* is enhanced in transgenic rice with suppression of ω -3 fatty acid desaturases. *Plant and Cell Physiology*, 48(9), 1263–1274.
<https://doi.org/10.1093/pcp/pcm107>

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ARTICLE ID: 10**Beyond the Field: Why India Needs a Dedicated Agricultural Management Service?****1.0 Introduction: The Seventy Eight Years of Stagnation**

In the turbulent aftermath of independence in 1947, Sardar Vallabhbhai Patel described the Indian Administrative Service as the nation's "steel frame." The metaphor captured the spirit of the time. A country reeling from Partition, communal unrest, and administrative disarray required a strong, centralized structure to hold the republic together and ensure continuity of governance. The bureaucracy provided that stability, offering discipline, uniformity, and a sense of national coherence when it was needed most.

Yet, nearly eight decades later, the very rigidity that once guaranteed order has begun to show its limitations. What was designed as a stabilizing framework now often functions as an inflexible cage. In sectors that demand deep technical expertise—particularly agriculture, where science, climate, and markets intersect—the traditional generalist model struggles to keep pace with rapidly evolving challenges. Innovation slows, scientific institutions feel constrained, and transformative ideas often get caught in layers of procedure rather than translated into action. The "steel frame" that once held the nation upright now risks becoming a "steel cage" that confines the very progress it was meant to protect.

1.1 The Agriculture Paradox

India today embodies a striking economic paradox. In the span of a few decades, the nation has journeyed from the humiliating "ship-to-mouth" existence of the 1960s to the status of a global food surplus power. The Green Revolution and the resilience of its farmers transformed a chronically food-deficit country into one capable of feeding itself and contributing to global grain markets. Yet, the very architect of this transformation—the Indian farmer—remains trapped in a cycle of debt, distress, and stagnation.

Even as harvests touch record highs and food stocks overflow, large parts of the rural landscape continue to reflect uncertainty and vulnerability. It is a sobering contradiction: a nation that can place a spacecraft on the lunar south pole still struggles to ensure that a farmer in Vidarbha receives timely, scientifically sound advice to protect his crop from a foreseeable pest attack. The distance between technological triumph and field-level reality remains one of India's most pressing development gaps.

1.2 Thesis Statement

This disconnect is neither a failure of our farmers nor of our scientists; it is, at its core, a failure of institutional design. The generalist bureaucrat, though adept at maintaining law and order or overseeing revenue administration, is not equipped with the technical depth required to lead a biological and scientific transformation in agriculture. If India is to realize its aspiration of a \$5 trillion economy, it must realign its governance architecture—deploying the bureaucrats for core civic administration while entrusting the ‘Primary Sector’ to a specialized, technically trained All-India cadre: the Indian Agriculture Management Service (IAMS).

2.0 The drawbacks of the Generalist Model in Rural India

The current administrative system is built on the cult of the "Generalist." The underlying assumption is that a smart individual, having passed a rigorous competitive exam, can manage any department with equal facility. In practice, this results in a revolving door of leadership that is toxic to long-term agricultural health.

Consider the typical trajectory of a senior bureaucrat: an officer may spend two years managing the Ministry of Coal, three years in the Department of Pharmaceuticals, and is then suddenly appointed as the Secretary of Agriculture. By the time this officer understands the complexities of soil health cards, the nuances of the Minimum Support Price (MSP) mechanism, or the technical hurdles of global WTO agri-subsidies, they are transferred to the Ministry of Urban Development. Agriculture is a sector governed by seasons, biological cycles, and decadal climate shifts; it cannot be managed by a leadership that views it as a mere administrative position in a diverse career.

2.1 The Policy vs. Implementation Gap

Because IAS officers lack a foundational background in agricultural sciences, the policies they design are often "top-down" and aesthetically pleasing on paper but biologically flawed in the field. Programs like PM-Kisan or Fasal Bima Yojna are managed as financial disbursement exercises rather than agricultural interventions.

A generalist bureaucrat views a drought through the lens of disaster relief and revenue remission. A specialist, however, would view a drought through the lens of crop-cycle adjustment, moisture-stress management, and the rapid deployment of drought-resistant seed varieties. Because the current leadership does not "speak the language" of the soil, there is a massive implementation gap. The "files" move at one speed, while the "fungus" or the "monsoon" moves at another.

2.2 The "Generalist" Blind Spot

We are entering an era of "Agriculture 4.0." The challenges of today and certainly of the next 25 years involve high-tech interventions:

- **Digital Agriculture Mission:** Utilizing blockchain for supply chain transparency.
- **Precision Farming:** Using AI and drone technology for targeted fertilizer application.
- **Biotechnology:** Navigating the regulatory and ethical landscape of CRISPR and GM crops.

A bureaucrat, whose training is rooted mainly in the liberal arts, law, or general management, lacks the technical depth to evaluate these technologies. When the decision-maker cannot distinguish between a minor genetic variation and a major ecological risk, they either become overly cautious (leading to policy paralysis) or overly

reliant on private-sector lobbyists who may not have the farmer's best interests at heart.

2.3 Seventy-Eight Years of Missed Opportunities

Critics of a specialized service often argue that 'the bureaucrat' has "done enough" since independence. But "enough" is no longer sufficient. Rural development has been treated as a welfare project for nearly eight decades—a "poverty alleviation" scheme managed by collectors. If we had treated agriculture as a technical industry managed by experts, our rural economy would resemble that of a developed nation. Instead, we have a system where the "expert" (the agricultural scientist) reports to the "administrator" (the generalist), ensuring that science is always subservient to bureaucracy.

3.0 Why Agriculture Requires "Technical Administration?"

In most developed economies, the management of food systems is not left to generalist bureaucrats but to "Agri-Administrators" who understand the chemical, biological, and economic interplay of the land. In India, we have erroneously categorized agriculture as a sub-set of general administration. This is a fundamental error. Administering a district's law and order requires an understanding of the Indian Penal Code; administering its agricultural output requires an understanding of hydrology, soil chemistry, veterinary sciences, and plant pathology.

When a bureaucrat lacks this foundation, they view agriculture through the lens of "welfare." They see a farmer as a recipient of a subsidy, not as a stakeholder in a high-tech industry. A technical cadre, the IAMS would view the farm as a biological factory. They would understand that a delay in the supply of a specific micronutrient isn't just a logistical failure; it's a biological catastrophe that can wipe out a season's GDP for

an entire block. Technical administration means moving from "managing files" to "managing ecosystems."

3.1 Scientific Accountability and the Power of the Expert

In the present administrative hierarchy, the agricultural scientist—whether from ICAR institutions or State Agricultural Universities—often occupies a subordinate, advisory position. The "expert" recommends; the "generalist" decides. This structural divide creates a troubling vacuum of accountability. When a policy falters because of a technical oversight, responsibility becomes diffused. The generalist administrator can claim that decisions were based on expert advice, while the scientist has no executive authority to implement or correct course.

A dedicated Indian Agricultural Management Service (IAMS) would remove this artificial separation between knowledge and authority. When the decision-maker is also the domain expert, accountability becomes direct and unambiguous. Such a technical cadre would be drawn from the country's brightest graduates in Agriculture, Horticulture, and Veterinary sciences—professionals who have spent four to seven rigorous years studying the very challenges they are expected to address. For them, a rust outbreak in wheat or Lumpy Skin Disease in cattle is not merely a headline; it is a professional responsibility and a problem they are specifically trained to solve.

3.2 From Welfare to Wealth Creation

Rural development in India has, for decades, been framed largely as an exercise in "poverty management." The system ensures the distribution of five kilograms of grain and a few thousand rupees through direct benefit transfers.

Proposed Administrative Structure for Agriculture

Administrative Level	Current Dominant Role (IAS)	Proposed Specialist Role (IAMS)	Key Responsibility
District	District Magistrate (DM/DC)	District Agricultural Commissioner	Planning crop patterns based on local soil and water data.
State	Secretary (Agriculture)	Director General (Agri-Sciences)	Integrating State Agri-Universities with field implementation.
Center	Union Secretary (MoA&FW)	Principal Agricultural Secretary	Representing India at the WTO/FAO and national policy design.

These measures are vital as safety nets, but they seldom generate lasting prosperity. Real wealth creation in rural India depends on the intelligent application of technology—efficient post-harvest systems, reliable cold-chain networks, value addition, and timely market intelligence that connects farmers to opportunities beyond the village mandi. The administrative focus of a bureaucrat has traditionally been on “distributive justice,” an essential pillar of social stability and civic life. But a specialized Indian Agricultural Management Service (IAMS) would bring a complementary emphasis on “productive efficiency.” Its mandate would be to unlock value, improve competitiveness, and integrate farmers into modern supply chains. By shifting the focus from mere subsistence to innovation and enterprise, such a service could transform the rural landscape from zones of distress into vibrant centers of agricultural entrepreneurship and growth.

4.0 Proposed Structure of the IAMS

To replace the current generalist dominance, the IAMS must be structured as a robust All-India Service with its own distinct hierarchy, reaching

from the grassroots of the District to the high-level policy corridors of New Delhi.

• The Hierarchical Shift

4.1 The Recruitment and Training Paradigm

The IAMS would not be open to just any graduate. Recruitment would be conducted via a specialized "Agricultural Civil Services Examination" by the UPSC.

- **Eligibility:** Strictly limited to candidates with professional degrees in Agriculture and Allied Sciences (Horticulture, Fisheries, Forestry, Dairy, etc.).
- **Training:** Instead of the generalist training at LBSNAA, the IAAS probationers would undergo intensive "Agri-Governance" training at institutions like the National Academy of Agricultural Research Management (NAARM).
- **Field Immersion:** Before taking charge, officers would be required to spend a mandatory year working directly within a Farmer Producer Organization (FPO) to understand the ground-level economics of the market.

4.2 Autonomy and Financial Powers

A fundamental weakness of the existing system lies in the dependence of the Agriculture Department on IAS-led district and finance authorities for the release of funds, even for urgent technical interventions. This structure often forces scientific priorities to compete with administrative procedures, diluting both speed and effectiveness. The proposed Indian Agriculture Management Service (IAMS) must therefore be vested with independent budgetary authority for agricultural infrastructure and innovation. When a technical expert determines that a district requires fifty new soil-testing laboratories, the decision should rest on scientific necessity—not on the need to convince a generalist administrator of the value of soil science. Fiscal autonomy for the IAMS would enable it to drive the “Lab-to-Land” mission with speed, precision, and purpose, free from avoidable bureaucratic bottlenecks.

5.0 Strategic Benefits: Scaling the Economy

Agriculture contributes roughly 15-18% to India's GDP but employs nearly 50% of its workforce. This is the “productivity gap” that keeps India from becoming a developed nation. An IAMS cadre would focus on “Value Chain Integration.” Instead of just growing more rice, they would focus on transforming that rice into high-value exports, managing the technical standards required for European or North American markets.

5.1 Global Negotiations: The Technical Battlefield

In the negotiating chambers of the World Trade Organization, the contest over agricultural subsidies and market access is decided by technical evidence, not by general rhetoric. Yet India is often represented by bureaucrats who must depend on briefing notes, while competitors

such as the United States, the European Union, and Brazil field seasoned agricultural specialists. The creation of an Indian Agriculture Management Service (IAMS) would ensure that India speaks through career experts—professionals who can navigate the complexities of ‘Sanitary and Phytosanitary’ measures with the same confidence and depth with which they discuss domestic crop productivity.

5.2 Climate Resilience: The Ultimate Challenge

Climate change is not a future threat; it is a present reality for the Indian farmer. Unexpected heatwaves in March or unseasonal rains in October can destroy millions of tons of grain. A generalist responds with “compensation.” An IAMS specialist responds with “adaptation”—rapidly shifting seeds, modifying sowing dates using predictive AI, and implementing micro-irrigation at a scale that generalists have failed to achieve for decades.

5.3 Breaking the Administrative Monopoly

The greatest obstacle to the creation of the IAMS is not a lack of evidence or institutional precedent, but the entrenched influence of what is often described as the “bureaucratic lobby.” For decades, this powerful cadre has protected its administrative domain with a zeal that sometimes borders on institutional protectionism. The familiar argument is that a “specialist” lacks the “breadth of vision” or the “neutrality” required to manage complex districts. Yet, this claim rests more on tradition than on contemporary realities. In a 21st century economy driven by science, data, and technology, breadth without depth can become a formula for well-intentioned but ineffective governance. Modern challenges from climate-resilient agriculture to biosecurity and digital supply chains demand not just administrative coordination, but domain expertise

at the highest decision-making levels. Governance today is no longer a zero-sum contest over authority; it is a collaborative enterprise built on specialized knowledge and institutional competence.

By retaining control over deeply technical sectors such as agriculture, the generalist system risks slowing innovation and diluting accountability. A more balanced arrangement would allow the traditional “steel frame” to concentrate on its core strengths law, order, and civic administration while a complementary “scientific frame” leads the transformation of rural economies. Such a division would not weaken the civil services; it would modernize them, aligning administrative structures with the complex, knowledge-intensive demands of a new India.

5.4 The \$5 Trillion Necessity

India’s aspiration to become a \$5 trillion economy and a global superpower is mathematically impossible if the sector that employs half its population remains a laggard. We cannot achieve “Viksit Bharat” (Developed India) by 2047 if our agricultural growth remains tethered to the whims of generalist bureaucrats who cannot distinguish between *Kharif* and *Rabi* without a briefing note.

The IAAS is not a radical experiment; it is a long-overdue correction. It is the logical progression of a maturing democracy that recognizes that specialized problems require specialized solutions. If we can have an Indian Forest Service (IFoS) to protect our trees and an Indian Medical Service (proposed) to protect our health, why should the very source of our sustenance—the soil—be left to the mercy of generalists?

6.0 The Final Word: A Living Frame for a Living Sector

Agriculture is not a static government department;

it is a living ecosystem. It responds to the chemistry of the soil, the biology of crops and livestock, and the physics of the atmosphere. To manage such a dynamic system, the administration itself must be equally dynamic—rooted in the soil, guided by science, and driven by a clear mission: to make the Indian farmer a confident, competitive participant in the global agricultural economy.

The “steel frame” served an essential purpose in the 20th century, providing stability and cohesion during a fragile phase of nation-building. But the demands of the 21st century are different. Today, India needs a “living frame”—an administrative structure that is adaptive, technically proficient, and innovation-oriented. A specialized Indian Agriculture Administrative Service is not merely an institutional reform; it is a strategic necessity for sustained national progress. Unless technical expertise is placed at the heart of decision-making in our fields and farm ministries, India’s growth story will remain unfinished. The specialist’s harvest is ready; it is time we empower those best equipped to cultivate it.

6.1 Final Call to Action: The Path Forward

To translate this vision into reality, the government must act with clarity and urgency on three immediate fronts:

6.1.1 Re-activate the 1965 Rajya Sabha Resolution: The legal foundation for an All-India Agricultural Management Service already exists. It is time to revive this long-forgotten resolution, update it to present-day realities, and place it at the center of administrative reform in the agricultural sector.

6.1.2 Establish an IAMS Commission: A dedicated task force of leading agricultural scientists, economists, and policy experts should be constituted to design the structure, mandate, and jurisdiction of the new cadre. This

commission must ensure that the service is technically sound, administratively efficient, and aligned with national development goals.

6.1.3 Pilot in High-Growth Zones: Rather than attempting an immediate nationwide rollout, the service should first be introduced in five high-potential agro-climatic zones. These pilot regions can serve as living laboratories, demonstrating how specialist-led governance can dramatically enhance productivity, farmer incomes, and value-chain efficiency within a single five-year plan.

The era of endless deliberation must now give way to decisive action. The challenges confronting Indian agriculture are too urgent, too complex, and too scientifically driven to be addressed through prolonged debate alone. What the sector needs today is not just more discussion, but deeper expertise at the helm.

The moment has come to place knowledge at the center of governance—to allow trained specialists to lead, innovate, and transform the rural economy with confidence and accountability. The time for debate has passed; the time for the expert has truly arrived.

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Impact of Agricultural Subsidies on Smallholder Farmers **‘Evidence and Policy Implications’**

Abstract-

Agricultural subsidies remain a key policy tool in developing economies, especially where smallholder farmers dominate. Globally, smallholders operating on less than two hectares make up over 80% of farms and produce nearly one-third of the world's food (FAO, 2023). In India, around 85% of farmers are small or marginal, with agriculture employing 42% of the workforce and contributing 18% to GDP (Government of India, 2024). Subsidies on fertilizers, electricity, irrigation, and credit have lowered input costs and improved productivity, playing a crucial role in food security. However, India's fertilizer subsidy alone, amounting to ₹2.05 lakh crore in 2023–24, reflects growing fiscal pressure (Ministry of Finance, 2024). Excessive input use has also caused groundwater depletion and soil degradation, particularly in intensively farmed regions. Despite their benefits, subsidies often suffer from inefficient targeting and environmental costs. This paper examines both the positive and negative impacts of agricultural subsidies on smallholders and proposes reforms emphasizing targeted support, resource efficiency, and sustainable growth.

Introduction-

Agriculture remains the backbone of most developing economies, providing livelihoods, food, and raw materials for industries. Yet, the sector is undergoing major change due to shifting demographics, economic growth, and evolving labour markets. Two key forces rising labour costs and rural–urban migration are now reshaping farm productivity and rural livelihoods (World Bank, 2020; FAO, 2022). In many countries, especially across Asia and Sub-Saharan Africa, farming still relies heavily on manual labour for planting, weeding, and harvesting. As non-farm opportunities expand, rural workers increasingly migrate to cities in search of better pay and living conditions (Harris & Todaro, 1970; Ge, 2020). This exodus leaves fewer hands on the farm, creating labour shortages during peak seasons and driving up rural wages (Chand et al., 2015; Zhang et al., 2019).

However, migration also brings opportunities. Many migrants send remittances home, helping families invest in fertilizers, irrigation, or machinery (Lucas, 2007; Adams & Cuecuecha, 2013). These funds can offset labour losses and raise productivity but only when farmers have access to credit, affordable machines, and supportive infrastructure (de Brauw, 2010; Awudu & Richard, 2018). Farmers are increasingly turning to mechanization as labour costs rise. Proper use of machinery enhances efficiency and ensures timely field operations, though its influence on land productivity is mixed.

Yet, access is uneven smallholders often struggle with high costs and limited infrastructure, leaving them at a disadvantage compared to larger farms. Beyond labour and mechanization, climate change and environmental pressures further complicate the picture. Erratic rainfall, rising temperatures, and soil degradation intensify the challenges faced by smallholders, making reliance on traditional labour-intensive practices even riskier (FAO, 2022).

The overall impact of these trends is complex and context-dependent. In areas with good infrastructure and credit systems, higher wages and migration can spur innovation. Elsewhere, they may lead to declining yields and reduced cultivation (Zhang et al., 2019; Singh & Kaur, 2021).

Types of agricultural subsidies-

Agricultural subsidies are key policy tools used by governments to reduce production costs, stabilize farm incomes, and strengthen food security. Broadly, they can be grouped into four categories: input subsidies, output or price support subsidies, credit and insurance subsidies, and infrastructure or investment subsidies each serving distinct purposes for smallholder farmers. Input subsidies are the most common, helping farmers afford essentials like fertilizers, seeds, electricity, and irrigation. In India, the fertilizer subsidy, exceeding ₹2 lakh crore in 2023–24 (Ministry of Finance, 2024), has boosted food grain output and supported the Green Revolution. However, it has also caused nutrient imbalance and soil degradation due to urea overuse (Gulati & Banerjee, 2023). Schemes like NFSM and RKVY provide subsidized high-yielding seeds, while electricity subsidies make irrigation cheaper but have led to groundwater depletion, especially in Punjab and Haryana (OECD, 2023). Output or price support subsidies, such as the Minimum Support Price (MSP) system, protect

farmers from market fluctuations by ensuring a guaranteed price for key crops (NITI Aayog, 2023). While MSPs have improved income stability and food security, they've also distorted cropping patterns toward water-intensive crops and benefited mainly a few states like Punjab and Haryana (World Bank, 2022).

Infrastructure and investment subsidies for irrigation systems, storage, mechanization, and solar pumps encourage long-term productivity and sustainability. Programs like the Sub-Mission on Agricultural Mechanization (SMAM) offer up to 50% subsidy on equipment for small and marginal farmers (Government of India, 2022). These supports are more sustainable, helping farmers build assets, reduce losses, and adopt modern technologies.

Positive Impacts on Smallholder Farmers-

Subsidies on fertilizers, seeds, and irrigation allow smallholders to use essential inputs that would otherwise be unaffordable. Empirical studies show that fertilizer subsidies have significantly contributed to India's Green Revolution, improving yields of rice and wheat.

Price support mechanisms (like MSP) provide a degree of income certainty, reducing exposure to market volatility. Subsidized insurance and credit also protect smallholders from crop failure and indebtedness.

Lowered costs encourage adoption of high-yielding varieties (HYVs), mechanization, and improved irrigation techniques. Over time, this can raise total factor productivity (TFP) and strengthen food security.

Subsidies indirectly stimulate rural economies by increasing farm income, purchasing power, and demand for local labor and services.

Negative Impacts and Challenges-

Despite being targeted toward the poor, subsidies often disproportionately benefit larger farmers, who consume more inputs. Leakage, corruption,

and poor targeting reduce effectiveness for smallholders.

Cheap fertilizers, electricity, and water have encouraged overuse of inputs, leading to groundwater depletion, soil degradation, and environmental pollution particularly in states like Punjab and Haryana.

High subsidy expenditure crowds out public investment in research, infrastructure, and rural education areas that yield more sustainable long-term benefits.

Subsidized inputs and price supports can distort market signals, discouraging crop diversification and the development of private markets for seeds and fertilizers.

Indicator	2000-02	2020-22	2022-24
Total Value of Agricultural Production (farm-gate)	USD 112,282 million	USD 445,545 million	USD 446,597 million
Producer Support Estimate (PSE) (in USD)	2,709 million	73,926 million	73,146 million
Percentage PSE (% of Gross Farm Receipts)	2.31 %	14.98 %	14.51 %
General Services Support Estimate (GSSE)	USD 3,526 million	USD 17,278 million	USD 18,644 million

Agricultural Support Metrics (OECD)

Interpretation:

India's PSE is strongly negative, meaning that policies on average tax producers (farmers), rather than subsidize them. The negative PSE is driven by large negative market price support domestic prices for some commodities are kept low relative to world prices.

At the same time, India gives significant budgetary transfers to farmers mainly via input subsidies for fertilisers, electricity, and irrigation. Investment in general services (GSSE) is increasing, suggesting spending on public goods (infrastructure, innovation) is rising.

Policy Implications-

Agricultural subsidies must shift from broad-based support to targeted and transparent delivery through Direct Benefit Transfer (DBT) systems to ensure benefits reach genuine smallholders. Input subsidies should be rationalized to encourage efficient fertilizer, water, and energy use, promoting sustainability. Policymakers should foster crop diversification by extending support beyond cereals to pulses, oilseeds, and horticultural crops. Integrating digital technology can improve subsidy monitoring and reduce leakages. Subsidies should be linked to environmental performance, rewarding climate-smart and resource-efficient farming. A portion of subsidy funds should be redirected toward infrastructure, research, and extension services to generate long-term growth. Finally, periodic evaluation and fiscal reforms are essential to enhance efficiency, equity, and sustainability in supporting smallholder farmers.

Conclusions-

Agricultural subsidies have been crucial in supporting smallholder farmers by lowering input costs, boosting productivity, and stabilizing incomes. Yet, their long-term effectiveness is

limited by poor targeting, inefficiencies, and environmental risks. While subsidies provide short-term relief, they often fail to deliver sustainable growth or equitable benefits. Reforming policies toward targeted, need-based, and performance-linked support can improve efficiency and inclusiveness. Encouraging crop diversification, sustainable resource use, and digital transparency will strengthen their impact. Redirecting part of subsidy spending to infrastructure, innovation, and farmer capacity building can yield greater long-term gains. Ultimately, subsidies must evolve from dependency tools into instruments of empowerment to ensure resilience and sustainability in smallholder agriculture.

References-

- Fan, S., Gulati, A., & Thorat, S. (2019). *The subsidy trap: Evidence and lessons for India's agricultural policy*. International Food Policy Research Institute (IFPRI).
- Food and Agriculture Organization of the United Nations. (2021). *The state of food and agriculture 2021*. FAO.
- Government of India, Ministry of Agriculture and Farmers Welfare. (2021). *Agricultural census 2020–21*.
- Government of India, Ministry of Finance. (2024). *Economic survey of India 2023–24*.
- Gulati, A., & Banerjee, P. (2023). *Rethinking Agricultural Subsidies: Balancing Welfare, Efficiency, and Sustainability*. Indian Council for Research on International Economic Relations (ICRIER).
- Gulati, A., & Sharma, P. (2022). *Revisiting India's agricultural subsidy regime: Challenges and policy options*. Indian Council for Research on International Economic Relations (ICRIER).
- Government of India, Ministry of Agriculture and Farmers Welfare. (2023). *Agricultural statistics at a glance 2023*. Government of India.
- Organisation for Economic Co-operation and Development. (2023). *Agricultural policy monitoring and evaluation 2023*. OECD Publishing.
- Singh, R., & Kaur, M. (2021). Impact of input subsidies on smallholder farmers in Punjab. *Journal of Agricultural Economics and Development Studies*, 9(3), 45–56.
- World Bank. (2022). *World development report 2022: Agriculture for inclusive growth*. World Bank.

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**High Demand of Navgrah-Rashi-Nakshatra Plants in India:
A Blend of Faith, Biodiversity and Green Economy**

Abstract

India is among the world's most biologically diverse countries which harboring nearly 8% of global biodiversity while supporting about 17% of the human population. Rooted within this ecological richness is a long-standing tradition of integrating nature with spirituality, where plants are persevered not only for their biological and utilitarian values but also for their cultural, religious and astrological significance. The concepts of Navgrah, Rashi, and Nakshatra plants, rooted in Vedic astrology (Jyotish Shastra), exemplify this integration by associating specific plant species with the nine planets, twelve zodiac signs, and twenty-seven lunar constellations, respectively. These associations have led to the development of Navgrah Vatika, Rashi Vatika, and Nakshatra Vatika, which function as living repositories of sacred and indigenous plants. In recent years, India has witnessed a remarkable surge in demand for Navgrah–Rashi–Nakshatra plants, driven by religious rituals, astrological practices, urban greening initiatives, wellness movements, and growing awareness of indigenous biodiversity. Many of the associated plant species encompasses well-documented medicinal, ecological, and cultural values, making these gardens significant not only from a spiritual perspective but also for biodiversity conservation, ethnobotanical knowledge preservation, and ecosystem service enhancement. Nakshatra and Navgrah vaticas contribute to *ex-situ* conservation of native and keystone species which support pollinators and wildlife, and enhance carbon sequestration and microclimatic regulation. Beyond ecological benefits, the increasing popularity of these thematic gardens has created new opportunities within the green economy, strengthening nursery industries, promoting eco-cultural tourism, and generating livelihood options in rural and peri-urban areas. Despite challenges such as regional variations in plant associations and limited scientific validation, Navgrah–Rashi–Nakshatra plantations represent a unique synthesis of faith-driven conservation and sustainable development. Integrating these traditional systems with modern agroforestry, urban forestry, and climate-smart land-use planning can further enhance their ecological, cultural, and socioeconomic relevance in contemporary India.

Keywords: Navgrah Vatika; Rashi Vatika; Nakshatra Vatika; Sacred Plants; Biodiversity Conservation; Green Economy

1. Introduction

India is one of the world's most ecologically diverse countries which hosting nearly 8% of global biodiversity and supporting over 17% of the world's population. India has a long-standing tradition of integrating nature with spirituality, where plants are not merely biological entities but sacred symbols deeply embedded in cultural, religious and astrological beliefs. Among these traditions, the concept of *Navgrah*, *Rashi* and *Nakshatra* plants holds a prominent place. The tradition of associating specific trees and plants with celestial bodies (grah), zodiac signs (rashis), and lunar constellations (nakshatras) reflects a deep integration of spirituality and nature in Indian worldviews (Maneesha et al., 2021). These associations have led to the creation of Navgrah, Rashi, and Nakshatra vaticas (gardens); where living collections that symbolize the nine planets, twelve zodiac signs, and twenty-seven nakshatras, respectively. Rooted in ancient Indian astrology (*Jyotish Shastra*) and Vedic scriptures, Navgrah plants are associated with the nine celestial planets and twelve plants with Rashi, while Nakshatra plants correspond to the 27 lunar constellations. In recent years, there has been a remarkable surge in demand for Navgrah-Rashi-Nakshatra plants across India, driven by religious practices, urban greening initiatives, wellness movements and increased awareness of indigenous biodiversity. This growing demand has transformed these traditionally preserved plants into a niche and vatika not only expanding sector within nursery production, medicinal plant cultivation and agroforestry, but also contributing simultaneously to cultural preservation, environmental sustainability and rural livelihoods.

2. Concept of Navgrah Vatika, Rashi Vatika and Nakshatra Vatika

2.1 Navgrah Vatika: The Navgrah system is based on nine planetary deities viz., Surya, Chandra, Mangala, Budha, Brihaspati, Shukra, Shani, Rahu and Ketu; each believed to influence human life spiritually. Specific plants are traditionally associated with these planets and are planted, worshipped, or used in rituals to mitigate malefic planetary effects. Many of these species are medicinally important, making Navgrah Vaticas valuable for both spiritual and healthcare traditions (Maneesha et al., 2021). A list of commonly accepted Navgrah plants is given below table 1 and diagrammatically represented in Figure 1.

Table 1: List of commonly accepted Navgrah plants

Sr. No.	Common Name	Botanical Name	Family	Position/ Direction	Associated Planet
1.	Aak	<i>Calotropis gigantea</i>	Euphorbiaceae	Middle	Surya (Sun)
2.	Palash	<i>Butea monosperma</i>	Fabaceae	South-East	Chandra (Moon)
3.	Khair	<i>Acacia catechu</i>	Fabaceae	South	Mangala (Mars)
4.	Apamarg	<i>Achyranthes aspera</i>	Amaranthaceae	North	Budha (Mercury)
5.	Peepal	<i>Ficus religiosa</i>	Moraceae	North-East	Brihaspati (Jupiter)
6.	Gullar	<i>Ficus racemosa</i>	Moraceae	East	Shukra (Venus)
7.	Shami	<i>Prosopis cineraria</i>	Mimosaceae	West	Shani (Saturn)
8.	Doob Grass	<i>Cynodon dactylon</i>	Poaceae	South-West	Rahu (Dragon's head)
9.	Kush Grass	<i>Desmostachya bipinnata</i>	Poaceae	North-West	Ketu (Dragon's tail)



Figure 1: Diagrammatic representation of Navagraha Vatika

2.2 Rashi Vatika: It is a themed garden where plants or trees are arranged according to zodiac signs, often based on astrological or traditional beliefs. Such gardens are commonly used for cultural, educational, spiritual, or landscape purposes, and sometimes linked with Vedic astrology and Nakshatra-based plant systems. Rashi-based plant systems link twelve zodiac signs with particular trees. These associations promote long-term tree conservation as individuals tend to plant and protect species linked to their birth sign, thereby supporting urban and rural greening initiatives (Raghupathy & Newmaster, 2009). A list of commonly accepted Navgrah plants is given below table 2 and diagrammatically represented in Figure 2.



Figure 2: Rashiphal Vatika Representation

Table 2: List of commonly accepted Rashi plants

Sr. No.	Common Name	Botanical Name	Family	Position / Direction	Associated Rashi (Zodiac)
1.	Rakta Chandan	<i>Pterocarpus santalinus</i>	Fabaceae	0-30°	Mesh (Aries)
2.	Sapta Parni	<i>Alstonia scholaris</i>	Apocyanaceae	30-60°	Vrishabh (Taurus)
3.	Panas (Jack fruit)	<i>Artocarpus hererophyllus</i>	Moraceae	60-90°	Mithun (Gemini)
4.	Palash	<i>Butea monosperma</i>	Fabaceae	90-120°	Karka (Cancer)
5.	Ber	<i>Ziziphus mauritiana</i>	Rhamnaceae	120-150°	Singh (Leo)
6.	Aam (Mango)	<i>Mangifera indica</i>	Anacardiaceae	150-180°	Kanya (Virgo)
7.	Bakul	<i>Mimusops elenji</i>	Sapotaceae	180-210°	Tula (Libra)
8.	Khair	<i>Acacia catechu</i>	Fabaceae	210-240°	Vrishchik (Scorpio)
9.	Peepal	<i>Ficus religiosa</i>	Moraceae	240-270°	Dhanu (Sagittarius)
10.	Sissam	<i>Dalbergia sissoo</i>	Fabaceae	270-300°	Makar (Capricorn)
11.	Shami	<i>Prosopis cineraria</i>	Mimosaceae	300-330°	Kumbh (Aquarius)
12.	Vata vruksha	<i>Ficus benghalensis</i>	Moraceae	330-360°	Meen (Pisces)

2.3 Nakshatra Vatika: Each of the 27 Nakshatras is associated with a specific tree or plant, traditionally recommended for plantation by individuals born under that Nakshatra. Planting and nurturing one's Nakshatra plant is believed to bring prosperity, health and spiritual balance. Nakshatra trees correspond to the 27 lunar constellations and are prominently promoted through Nakshatra Vanas across India. These systems conserve diverse native tree species and act as repositories of ethnobotanical knowledge

(Pandey et al., 2020). A list of commonly accepted Nakshatra plants is given below table 3 and diagrammatically represented in Figure 3.

3. Cultural and Philosophical Foundations

Vedic astrology considers the planets, zodiac signs, and stars as influential forces affecting human life and destiny. Ancient traditions prescribed planting specific species to harmonize these influences by an idea that underpins Navgrah and Rashi vatikas. These gardens were traditionally installed near temples and sacred places for worship, contemplation, and holistic well-being. The practice reflects a philosophical belief in cosmic order (rta) and the salutary

interaction between humans and the environment. Indian philosophy perceives nature as sacred, emphasizing harmony between cosmic forces and living beings. Sacred groves, temple trees, and astrology-based plantations exemplify this worldview, where faith acts as a strong driver for conservation and sustainable resource use (Gadgil & Guha, 1992).

4. Biodiversity Significance of Navgrah–Rashi–Nakshatra Plants

Plants associated with Navgrah and Nakshatra gardens often include medicinal and ecologically significant species.

Figure 3: Nakshatra Vatika Representation

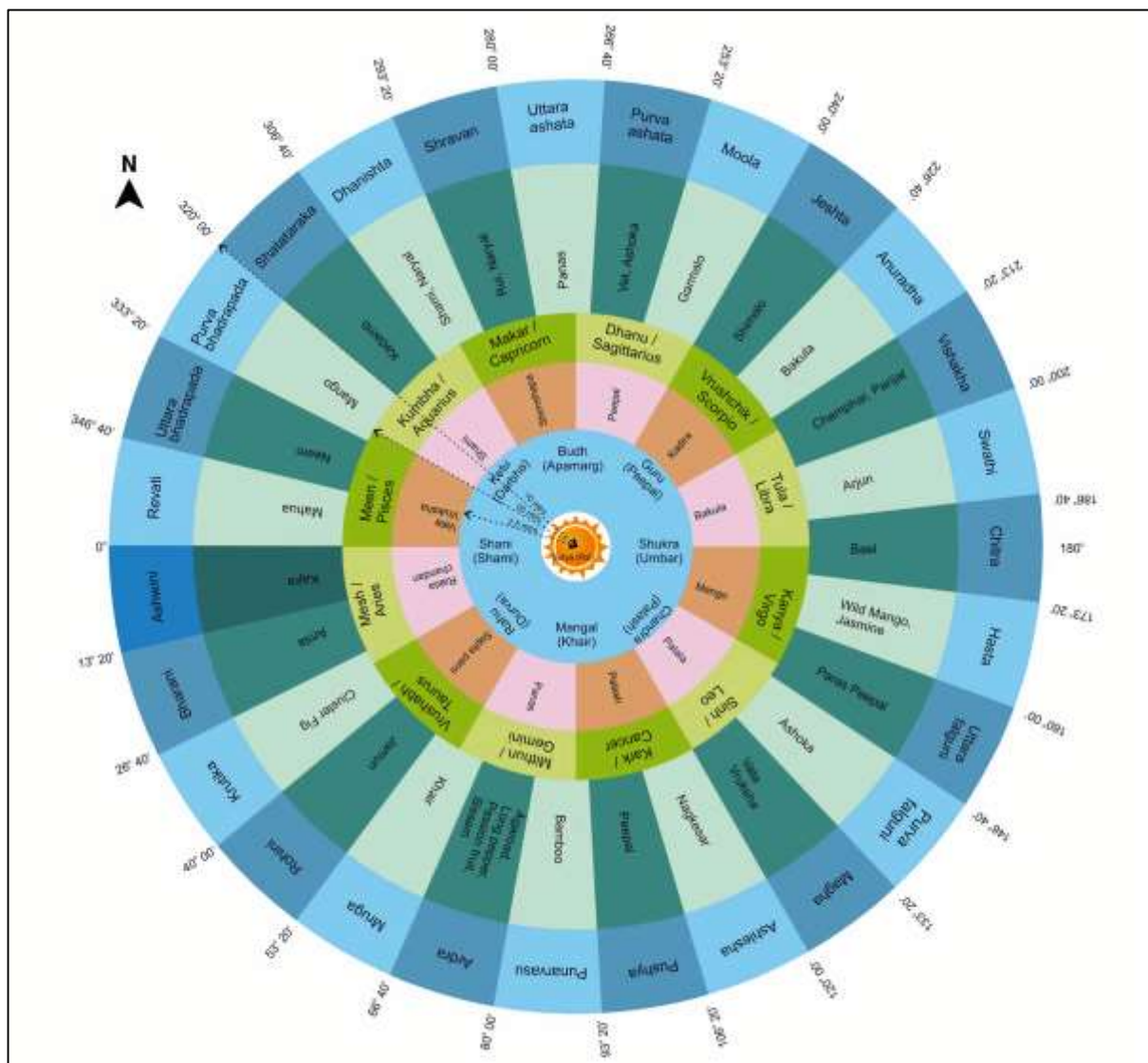


Table 3: List of commonly accepted Nakshatra plants

Sr. No.	Common Name	Botanical Name	Family	Position/ Direction	Associated Rashi (Zodiac)
1.	Kajra	<i>Strychnos nux-vomica</i>	Loganiaceae	00°00′-13°20′	Ashwini (Beta Arietis)
2.	Amla	<i>Embilica officinalis</i>	Euphorbiaceae	13°20′-26°40′	Bharani (41 Arietus)
3.	Umbar	<i>Ficus racemosa</i>	Moraceae	26°40′-40°00′	Kritika (Etatauri Alcyone-2)
4.	Jamun	<i>Syzigium cumini</i>	Myrtaceae	40°00′-53°20′	Rohini (Aldebaran)
5.	Khair	<i>Acacia catechu</i>	Leguminoseae	53°20′-66°40′	Mrigashirsha (Lambda orionis)
6.	Sissam	<i>Dalbergia sissoo</i>	Fabaceae	66°40′-80°00′	Ardra (Gamma)
7.	Bamboo	<i>Dendrocalamus strictus</i>	Poaceae	80°00′-93°20′	Punarvasu (Beta Geminorum pollux)
8.	Peepal	<i>Ficus religiosa</i>	Moraceae	93°20′-106°40′	Pushya (Delta Cancri)
9.	Nagkesar	<i>Messua ferrea</i>	Calophyllaceae	106°40′-120°00′	Ashlesha (Zeta Hydare)
10.	Vata vruksh	<i>Ficus bengalensis</i>	Moraceae	120°00′-133°20′	Magha (Regulus/ Roleonis)
11.	Palash	<i>Butea monospema</i>	Fabaceae	133°20′-146°40′	Purva phalguni (Delta Leonis)
12.	Payar Peepal	<i>Ficus rumphii</i>	Moraceae	146°40′-160°00′	Uttara phalguni (Denebala)
13.	Chameli	<i>Jasminum grandiflorum</i>	Oleaceae	160°00′-173°20′	Hasta (Delta Corvi)
14.	Bael	<i>Aegle marmelos</i>	Rutaceae	173°20′-186°40′	Chitra (Virginis spica)
15.	Arjun	<i>Terminalia arjuna</i>	Combretaceae	186°40′-200°00′	Swathi (Alpha Bootis/ Arcturus)
16.	Champhar	<i>Flacourtia montana</i>	Oleaceae	200°00′-213°00′	Vishakha (Alpha Librae)
17.	Bakul	<i>Mimusops elenjii</i>	Sapotaceae	213°00′-226°40′	Anuradha (Delta Scorpii)
18.	Shimalo	<i>Bombax malabaricum</i>	Bombacaceae	226°40′-240°00′	Jeshta (Antares)
19.	Garmalo	<i>Cassia fistula</i>	Leguminaceae	240°00′-253°20′	Moola (Lambada Scorpi)
20.	Vet	<i>Calamus rotang</i>	Arecaceae	253°20′-266°40′	Purva ashata (Delta sagittarii)
21.	Panas	<i>Artocarpus heterophyllus</i>	Moraceae	266°40′-280°00′	Uttara ashata (Sigma sagittavivi)
22.	Rui	<i>Calotropis gigantia</i>	Asclepiadaceae	280°00′-293°20′	Shravan (Alpho Aquila/ Altair)
23.	Shami	<i>Prosopis cineraria</i>	Mimosaceae	293°20′-306°40′	Dhanishtha (Beta Dalphini)
24.	Kadamb	<i>Anthocephalus cadamba</i>	Rubiaceae	306°40′-320°00′	Shatataaraka (Lambda Aquarii)
25.	Aam	<i>Mangifera indica</i>	Anacardiaceae	320°00′-333°20′	Purva Bhadrapada (Beta pegasi/ Markab)
26.	Neem	<i>Azadirachta indica</i>	Meliaceae	333°20′-346°40′	Uttara Bhadrapada (Gamma Pegasi/ Algenib)
27.	Mahua	<i>Madhuca indica</i>	Sapotaceae	346°40′-360°00′	Revati (Zeta piscium)

Studies have documented that nakshatra vanasgardens of nakshatra-associated trees, harbor a rich diversity of species and families, many of which possess therapeutic phytochemicals and volatile compounds with potential health benefits. This diversity contributes to *ex-situ conservation* and protects rare and indigenous taxa that might otherwise be neglected. For example, *Ficus religiosa* (Peepal) is sacred fig which revered in multiple Indian temples for its longevity and spiritual symbolism.

4.1 Species Diversity and Indigenous Knowledge: These gardens often include indigenous, multipurpose, and keystone species, many of which are disappearing from natural habitats. Their preservation helps maintain genetic diversity and sustains indigenous knowledge systems (Kala, 2010).

5.2 Medicinal and Ecological Importance: A majority of associated species possess pharmacological properties, while ecologically they support pollinators, birds, and soil health. Thus, these plantations function as both medicinal gardens and ecological refuges (Pandey et al., 2020).

6. Drivers of High Demand in Recent Era

6.1 Faith, Rituals and Spiritual Practices: The enduring belief in astrology as an influence on life outcomes sustains the demand for Navgrah and Nakshatra plants.

(Source: Maneesha et al., 2021)

Many communities actively plant these species in homes, institutions, and parks to align with ritual calendars or personal birth charts. Astrological consultations, religious ceremonies, and temple landscaping significantly increase the demand for these plants. Faith-based motivations ensure long-term protection and nurturing of planted species (Raghupathy & Newmaster, 2009).

6.2 Role of Traditional Medicine and Ayurveda: Numerous Navgrah and Nakshatra

plants are important to Ayurvedic and ethnomedicinal systems, fostering their commercial value. Their use ranges from herbal remedies to phytochemical industries, reinforcing a market for sustainably sourced native flora. These plants are extensively used in Ayurveda, Siddha, and folk medicine, increasing their commercial cultivation and market value (Kala, 2010).

6.3 Educational, Institutional and Ecotourism Landscape Uses:

Modern botanical gardens and universities are incorporating these thematic gardens into public outreach. For example, academic institutions have established Navgrah vaticas to foster awareness of biodiversity and cultural botany, positioning these spaces as “living classrooms”. Thus, educational institutions, botanical gardens, and urban parks are increasingly adopting these thematic gardens to promote environmental awareness, ecotourism and cultural education (Pandey et al., 2020).

7. Role in Green Economy and Sustainable Development

7.1 Nursery Industry and Plant Trade: The rising popularity of astrology-based plantations has strengthened the nursery sector, generating employment and supporting local entrepreneurs (Nair, 2011).

7.2 Ecotourism and Thematic Gardens: Navgrah and Nakshatra Vaticas serve as eco-cultural tourism attractions, blending spirituality, education, and recreation activities in India (Pandey et al., 2020).

7.3 Employment and Livelihood Opportunities: Cultivation, maintenance, and marketing of these plants contribute to green livelihoods, especially in rural and peri-urban regions of in India (Nair, 2011).

8. Ecological Services and Environmental Benefits

The systematic cultivation of Navgrah and

Nakshatra plants has relevance beyond cultural symbolism. By conserving medicinal and native species, these gardens enhance ecosystem services such as carbon sequestration, soil stabilization, and pollinator habitat provision. Additionally, they contribute to the local green economy through plant nurseries, heritage tourism, and value-added medicinal goods. Economic benefits also arise from sustainable agriculture initiatives like Nakshatra Vanam projects, which integrate traditional astrology with modern agronomy, yielding both social cohesion and income generation.

8.1 Biodiversity Conservation: By encouraging the planting of native trees, these systems enhance *ex-situ conservation* and complement formal biodiversity protection measures (Gadgil & Guha, 1992).

8.2 Carbon Sequestration and Climate Resilience: Perennial tree species used in these gardens contribute to carbon sequestration, microclimate regulation, and climate adaptation, aligning traditional practices with global sustainability goals (SDGs) (Nair, 2011).

9. Challenges and Future Prospects

Challenges include scientific validation gaps, regional inconsistencies in plant associations, and limited awareness. Future prospects lie in integrating these gardens with urban forestry, agroforestry, and climate-smart land-use planning (Kala, 2010; Nair, 2011).

10. Conclusion

Navgrah-Rashi-Nakshatra plants represent a unique synthesis of faith-driven conservation, biodiversity protection, and green economic development. The high demand for Navgrah, Rashi, and Nakshatra plants in India is a multidimensional phenomenon rooted in traditional belief systems, ecological conservation, and emerging economic opportunities. By linking ancient cultural

practices with biodiversity and sustainable development, India's thematic plant gardens exemplify an enduring synthesis of faith and environmental stewardship. Strengthening research, policy support, and community participation can further enhance their ecological and socioeconomic value.

References

- Gadgil, M., & Guha, R. (1992). *This fissured land: An ecological history of India*. Oxford University Press.
- Gadgil, M., & Vartak, V. D. (1976). Sacred groves of India: A plea for continued conservation. *Journal of the Bombay Natural History Society*, 73, 314–320.
- Kala, C. P. (2010). Ethnobotany and ecological conservation in the Indian Himalaya. *Journal of Environmental Biology*, 31(2), 161–170.
- Maneesha, S. R., Vidula, P., Ubarhande, V. A., & Chakurkar, E. B. (2021). Astrologically designed medicinal gardens of India. *International Journal of Bio-resource and Stress Management*, 12(6), 485–492.
- Nair, P. K. R. (2011). Agroforestry systems and environmental quality: Introduction. *Journal of Environmental Quality*, 40(3), 784–790.
- Pandey, R., Kumar, A., & Singh, L. (2020). Nakshatra vana: A traditional approach for biodiversity conservation. *Indian Journal of Traditional Knowledge*, 19(4), 735–742.
- Raghupathy, S., & Newmaster, S. G. (2009). Valorizing the 'sacred groves' of India: Conservation and cultural significance. *Biodiversity and Conservation*, 18, 289–307.

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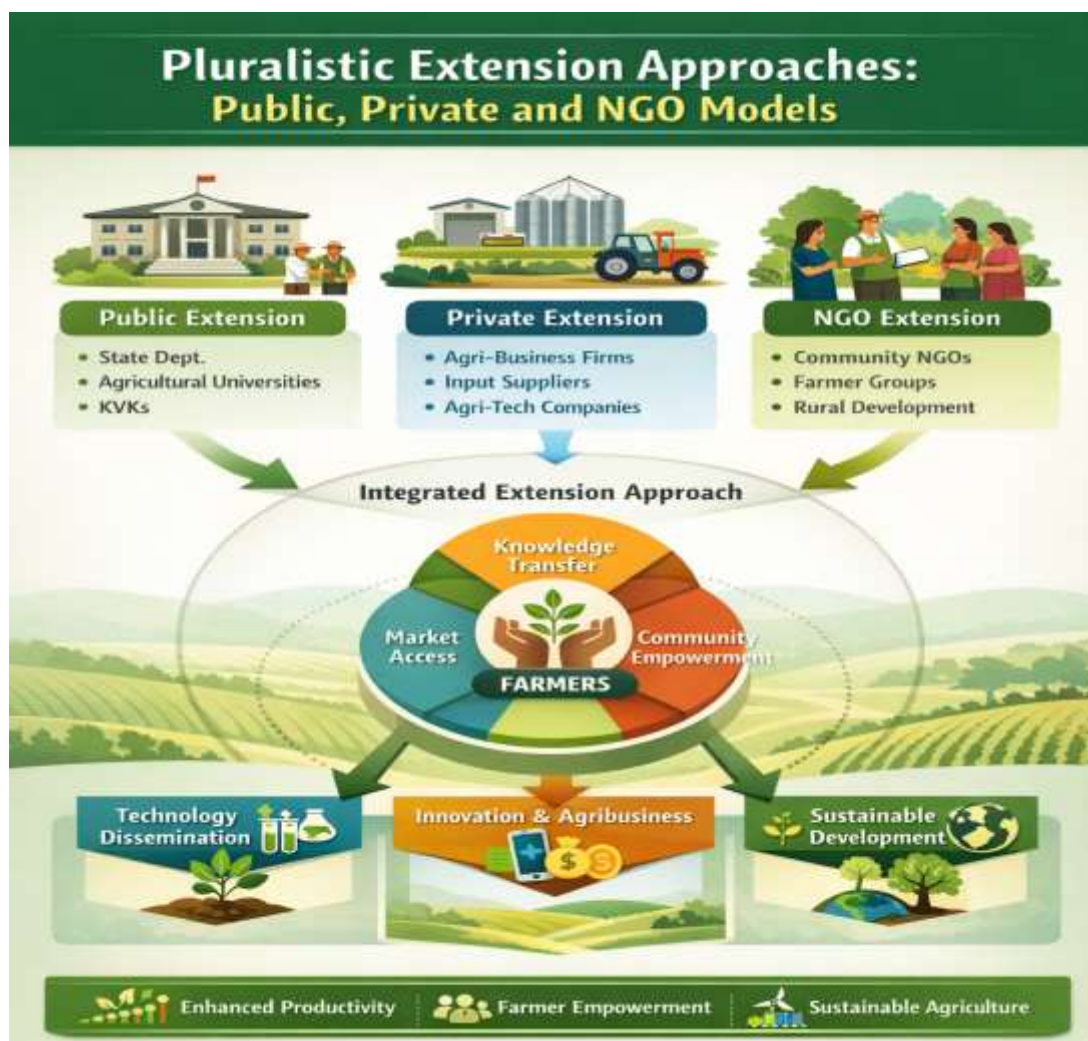
PLURALISTIC EXTENSION APPROACHES IN AGRICULTURE

ABSTRACT

Agricultural extension plays a crucial role in enhancing farmers' access to knowledge, technologies, and advisory services required for sustainable agricultural development. Traditionally, extension services were largely delivered through public sector institutions; however, the increasing complexity of agriculture, driven by climate change, market globalization, commercialization, and diversified farmer needs, has necessitated alternative and complementary approaches. In this context, pluralistic extension approaches involving public, private, and non-governmental organizations (NGOs) have gained prominence. Pluralistic extension refers to a multi-actor system in which different extension service providers operate collaboratively, each contributing unique strengths to agricultural development. Public extension institutions ensure scientific credibility, policy support, and inclusiveness, particularly for small and marginal farmers. Private extension agencies bring efficiency, innovation, market orientation, and the use of modern digital tools, while NGO-based extension emphasizes participatory approaches, empowerment, sustainability, and outreach to marginalized and vulnerable communities. This article discusses the concept of pluralistic extension approaches and provides a detailed analysis of public, private, and NGO extension models, highlighting their roles, strengths, and limitations. The importance of pluralistic extension in improving outreach, service quality, farmer choice, innovation, and sustainability is emphasized. A comparative analysis demonstrates that no single extension model can independently address the diverse challenges of modern agriculture. The integration and coordination of public, private, and NGO efforts are therefore essential for building an inclusive, efficient, and resilient agricultural extension system capable of responding to evolving farmer needs and promoting sustainable rural development.

INTRODUCTION

Agricultural extension is a vital support system that helps farmers gain access to new knowledge, improved technologies, skill development and timely information for better decision-making. For many decades, agricultural extension services were mainly provided by the **public sector**, especially through government departments and agricultural universities. These services focused on transferring research findings from laboratories and research stations directly to farmers, with the aim of increasing agricultural production and ensuring food security.



Over time, agriculture has become more complex due to factors such as climate change, market globalization, diversification of crops, commercialization of farming and increasing demand for quality and value-added products. Farmers today require not only production-related advice but also information on marketing, processing, financial management, climate resilience and digital tools. The public extension system alone has found it difficult to address these diverse and growing needs because of **limited manpower, financial constraints and administrative challenges**.

To overcome these limitations, the concept of **pluralistic extension approaches** has emerged. Pluralistic extension refers to a system

where **multiple actors**, including public institutions, private organizations and non-governmental organizations (NGOs), jointly participate in delivering extension services to farmers. Each of these agencies operates with different objectives, methods and strengths, thereby complementing one another in reaching various categories of farmers.

In a pluralistic extension system, public agencies ensure equity and inclusiveness, private agencies promote efficiency and market-oriented services and NGOs emphasize participation, empowerment and sustainability. Instead of working in isolation, these actors contribute collectively to agricultural development. This approach improves the overall effectiveness of

extension by expanding outreach, enhancing service quality and ensuring that farmers receive need-based and location-specific advisory support. Thus, pluralistic extension approaches represent a shift from a **single-provider model** to a **multi-stakeholder system**, which is better suited to address the challenges of modern agriculture and rural development.

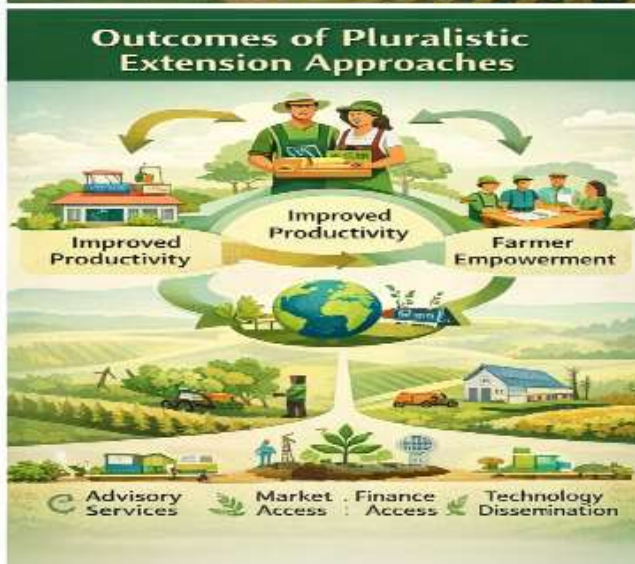
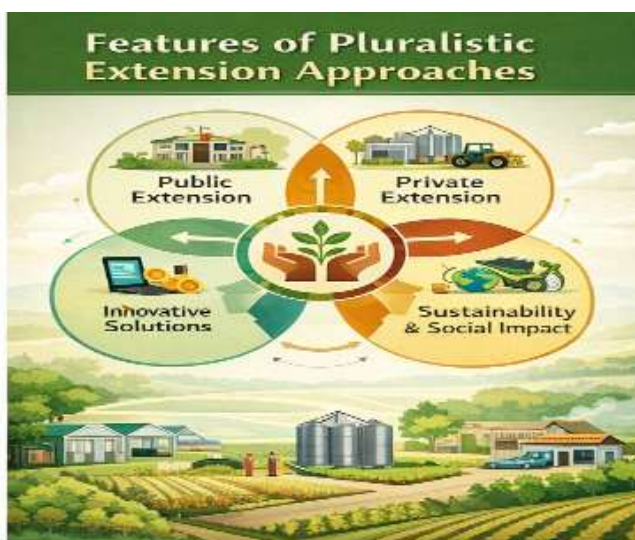
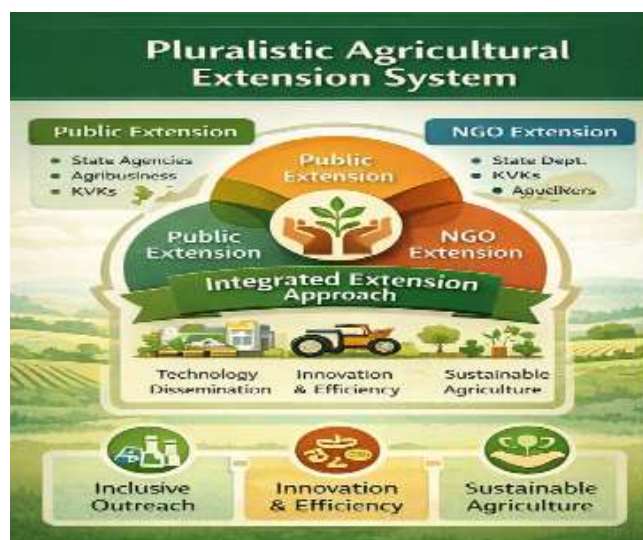
Agricultural extension today operates in an environment characterized by rapid technological change, increasing information needs, and diverse farming contexts. Farmers differ widely in terms of resource availability, cropping patterns, market access, and exposure to information, making a uniform extension approach ineffective. The growing emphasis on commercialization, sustainability, and resilience has further expanded the scope of extension beyond production-oriented advice to include value chain development, risk management, and digital advisory services. In this dynamic context, a pluralistic extension system that brings together public institutions, private enterprises, and non-governmental organizations offers a more adaptable and responsive framework for delivering agricultural knowledge and services. By leveraging the comparative advantages of multiple stakeholders, pluralistic extension strengthens linkages between research, extension, markets, and farming communities, thereby enhancing the overall effectiveness and impact of agricultural development initiatives.

PRIVATE EXTENSION MODEL

The private extension model refers to agricultural advisory services provided by private sector organizations, including agribusiness companies, input suppliers, seed companies, fertilizer and pesticide firms, agri-consultancy services, contract farming agencies and agri-tech startups. Unlike public extension, private extension services are generally market-driven and focus on improving farm

profitability and efficiency. Private extension has grown rapidly due to the commercialization of agriculture, expansion of high-value crops and increasing demand for specialized, timely and location-specific advisory services. These services are often linked to the sale of agricultural inputs or output marketing arrangements. For example, seed companies provide technical guidance on crop cultivation, while agri-input dealers advise farmers on fertilizer and pesticide usage. One of the major strengths of the private extension model is its efficiency and responsiveness. Private agencies operate in a competitive environment and therefore emphasize quality service delivery, quick feedback and adoption of modern communication tools such as mobile applications, helplines, digital platforms, precision advisory systems and decision-support tools. This allows farmers to access real-time information related to weather, pest management, nutrient application and market prices. Private extension is particularly effective in commercial agriculture, including horticulture, floriculture, plantation crops, dairy, poultry and export-oriented farming systems. Farmers engaged in these enterprises are often willing to pay for advisory services because of higher returns on investment. In some cases, private extension services are offered free of cost but are indirectly compensated through increased sales of inputs.

However, the private extension model also has limitations. Its reach is often restricted to progressive and resource-rich farmers, while small and marginal farmers may be excluded due to cost constraints. There is also a risk of biased advice, as recommendations may be influenced by commercial interests rather than long-term sustainability. Moreover, private extension services may not adequately address social, environmental and equity-related concerns. Despite these limitations, private extension plays a vital role in a pluralistic extension system by complementing public extension services. It brings innovation, investment and market orientation into extension delivery. When supported by proper regulation and coordination with public agencies, private extension can significantly enhance agricultural productivity and competitiveness.



PUBLIC EXTENSION MODEL

The public extension model refers to agricultural extension services that are planned, funded and implemented by government institutions with the primary objective of promoting agricultural development and farmer welfare. This model has been the backbone of extension systems in many developing countries, including India and plays a crucial role in ensuring food security, rural livelihoods and sustainable agricultural growth. In India, public extension is mainly carried out through State Departments of Agriculture, Krishi Vigyan Kendras (KVKs), Agricultural Universities, ICAR institutions, ATMA (Agricultural Technology Management Agency) and line departments related to horticulture, animal husbandry and fisheries.

These institutions function at national, state, district and village levels to provide technical knowledge, training and advisory services to farmers. The major focus of the public extension model is technology transfer from research institutions to farmers. Scientists develop improved varieties, crop management practices and resource conservation technologies, which are then disseminated through extension personnel using methods such as field demonstrations, training programmes, farmer meetings, exposure visits, soil health campaigns and advisory bulletins. Public extension services are generally provided free of cost, making them accessible to small and marginal farmers.

One of the key strengths of the public extension model is its wide outreach and credibility.

Government extension workers are trusted sources of information and public institutions have the mandate to serve all categories of farmers, including women farmers, tribal farmers and resource-poor households. Public extension also plays a significant role in implementing national and state-level agricultural policies, schemes and subsidies. However, the public extension system faces several challenges. These include inadequate manpower, high farmer-to-extension worker ratio, limited financial resources, bureaucratic procedures and slow adoption of innovative approaches. Due to these constraints, personalized and timely advisory services are often difficult to provide, especially in remote and interior areas. Despite these limitations, the public extension model remains essential in a pluralistic extension system. It provides the institutional framework, policy support and regulatory guidance necessary for coordinating other extension service providers. When effectively integrated with private and NGO efforts, public extension can ensure inclusive, equitable and sustainable agricultural development.

NGO-BASED EXTENSION MODEL

The NGO-based extension model refers to agricultural extension services provided by non-governmental organizations (NGOs) that work at the grassroots level with farming communities. These organizations are generally non-profit in nature and focus on people-centred, participatory and sustainable development approaches rather than commercial objectives. NGO-based extension has gained importance particularly in areas where public and private extension services have limited reach. NGOs play a significant role in working with small and marginal farmers, tribal communities, women farmers, landless labourers and other vulnerable groups. Their extension activities often integrate agriculture with allied sectors such as nutrition, health, natural resource management and livelihood security. Unlike conventional technology-transfer approaches, NGO extension emphasizes capacity building, empowerment and behavioural change among farmers.

One of the distinguishing features of NGO-based extension is its participatory approach. NGOs actively involve farmers in problem identification, planning, implementation and evaluation of extension programmes. Methods such as Participatory Rural Appraisal (PRA), Farmer Field Schools (FFS), Self-Help Groups (SHGs), producer groups and community-based organizations are commonly used to enhance learning and collective action. This approach strengthens farmers' confidence and promotes local innovation. NGOs are particularly effective in promoting sustainable and eco-friendly agricultural practices, including organic farming, integrated farming systems, natural resource conservation and climate-resilient agriculture. Due to their close association with communities, NGOs are able to address socio-cultural barriers, gender issues and traditional knowledge systems more effectively than formal institutions.

However, NGO-based extension also faces certain challenges. Many NGOs depend on project-based funding, which may limit the continuity and scale of their interventions. Their geographical coverage is often restricted and technical expertise may vary across organizations. Despite these constraints, NGOs contribute significantly to social inclusion, innovation and sustainability in extension services. In a pluralistic extension system, NGO-based extension acts as a bridge between farmers and formal institutions, facilitating better communication, trust and adoption of technologies. When integrated with public and private extension efforts, NGOs enhance the overall effectiveness and inclusiveness of agricultural extension.

IMPORTANCE OF PLURALISTIC EXTENSION APPROACHES

Pluralistic extension approaches are increasingly important in addressing the complex and diverse challenges faced by modern agriculture. No single extension agency can effectively meet the varied needs of farmers, which range from crop production and livestock management to marketing, climate adaptation, nutrition and digital literacy. By involving multiple actors such as public institutions,

private organizations and NGOs, pluralistic extension ensures that farmers receive comprehensive and need-based advisory services. One of the major importance of pluralistic extension lies in its ability to expand outreach and accessibility. Public extension systems often face limitations in manpower and resources, while private and NGO agencies can supplement these gaps by reaching different categories of farmers. This multi-actor involvement improves coverage in remote, tribal and underserved regions, thereby promoting inclusive agricultural development.

Pluralistic extension approaches also enhance the quality and relevance of extension services. Private agencies introduce innovation, efficiency and market orientation, while NGOs contribute participatory methods and social sensitivity. Public institutions ensure scientific validity and policy alignment. The combination of these strengths results in more accurate, timely and location-specific recommendations for farmers. Another significant importance of pluralistic extension is its role in promoting farmer choice and accountability. Farmers are no longer dependent on a single source of information; instead, they can access advisory services from multiple providers and select what best suits their needs. This competitive environment encourages service providers to improve performance, transparency and responsiveness.

Pluralistic extension also supports sustainable agricultural development. NGOs and public institutions emphasize environmental conservation, climate-resilient practices and social equity, while private agencies facilitate access to inputs, markets and value chains. Together, they help farmers adopt sustainable practices without compromising economic viability. Furthermore, pluralistic extension strengthens innovation and knowledge exchange by encouraging collaboration among research institutions, extension agencies, private firms and farmer organizations. Such partnerships accelerate technology dissemination, improve feedback mechanisms and foster continuous learning within the agricultural system. Overall, pluralistic extension approaches are essential for building a resilient, inclusive and efficient agricultural extension system

that responds effectively to the evolving needs of farmers and contributes to long-term rural development.

COMPARATIVE ANALYSIS OF PUBLIC, PRIVATE AND NGO EXTENSION MODELS

A comparative analysis of public, private and NGO-based extension models helps in understanding their distinct roles, strengths and limitations within a pluralistic extension system. Each model operates with different objectives, funding mechanisms and service delivery approaches, yet all contribute to agricultural development in complementary ways. The public extension model primarily focuses on social welfare, food security and inclusive agricultural growth. It aims to serve all categories of farmers, particularly small and marginal farmers, by providing free or subsidized advisory services. Public extension is science-based and policy-driven, ensuring the dissemination of research-backed technologies. However, its effectiveness is often constrained by limited manpower, budgetary restrictions and bureaucratic procedures, which may reduce timeliness and personalization of services.

In contrast, the private extension model is market-oriented and profit-driven. It emphasizes efficiency, innovation and responsiveness to farmer demands. Private extension services are usually targeted towards commercial and progressive farmers and are often linked with input supply or output marketing. While private extension enhances productivity and market integration, its reach among resource-poor farmers is limited and recommendations may sometimes be influenced by commercial interests.

The NGO-based extension model places strong emphasis on participation, empowerment and sustainability. NGOs work closely with farming communities, especially in remote, tribal and marginalized areas. Their extension approaches are people-centered and often integrate agriculture with social development, nutrition and environmental conservation. However, NGO extension is generally limited in scale and depends heavily on external funding, which can affect continuity.

From a comparative perspective, public extension

ensures equity and wide coverage, private extension promotes efficiency and commercialization and NGO extension strengthens community participation and social inclusion. A pluralistic extension system effectively combines these models to overcome individual limitations and maximize collective strengths.

Thus, the comparative analysis clearly indicates that no single extension model is sufficient on its own. The integration and coordination of public, private and NGO extension services is essential for creating a balanced, effective and sustainable agricultural extension system.

CONCLUSION

The changing nature of agriculture, characterized by technological advancement, market orientation, climate variability and diversified farmer needs, demands an extension system that is flexible, inclusive and responsive. The traditional reliance on a single extension agency is no longer sufficient to address the complex challenges faced by farming communities. In this context, pluralistic extension approaches, involving public, private and NGO-based models, have emerged as an effective and practical solution for strengthening agricultural extension systems. Each extension model contributes unique strengths to the overall system. Public extension plays a crucial role in ensuring equity, scientific credibility and policy implementation, particularly for small and marginal farmers.

Private extension enhances efficiency, innovation and market linkages, especially in commercial and high-value agriculture. NGO-based extension strengthens community participation, empowerment and sustainability by working closely with marginalized and vulnerable groups. When these models function independently, their impact remains limited; however, when integrated, they create a balanced and comprehensive extension framework. The success of pluralistic extension lies in effective coordination, convergence and mutual accountability among stakeholders. Strong institutional mechanisms, supportive policies and capacity-building initiatives are essential to harmonize the efforts of different extension providers. Ensuring quality control, transparency and farmer-centric service delivery further enhances the effectiveness of pluralistic systems. Ultimately, pluralistic extension approaches contribute to inclusive agricultural development, improved farm productivity, sustainable resource management and enhanced rural livelihoods. By combining the strengths of public, private and NGO models, pluralistic extension provides a resilient pathway for addressing present and future challenges in agriculture. Strengthening collaboration among stakeholders and placing farmers at the center of extension efforts will be key to realizing the full potential of pluralistic extension systems.

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Gujarat Shift toward Organic Farming: Enhancing Soil Health, Human Well-being and Market Opportunities

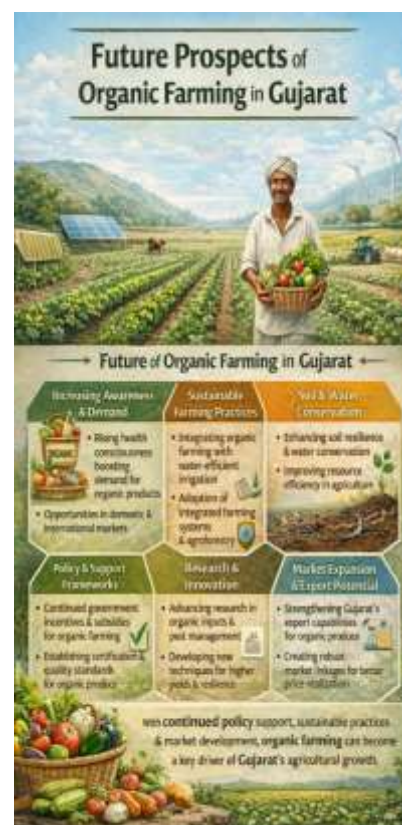
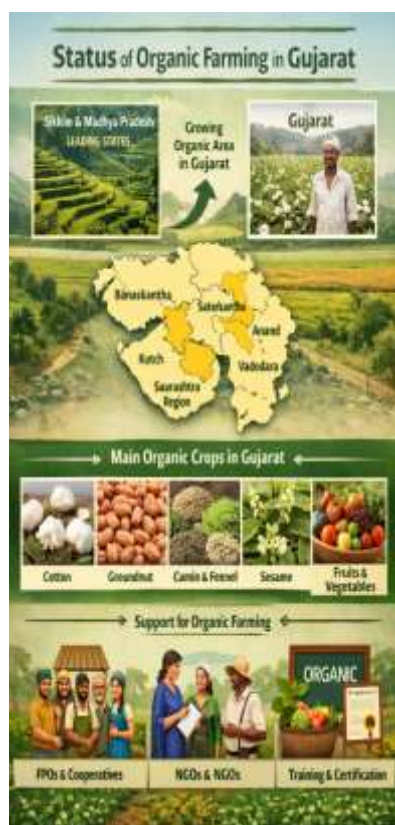
Abstract

Organic farming has emerged as a sustainable alternative to conventional agricultural systems that are strongly reliant on synthetic fertilizers, pesticides and intensive resource use. In recent years, Gujarat farmers have shown a growing interest in organic farming due to concerns related to soil degradation, declining farm profitability, environmental pollution and human health risks associated with chemical-based agriculture. Gujarat shifted toward organic farming, focusing on its role in improving soil health, enhancing human well-being and expanding market opportunities for farmers. The current status of agriculture in Gujarat; principles and practices of organic farming; government initiatives; impacts on soil physical, chemical, and biological properties; health and nutritional benefits of organic produce; and emerging domestic and export market opportunities. Challenges in adoption and future prospects are also critically surveyed. This study concludes that organic farming, when supported by appropriate policies, capacity building and market linkages, can play a vital role in achieving sustainable agricultural development in Gujarat.

Keywords: Organic farming; Sustainable agriculture; Soil health; Gujarat agriculture; Market opportunities

Introduction

Agriculture has always been the backbone of the Indian economy, providing livelihoods to a large proportion of the population and ensuring food security for the nation. Gujarat, one of India's leading agricultural states, has made significant progress in agricultural productivity through irrigation development, improved crop varieties and modern farming technologies. However, the widespread use of chemical fertilizers, pesticides and monocropping systems has raised serious concerns about soil health, environmental sustainability and human health. Over the past few decades, signs of soil degradation, such as declining organic matter, nutrient imbalance, salinity and reduced microbial activity, have been observed in several parts of Gujarat. Moreover, consumers are becoming increasingly aware of the health risks associated with pesticide residues in food. These factors have encouraged policymakers, farmers, researchers and consumers to explore alternative farming systems that are environmentally friendly, economically viable and socially acceptable. Organic farming has gained attention as a holistic approach that emphasizes the use of natural inputs, ecological balance and sustainable resource management. The Gujarat shift toward organic farming reflects a broader national and global movement toward sustainable agriculture.



Overview of Agriculture in Gujarat

Gujarat has diverse agro climatic profiles, ranging from arid and semiarid regions to coastal and irrigated areas. The major crops grown in the state include cotton, groundnut, wheat, rice, maize, pearl millet, castor, cumin, fennel, fruits, and vegetables. The state is known for its leadership in cotton production, oilseeds and horticultural crops.

The Green Revolution and subsequent agricultural intensification increased crop yields but also led to excessive dependence on chemical fertilizers and pesticides. For crops such as cotton and vegetables, pesticide use has been particularly common. Over time, this has resulted in issues such as pest resistance, soil nutrient depletion, groundwater contamination and rising input costs for farmers.

In response to these challenges, Gujarat has begun promoting sustainable agricultural practices, including organic farming, natural

farming, integrated nutrient management and water-use efficiency. Organic farming is increasingly viewed as a long-term solution for restoring soil fertility and improving farm resilience.

Concept and Principles of Organic Farming

Organic farming is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions rather than the use of synthetic inputs. The key principles of organic farming include the following:

- **Principle of Health:** Organic farming aims to sustain and enhance the health of soil, plants, animals, humans and the planet as a whole.
- **Principle of Ecology:** This principle is based on living ecological systems and works with them rather than against them.

- **Principle of Fairness:** Organic agriculture builds on relationships that ensure fairness with respect to the common environment and life opportunities.
- **Principle of Care:** Organic farming is managed in a precautionary and responsible manner to protect the health and well-being of current and future generations.

In practice, organic farming involves the use of organic manures, compost, green manures, biofertilizers, biological pest control, crop rotation, intercropping and mulching.

Status of Organic Farming in Gujarat

Compared with that in states such as Sikkim and Madhya Pradesh, organic farming in Gujarat is still in a developing stage. However, there has been a steady increase in the area under organic cultivation. Several districts, including Banaskantha, Sabarkantha, Anand, Vadodara, Kutch and parts of Saurashtra, have shown interest in organic practices.

Crops commonly grown under organic farming in Gujarat include cotton, groundnut, cumin, fennel, sesame, pulses, fruits and vegetables. Farmer producer organizations (FPOs), nongovernmental organizations (NGOs) and cooperatives play important roles in promoting organic farming by providing training, certification support and market linkages.

Government Initiatives Promoting Organic Farming in Gujarat

The Government of India and the Government of Gujarat have launched several schemes to encourage organic farming. Important initiatives include the following:

- ❖ **Paramparagat Krishi Vikas Yojana (PKVY):** Promotes cluster-based organic farming and provides financial assistance for organic inputs and certification.

- ❖ **Mission Organic Value Chain Development:** Supports value chain development for organic produce.

- ❖ **National Mission on Sustainable Agriculture (NMSA):** Encourages sustainable farming practices, including organic agriculture.

- ❖ **State-level programs:** Gujarat has introduced training programs, demonstrations and subsidies for organic inputs such as vermicompost units and biofertilizers.

These initiatives aim to reduce farmers' dependence on chemical inputs and promote environmentally sustainable agriculture.

Impact of Organic Farming on Soil Health

Soil health is the foundation of sustainable agriculture. Organic farming has a positive effect on the physical, chemical and biological properties of soil.

Physical Properties of Soil

Organic practices improve soil structure, aggregation and porosity. The addition of organic matter through compost, farmyard manure and crop residues enhances the WHC and reduces soil erosion. In the arid and semiarid regions of Gujarat, improved soil moisture retention is particularly important for crop resilience.

Chemical properties of the soil

Organic farming helps maintain balanced nutrient availability. Unlike chemical fertilizers, organic inputs release nutrients slowly and improve nutrient use efficiency. The regular application of organic manure increases soil organic carbon, which is essential for long-term fertility. It also helps reduce soil salinity and maintains a favorable soil pH.

Biological Properties of Soil

Soil microorganisms play crucial roles in nutrient cycling and plant health. Organic farming promotes microbial diversity and activity by

providing organic substrates. Increased populations of beneficial bacteria, fungi and earthworms increase nutrient availability and suppress soil-borne diseases.

Environmental benefits of organic farming

Organic farming contributes to environmental sustainability by reducing pollution and conserving natural resources. The avoidance of synthetic pesticides and fertilizers minimizes contamination of soil and water bodies. Organic practices also promote biodiversity by creating favorable habitats for beneficial insects, birds and soil organisms.

In the context of climate change, organic farming helps mitigate greenhouse gas emissions by increasing soil carbon sequestration and reducing energy-intensive chemical inputs.

Organic farming and human well-being

Human well-being is closely linked to the quality of food and the environment. Organic farming contributes to improved health outcomes in several ways.

Food Safety and Nutrition

Organic foods are produced without synthetic pesticides or chemical residues, making them safer for consumption. Several studies suggest that organic produce may contain relatively high levels of certain vitamins, minerals and antioxidants.

Farmer health

Reduced exposure to toxic agrochemicals improves the health and safety of farmers and farm workers. Organic farming reduces the risk of pesticide poisoning and long-term health problems.

Rural livelihoods and social well-being

Organic farming can enhance rural livelihoods by reducing input costs and increasing farm income through best prices. It also encourages community participation, traditional knowledge and collective action.

Market Opportunities for Organic Produces in Gujarat

The market for organic products is expanding rapidly at both the national and international levels. Urban consumers are increasingly willing to pay a premium for organic food because of health and environmental concerns.

Domestic Market

In India, the demand for organic food is growing in metropolitan cities. Gujarat proximity to major urban markets provides an advantage for organic farmers. Retail chains, farmer markets and online platforms are creating new marketing channels.

Export potential

Gujarat has strong export infrastructure, including ports and logistics facilities. Organic cotton, spices, oilseeds and processed foods from Gujarat have significant export potential. Certification and quality assurance are key factors for accessing international markets.

Role of Farmer Producer Organizations

FPOs play an important role in the aggregation, processing, branding and marketing of organic produce. They help small farmers overcome scale-related challenges and improve their bargaining power.

Challenges in Adoption of Organic Farming

Despite the multiple environmental, health and economic benefits of organic farming, its adoption in Gujarat faces several challenges. These challenges are technical, economic, institutional and market related, and they often discourage farmers from shifting from conventional farming systems to organic practices.

One of the major challenges is the initial decline in crop yields during the transition period from conventional to organic farming. As synthetic fertilizers and pesticides are withdrawn,

soil ecosystems require time to recover, which can temporarily reduce productivity. This yield reduction directly affects farm income and creates financial risk, particularly for small and marginal farmers.

The limited availability of organic inputs such as farmyard manure, compost, vermicompost, biofertilizers and biopesticides is another significant constraint. Many farmers do not have sufficient livestock or resources to produce organic inputs on their farms. In addition, the transportation and storage of bulky organic materials increase labor and cost requirements.

Certification procedures and associated costs also pose challenges. Organic certification is often complex, time-consuming and expensive for individual farmers. Maintaining detailed records and complying with certification standards require technical knowledge and institutional support, which are not always easily accessible.

A lack of technical knowledge and awareness among farmers further limits the adoption of organic farming. Many farmers are unfamiliar with organic nutrient management, biological pest control methods and crop diversification strategies. Limited extension services and inadequate training opportunities worsen this knowledge gap.

Market access and price uncertainty remain critical challenges. Although organic products generally fetch premium prices, farmers often struggle to find reliable markets. Inconsistent demand, a lack of organized marketing channels and the absence of assured procurement systems reduce farmer confidence in organic farming.

Finally, policy and institutional limitations, such as insufficient transition support and weak coordination among stakeholders, slow the large-scale adoption of organic farming.

Addressing these challenges requires integrated efforts involving policy reforms, research, extension services and market development.

Strategies to Overcome Challenges in Organic Farming

To promote organic farming successfully in Gujarat, addressing the existing challenges through well-planned and coordinated strategies is essential. Capacity building, institutional support and market development are key components of this process. Farmers need continuous technical guidance during the transition phase to minimize yield losses and improve confidence in organic practices.

Training programs, field demonstrations, and exposure visits should be strengthened to increase farmers' practical knowledge of organic nutrient management, pest control and soil health improvement. The promotion of on-farm production of organic inputs such as compost, vermicompost, green manure and biofertilizers can reduce the dependency on external inputs and lower production costs.

Group-based approaches, such as farmer clusters and farmer producer organizations (FPOs), can help reduce certification costs and improve collective marketing. Participatory guarantee systems (PGSs) are particularly suitable for small and marginal farmers, as they are cost-effective and locally managed. Strengthening market linkages through dedicated organic markets, branding and direct farmer–consumer connections will ensure better price realization and income stability.

Role of Research, Education and Extension

Research, education and extension play vital roles in the long-term success of organic farming in Gujarat. State agricultural universities and research institutions must focus on developing region-specific organic farming

technologies suitable for different agro climatic zones of the state. Long-term experiments on organic nutrient management, soil health restoration and pest and disease control are essential for generating scientific evidence and farmer confidence.

Extension services should emphasize participatory approaches that actively involve farmers in learning and decision-making. Krishi Vigyan Kendras (KVKs) can serve as important platforms for training, demonstrations and dissemination of organic farming practices. The use of digital tools, mobile-based advisory services and online knowledge platforms can further enhance outreach and information delivery to farmers, especially in remote areas.

Policy Support and Institutional Framework

Strong policy support and an effective institutional framework are crucial for scaling up organic farming in Gujarat. Government policies should provide incentives during the transition period, including financial support, input subsidies and risk mitigation measures. The integration of organic farming into state agricultural development programs can ensure long-term commitment and resource allocation.

Coordination among various stakeholders, such as government departments, research institutions, nongovernmental organizations and farmer groups, is essential for effective implementation. Public-private partnerships can also play a significant role in developing organic value chains, processing facilities and export infrastructure. A transparent and farmer-friendly certification system will further encourage wider adoption.

Future Prospects of Organic Farming in Gujarat

The future of organic farming in Gujarat appears promising because of increasing consumer awareness, increasing health

consciousness and increasing demand for organic products in both domestic and international markets. Organic farming has the potential to increase soil resilience, conserve natural resources and reduce the environmental footprint of agriculture.

The gradual and location-specific expansion of organic farming, rather than the complete replacement of conventional systems, may be more practical. The integration of organic farming with other sustainable practices, such as integrated farming systems, water-efficient irrigation and agroforestry, can further strengthen farm sustainability. With continued policy support, research advancements and market development, organic farming can become an important pillar of Gujarat agricultural growth.

Conclusion

The Gujarat shift toward organic farming represents a significant step toward sustainable and inclusive agricultural development. Organic farming improves soil health, enhances human well-being and creates new market opportunities, thereby addressing many of the limitations of conventional agriculture. Although challenges related to yield stability, input availability, certification and market access remain, these challenges can be effectively managed through coordinated efforts involving policy support, research, extension services and farmer participation. In the long run, organic farming can contribute to environmentally sustainable agriculture, improved rural livelihoods, food safety and climate resilience in Gujarat.

References

- Altieri, M. A. (1995). *Agroecology: The Science of Sustainable Agriculture*. Westview Press, Boulder, USA.
- Food and Agriculture Organization (FAO). (2018). *The State of the World's Biodiversity for Food and Agriculture*. FAO, Rome.

- Government of Gujarat. (2022). *Agricultural Statistics at a Glance*. Department of Agriculture, Farmers Welfare and Co-operation, Gandhinagar.
- Government of India. (2020). *Paramparagat Krishi Vikas Yojana (PKVY) – Operational Guidelines*. Ministry of Agriculture and Farmers Welfare, New Delhi.
- Government of India. (2021). *National Mission on Sustainable Agriculture (NMSA)*. Ministry of Agriculture and Farmers Welfare, New Delhi.
- IFOAM – Organics International. (2005). *Principles of Organic Agriculture*. IFOAM, Bonn, Germany.
- Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science*, 304(5677), 1623–1627.
- Lampkin, N. (2002). *Organic Farming*. Old Pond Publishing, Ipswich, UK.
- Mahapatra, B. S., & Kumar, A. (2018). Organic farming in India: Status, issues and prospects. *Indian Journal of Agronomy*, 63(2), 141–152.
- Ministry of Commerce and Industry. (2021). *Export Opportunities for Organic Products from India*. Government of India, New Delhi.
- NCOF (National Centre of Organic Farming). (2020). *Organic Farming in India – Status and Prospects*. Ministry of Agriculture and Farmers Welfare, Ghaziabad.
- Pimentel, D., Hepperly, P., Hanson, J., Douds, D., & Seidel, R. (2005). Environmental, energetic, and economic comparisons of organic and conventional farming systems. *BioScience*, 55(7), 573–582.
- Reganold, J. P., & Wachter, J. M. (2016). Organic agriculture in the twenty-first century. *Nature Plants*, 2, 15221.
- Sarkar, S., & Singh, S. R. (2017). Organic farming and its impact on soil health and crop productivity. *Journal of Environmental Biology*, 38(3), 439–445.
- Willer, H., & Lernoud, J. (2022). *The World of Organic Agriculture: Statistics and Emerging Trends*. Research Institute of Organic Agriculture (FiBL), Switzerland.

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ARTICLE ID: 15

EFFECT OF DIFFERENT OIL CAKES ON SOIL QUALITY

Abstract

Oil cakes, derived as by-products from oilseed processing, play a significant role in improving soil quality and supporting sustainable agricultural practices. These organic amendments are rich sources of nitrogen, phosphorus, potassium, sulphur, and essential micronutrients, released gradually through microbial decomposition. Regular soil application enhances soil organic carbon, improves aggregate stability, and reduces bulk density, leading to better aeration and root development. Oil cakes also increase soil water-holding capacity, helping crops tolerate moisture stress more effectively. Enhanced microbial biomass and enzyme activity promote efficient nutrient cycling and long-term soil fertility. Certain oil cakes, such as neem and castor, release bioactive compounds that suppress soil-borne pests and pathogenic organisms, contributing to healthier rhizosphere conditions. Comparative responses among neem, mustard, groundnut, and castor cakes show that nutrient composition and decomposition rate influence soil physical, chemical, and biological properties differently across soil types and crops. Use of oil cakes lowers dependency on synthetic fertilizers, reduces nutrient losses, and supports eco-friendly soil management.

Keywords: *Oil cakes; Soil quality; Organic amendments; Soil fertility; Microbial activity; Sustainable agriculture; Nutrient cycling*

1. Introduction

- **Oil cakes as organic soil amendments:** Oil cakes are nutrient-rich residues obtained after oil extraction from seeds such as neem, mustard, groundnut, and castor. They contain 3–8% nitrogen, 1–2% phosphorus, and 1–2% potassium, along with calcium, sulphur, and micronutrients. Regular soil application increases soil organic carbon by 0.2–0.5% per season and improves nutrient availability through slow mineralization.
- **Importance of soil quality in sustainable agriculture:** Soil quality determines crop productivity, water retention, and nutrient cycling. Studies show that soils amended with oil cakes record 15–30% higher microbial biomass, 10–25% improvement in water-holding capacity, and reduced bulk density. Enhanced biological activity supports long-term fertility, lowers dependency on synthetic fertilizers, and maintains ecological balance in farming systems.

2. What Are Oil Cakes?

- Definition and common types
Oil cakes are solid organic residues left after mechanical or solvent extraction of oil from oilseeds. Commonly used types include neem cake (4–5% N, natural nitrification inhibitors), mustard cake (5–6% N, rapid mineralization), groundnut cake (7–8% N, high protein content), and castor cake (4–5% N, rich in sulphur). These materials act as slow-release nutrient sources and organic soil conditioners.

carbon-to-nitrogen ratio ranges between 5:1 and 12:1, enabling faster decomposition and efficient nutrient release in soil systems.

3. Nutrient Contribution of Oil Cakes

- Role in supplying nitrogen, phosphorus, and micronutrients

Oil cakes supply essential plant nutrients through gradual decomposition. Nitrogen content ranges from 3–8%, phosphorus from 1–2%, and potassium from 1–2% depending on cake type. Neem and castor cakes provide 20–30 kg sulphur per tonne, while groundnut and mustard cakes contribute iron, zinc, and manganese in trace amounts. Nutrient release efficiency reaches 60–70% within one cropping season, supporting steady plant uptake.

- Improvement of soil organic matter
Soil organic matter increases with regular oil cake application due to high biodegradable carbon content. Long-term field data indicate a 0.3–0.6% rise in organic carbon after repeated use. Enhanced organic matter improves aggregate stability by 15–25%, supports microbial activity, and strengthens nutrient retention capacity in cultivated soils.

4. Effects on Soil Physical Properties

- Impact on soil structure and aeration
Oil cake application enhances soil aggregation through increased organic binding agents. Field observations report a 20–35% rise in stable soil



- By-products of oil extraction
Oil cakes originate from oil processing industries and represent nearly 60–70% of the original seed mass after oil removal. Each tonne of oilseed processing yields 500–650 kg of cake, making them readily available organic inputs. Their

Table : Nutrient Contribution of Oil Cakes

Oil Cake Type	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Sulphur (kg t ⁻¹)	Key Micronutrients	Special Soil Benefit
Neem cake	4.0–5.0	1.0–1.5	1.0–1.5	20–25	Zn, Fe	Improves N-use efficiency, pest suppression
Mustard cake	5.0–6.0	1.5–2.0	1.0–1.2	25–30	Zn, Mn	Rapid nutrient mineralization
Groundnut cake	7.0–8.0	1.5–2.0	1.2–1.5	15–20	Fe, Cu	High N supply, boosts soil organic carbon
Castor cake	4.0–5.0	1.0–1.5	1.0–1.2	30–35	Zn, Mn	Improves soil structure, nematode control
Sesame cake	6.0–7.0	1.5–2.0	1.0–1.3	18–22	Fe, Zn	Enhances microbial activity

Note: Nutrient composition varies with oil extraction method and seed quality.

aggregates and a 10–20% reduction in bulk density after repeated use. Improved pore space promotes better aeration, supporting root growth and efficient gas exchange in cultivated soils.

- Improvement in water-holding capacity
Water-holding capacity improves due to higher organic matter and better soil porosity. Experimental data show 15–30% greater moisture retention in oil cake-amended soils. This improvement reduces irrigation frequency, minimizes moisture stress during dry periods, and enhances crop resilience under variable climatic conditions.

5. Effects on Soil Biological Activity

- Enhancement of beneficial microorganisms
Oil cakes act as energy sources for soil microbes due to high organic carbon and protein content. Application increases microbial biomass carbon by 20–40% and raises enzymatic activities such as dehydrogenase and phosphatase by 25–50%. Improved microbial populations enhance nutrient mineralization and root-microbe interactions.
- Suppression of soil-borne pests and pathogens
Neem and castor cakes release bioactive compounds like azadirachtin and ricin during decomposition. These compounds reduce nematode populations by 30–60% and lower incidence of fungal pathogens such as *Fusarium* and *Rhizoctonia* by 20–45%, supporting healthier root zones and improved crop establishment.

6. Comparison of Different Oil Cakes

- Relative benefits of major oil cakes on soil quality

Neem cake improves nitrogen-use efficiency by 15–25% due to natural nitrification inhibition. Mustard cake releases nutrients rapidly, raising available nitrogen within 15–20 days after application. Groundnut cake contributes the highest nitrogen content (7–8%) and increases soil organic carbon by 0.4–0.6%. Castor cake enhances sulphur availability and reduces soil

compaction, lowering bulk density by 10–15%.

- Crop- and soil-specific responses
Light-textured soils show stronger moisture retention gains of 20–30% with groundnut and castor cakes. Heavy soils respond better to neem and mustard cakes through improved aeration and microbial balance. Cereal and vegetable crops record 12–28% yield improvement, while oilseed and pulse crops benefit from enhanced root development and nutrient uptake efficiency.

7. Environmental and Economic Benefits

- Reduction in chemical fertilizer use
Oil cakes supply slow-release nutrients that replace 20–40% of synthetic nitrogen fertilizers under integrated nutrient management. Field evaluations show lower nitrate leaching by 25–35% and improved nutrient-use efficiency. Reduced fertilizer dependence supports balanced soil chemistry and limits long-term degradation.
- Eco-friendly and cost-effective soil management
Organic soil management using oil cakes lowers input costs by 15–30% through utilization of agro-industrial by-products. Carbon footprint declines due to reduced fertilizer manufacturing demand, while soil carbon sequestration increases by 0.3–0.5 t ha⁻¹ year⁻¹, supporting environmentally responsible and economically sustainable farming practices.

Conclusion

Oil cakes serve as effective organic soil amendments that enhance soil quality through improved nutrient supply, physical structure, and biological activity. Rich nitrogen, phosphorus, sulphur, and micronutrient content supports steady crop nutrition while gradual decomposition increases soil organic carbon and aggregation. Improved aeration, moisture retention, and reduced bulk density create favourable root environments, while enhanced microbial populations strengthen nutrient cycling. Bioactive compounds released during

decomposition help suppress soil-borne pests and pathogens, contributing to healthier cropping systems. Use of different oil cakes allows targeted management based on soil texture and crop requirements. Reduced reliance on chemical fertilizers lowers production costs, minimizes nutrient losses, and decreases environmental stress. Consistent application supports long-term soil fertility, sustainable productivity, and ecological balance, making oil cakes a practical component of modern soil management strategies.

References

- Baheti, B. L., Bhati, S. S. and Singh, H. (2019). Efficacy of different oil-cakes as soil amendment for the management of root-knot nematode, *Meloidogyne incognita* infecting okra (*Abelmoschus esculentus* L.). *International Journal of Current Microbiology and Applied Sciences*. **8**(12): 799-808.
- Gaiind, S., Nain, L. and Patel, V. B. (2009). Quality evaluation of co-composted wheat straw, poultry droppings and oil seed cakes. *Biodegradation*. **20**(3): 307-317.
- Jalili Ghazizadeh, M., Khalaj, S. and Aghamir Mohammadali, F. S. (2021). The role of food wastes and oil Cakes in soil fertility. *Journal of Environmental Science Studies*. **6**(2): 3613-3625.
- Radwan, M. A., El-Maadawy, E. K., Kassem, S. I. and Abu-Elamayem, M. M. (2009). Oil cakes soil amendment effects on *Meloidogyne incognita*, root-knot nematode infecting tomato. *Archives of Phytopathology and Plant Protection*. **42**(1): 58-64.
- Rafi, H., Dawar, S. and Tariq, M. (2016). Combined effect of soil amendment with oil cakes and seed priming in the control of root rot fungi of leguminous and non-leguminous crops. *Pak. J. Bot.* **48**(3): 1305-1311.
- Sharma, A. and Sharma, S. K. (2003). Effect of oil cakes on soil borne disease management and soil microflora in apple. In *VII International Symposium on Temperate Zone Fruits in the Tropics and Subtropics-Part Two*. 696 (pp. **341-348**).
- Sumbul, A., Rizvi, R., Mahmood, I. and Ansari, R. A. (2015). Oil-cake amendments: Useful tools for the management of phytonematodes. *Asian Journal of Plant Pathology*. **9**(3): 91-111.
- Tiyyagi, S. A., Khan, A. V. and Alam, M. M. (2001). Role of oil-seed cakes for the management of plant-parasitic nematodes and soil-inhabiting fungi on lentil and mungben. *Archives of Phytopathology & Plant Protection*. **33**(6): 453-472.

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ARTICLE ID: 16

A Farmer-Level Success in Mandya, Karnataka: Eco-friendly Management of Root-Knot Nematode in Paddy through Biofor PF-2 enriched FYM

Introduction

Rice (*Oryza sativa* L.) is the most important staple food crop in Karnataka, grown widely under irrigated and semi-dry conditions. In recent years, the rice root-knot nematode, *Meloidogyne graminicola*, has emerged as a major hidden threat, particularly in the Cauvery command areas. Unlike foliar pests, nematode infestations often go unnoticed until yield losses become severe. *M. graminicola* is known for its ability to cause characteristic hook-shaped galls on roots, restrict nutrient uptake, and stunt plant growth.

The pyriform-shaped females lay eggs within the root cortex, where juveniles undergo their first molt inside the eggs, developing into pre-parasitic second-stage juveniles. These second-stage juveniles are initially non-parasitic but become parasitic once they invade the root elongation zone. Throughout the year, soil population levels fluctuate, influenced by factors such as soil structure, temperature, pH, moisture, and the plant's growth stage, all of which affect the nematode's survival and infection capability.

The newly parasitic second-stage juveniles migrate intercellularly within the rice root cortex towards the root tip. There, they penetrate the vascular cylinder and establish specialized feeding sites in the stele near the root meristem by inducing the formation of five to eight giant cells. Once established, the nematode becomes sedentary and feeds on these giant cells. After undergoing three more molts, it reaches adulthood—females adopting a pear-shaped form, while males appear threadlike. Unlike other *Meloidogyne* species, where eggs are laid in egg masses protruding into the soil, *M. graminicola* lays eggs protected inside the root cortex.



Before treatment



After treatment



Galled roots

This offers protection from predators, pathogens, and host immune responses. This adaptation also allows the nematode to survive flooded conditions common in rice cultivation. The next generation of nematodes develops inside these internal egg masses, continuing to form additional feeding sites within the root.

The increasing incidence of nematodes in farmers' fields has highlighted the urgent need for sustainable management strategies that enhance soil health while reducing chemical dependency. Biological control using beneficial microbes enriched in organic substrates has shown promise as an eco-friendly option. This success story highlights an effective field intervention demonstrating the potential of enriched organic amendments to manage *M. graminicola* in farmer fields.

Farmer Details

- **Farmer Name:** Shri. Chandra Mohan
- **Location:** Vaddaragudi, K.R. Pete Taluk, Mandya District, Karnataka
- **Problem Identified:** Severe infestation of *Meloidogyne graminicola* in paddy

Shri. Chandra Mohan approached the nematologists' team for solutions after observing unusual stunting and poor growth in his rice field during the early tillering stage. During field inspection, the following symptoms were recorded:

Above-Ground Symptoms

- Stunted seedlings with uneven growth
- Poor tillering and weak secondary shoots
- Yellowing of foliage, mimicking nutrient deficiency
- Reduced vigor and delayed crop establishment

Below-Ground Symptoms

Upon uprooting and washing the roots:

- Extensive galling characteristic of *Meloidogyne* infection

- Poor root branching
- Reduced root biomass

Initial soil analysis indicated a nematode population of 475 juveniles per 200 cc soil, reflecting a high level of infestation. To provide an eco-friendly solution, the farmer was advised to adopt biological management using FYM enriched with Biofor PF-2, a *Pseudomonas fluorescens* formulation known for its antagonistic activity against plant-parasitic nematodes. Application rate: FYM enriched with Biofor PF-2 @ 20 g/m²

Method of Application

- Preparation of enriched FYM: FYM was thoroughly mixed with Biofor PF-2 @ 20 g/m².
- Application timing: Applied as basal dose before transplanting.
- Incorporation: Spread uniformly and mixed into the top 10–12 cm of soil.

Mode of action: Improvement of soil organic matter, enhancement of antagonistic microbial activity, and suppression of nematode populations.

Outcome and Impact

The intervention resulted in:

- Significant reduction in nematode population:
 - *Before treatment:* 475/200 cc soil
 - *After treatment:* 123/200 cc soil
- Improved plant growth, enhanced tillering and uniform growth, Greener foliage indicating improved nutrient uptake, Strong, well-branched root systems, Faster crop recovery compared to the untreated area
- **Yield enhancement:** The farmer recorded a 35% increase in grain yield after adopting the enriched FYM treatment. This improvement is significant for a smallholder farmer in a region where even 10–15% yield enhancement is economically meaningful.

- **Economic benefit:** The cost-benefit assessment showed a Benefit–Cost Ratio (B:C) of 1:2.9, clearly demonstrating the profitability of the intervention. Low input cost (locally available FYM + Biofor PF-2), High economic return through increased yield.
- **Soil health improvement:** Beyond nematode management, the practice contributed to increased microbial activity, higher organic carbon content, improved soil texture and water-holding capacity.

These benefits support long-term soil sustainability and resilience of the cropping system.

Conclusion

The success of Biofor PF-2 enriched FYM in Shri. Chandra Mohan’s field demonstrates the practical feasibility and effectiveness of biological management against *Meloidogyne graminicola* in rice-growing regions of Karnataka. This eco-friendly approach not only suppresses nematode populations but also enhances soil health and productivity, offering a sustainable alternative to chemical nematicides.

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ARTICLE ID: 17

Herbicide Drift Management in Cotton: Precautions and Field-Level Strategies

Introduction

Cotton (*Gossypium hirsutum* L.) is one of the most economically important fibre crop globally and plays a crucial role in sustaining rural livelihoods in India. The increasing dependence on herbicides for weed management in modern agriculture has significantly reduced labour efficiency and crop productivity. However, the indiscriminate and improper use of herbicides has led to unintended consequences, among which **herbicide drift** has emerged as a major threat to cotton cultivation. Herbicide drift is defined as the off-target movement of herbicides from the site of application to adjacent non-target areas, causing injury to sensitive crops. According to Norsworthy et al. (2012), herbicide drift and volatilization are among the primary causes of unintended crop injury in agricultural landscapes. Cotton is highly sensitive to several herbicides, and even exposure to sub-lethal doses can result in morphological abnormalities and yield reduction.

Herbicide Drift: Nature and Mechanism: Herbicide drift occurs in two major forms: spray drift and vapour drift. Spray drift refers to the physical movement of herbicide droplets during application, while vapour drift involves the volatilization of herbicides after application under favorable environmental conditions. Al-Khatib and Peterson (2019) reported that fine droplets produced during spraying can travel long distances, especially under windy conditions, leading to significant off-target deposition.

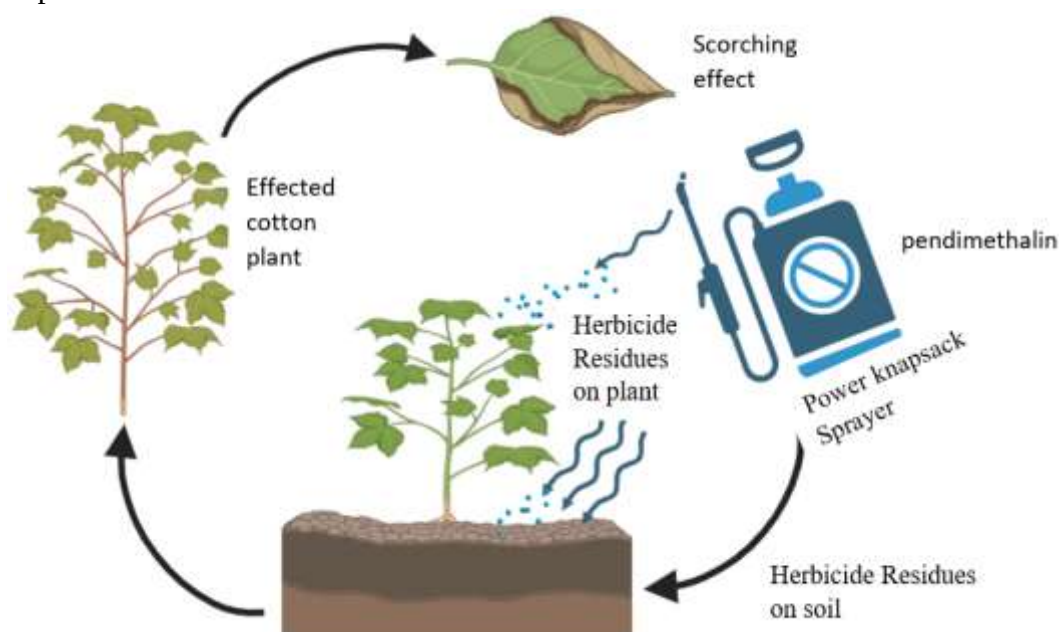


Fig 1: Mechanistic Pathway of Herbicide Drift and Residue- Mediated stress in cotton

Growth regulator herbicides such as 2,4-D and dicamba are particularly prone to volatilization and drift. Riar et al. (2013) observed that dicamba and 2,4-D vapours can cause visible injury to sensitive crops even at extremely low concentrations. Similarly, Duke and Powles (2008) highlighted that glyphosate drift can disrupt physiological processes in non-target plants, resulting in growth inhibition and yield losses.

Sensitivity of Cotton to Herbicide Drift

Cotton is considered one of the most herbicide-sensitive crops due to its physiological and morphological characteristics. Singh and Yadav (2020) reported that cotton exhibits severe phytotoxic symptoms when exposed to growth regulator herbicides, even at trace levels. The sensitivity of cotton is highest during critical growth stages such as seedling establishment, squaring, flowering, and boll development.

Research evidence indicates that herbicide drift during reproductive stages can significantly reduce boll formation and lint quality. According to the FAO (2021), exposure of sensitive crops to herbicide drift can lead to irreversible damage and long-term productivity losses.

Symptoms of Herbicide Drift Injury in Cotton:

Herbicide drift injury in cotton manifests through a range of morphological and physiological symptoms. These include: Leaf cupping, crinkling, and distortion, Narrow and strap-like leaves, twisting of stems and petioles, Scorching Effect, Reduced internode length and stunted growth, Delayed flowering and boll development, Boll shedding and malformed bolls.

Norsworthy et al. (2012) stated that leaf deformation and abnormal growth patterns are characteristic indicators of exposure to growth regulator herbicides. Similarly, Singh et al. (2019) reported that herbicide drift can significantly alter plant hormonal balance, leading to abnormal

morphogenesis in cotton.

Factors Influencing Herbicide Drift: Herbicide drift is influenced by multiple interacting factors related to application technology, environmental conditions, and herbicide properties. Al-Khatib and Peterson (2019) emphasized that spray droplet size, wind speed, temperature, and humidity are the critical factors of drift effect in plants. Major factors contributing to herbicide drift in cotton-growing regions include: Use of fine spray droplets and high spray pressure, High wind velocity during herbicide application, High temperature and low relative humidity, Use of volatile herbicide formulations, Improper nozzle selection and boom height, Lack of awareness among farmers.

Table: 1 Herbicide Drift Risk–Response–Control Matrix in Cotton

Risk Driver	Drift Pathway	Exposure Route	Cotton Stress Response	Yield Impact	Control Logic
Wind + Fine droplets	Atmospheric drift	Foliar absorption	Leaf scorching, epinasty	10–40% loss	Droplet engineering
High temperature + volatile herbicides	Vapor drift	Stomatal uptake	Hormonal imbalance	15–35% loss	Chemical selection
Soil adsorption + runoff	Soil-mediated drift	Root uptake	Growth retardation	5–25% loss	Soil management
Re-suspension of residues	Secondary drift	Foliar + root	Chronic phytotoxicity	5–20% loss	Residue management
Human error	Operational drift	Multi-route	Non-uniform damage	Variable	Precision spraying

FAO (2021) reported that inappropriate application practices and lack of adherence to

label recommendations significantly increase the risk of herbicide drift.

Precautions and Field-Level Management Strategies

Optimization of Spray Technology: The adoption of improved spray technology is one of the most effective approaches to minimize herbicide drift. Air-induction and low-drift nozzles have been shown to reduce the formation of fine droplets and drift potential. According to Al-Khatib and Peterson (2019), the use of coarse droplets and reduced spray pressure can significantly decrease off-target herbicide movement.

Weather-Based Application Decisions: Environmental conditions play a crucial role in herbicide drift. Herbicide application should be avoided during high wind speed, high temperature, and low humidity. Norsworthy et al. (2012) recommended that herbicide spraying should be carried out under moderate temperature and low wind conditions to minimize drift risk.

Selection of Herbicide Formulations: The choice of herbicide formulation is critical in drift management. Low-volatility formulations should be preferred over volatile ester formulations, especially near cotton fields. Riar et al. (2013) highlighted that formulation type significantly influences volatilization potential and off-target movement of herbicides.

Management of Drift Injury in Cotton: Light irrigation, foliar nutrition, and stress avoidance can aid partial recovery from herbicide drift injury in cotton, though severe damage may cause permanent yield loss (Singh and Yadav, 2020).

Conclusion: Herbicide drift is a growing challenge in cotton cultivation, as cotton is highly sensitive to many herbicides and even low-dose exposure can cause serious crop injury and yield loss. The use of improved spray technology, proper herbicide selection, suitable environmental

conditions, and effective field-level management is essential to minimize drift. Strengthening farmer awareness is crucial for sustainable cotton production.

References

1. Al-Khatib, K., & Peterson, D.E. (2019). Herbicide drift and off-target movement: Causes and mitigation strategies. *Weed Technology*, 33(2), 189–198.
2. Duke, S.O., & Powles, S.B. (2008). Glyphosate: A once-in-a-century herbicide. *Pest Management Science*, 64(4), 319–325.
3. FAO. (2021). Guidelines on pesticide application and drift management. FAO Plant Production and Protection Paper, Rome.
4. ICAR–Directorate of Weed Research. (2022). Herbicide stewardship and safe use in Indian agriculture. ICAR Publications, India.
5. Norsworthy, J.K., et al. (2012). Reducing the risks of herbicide drift and volatilization. *Weed Science*, 60(1), 31–62.
6. Peterson, D.E., & Al-Khatib, K. (2018). Spray drift management in modern agriculture. *Agronomy Journal*, 110(5), 1805–1814.
7. Riar, D.S., Norsworthy, J.K., & Steckel, L.E. (2013). Off-target movement of dicamba and 2,4-D in sensitive crops. *Weed Technology*, 27(4), 708–716.
8. Singh, S., & Yadav, D.B. (2020). Herbicide drift and its impact on crop production in India. *Indian Journal of Weed Science*, 52(3), 245–252.
9. Singh, V., Sharma, A., & Kumar, R. (2019). Physiological responses of crops to herbicide stress. *Journal of Crop Science*, 10(2), 101–110.
10. WHO & FAO. (2020). International code of conduct on pesticide management. Rome.

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ARTICLE ID: 18

YOUTH ATTITUDES ON MARRIAGE

Abstract

Marriage is widely understood as a deliberate personal decision rather than a mandatory social expectation. Growing individualism, along with increased focus on education and career development among youth, has contributed to the postponement of marriage. This article examines core dimensions of marital attitudes like marital optimism vs pessimism, romanticism vs realism, religious vs secular orientation and individualism vs interdependence. These dimensions shape youth expectations about love, responsibility, stability and partnership within marriage.

Key words: Marriage, Marital optimism, marital pessimism, Romanticism, Realism, Religious, Secular orientation, Individualism, Interdependence and Influence of Parenting and Media

Introduction

In this modern era, attitudes towards marriage have become diverse and flexible as it reflects on social, economic and cultural change. Many individuals view marriage as a personal choice based on mutual respect, shared goals rather than a social or familial obligation. In recent times, greater focus on education and career aspirations, gender equality and individual interdependence has reshaped views and expectations on marriage.

The term 'marriage' carries with it centuries of history, intertwining cultures and traditions that shape our understanding of love and commitment. The Latin term '*maritare*,' which means to wed or to marry. According to the American Psychological Association (APA, 2018), Marriage is a social institution in which two individuals, or in some cases more people, commit themselves to a socially sanctioned relationship in which sexual intercourse is legitimized and there is legally recognized responsibility for any offspring as well as for each other. Marriage attitudes signify how individuals think, feel and behave toward the institution of marriage.

Core Dimensions of Attitudes on Marriage

1. Marital Optimism vs Marital Pessimism

Individuals with marital optimism believe that marriage is meaningful, stable, and capable of bringing long- term happiness. They speak positively about marriage and believe that conflicts can be resolved through communication, value of commitment and shared responsibilities.

Marital pessimists doubt the success of marriage, associate it with conflict, restriction, or failure, and fear of divorce or dissatisfaction. They believe marriage limits personal freedom, prefer delaying or avoiding marriage and commonly think that marriage doesn't work in modern times.

2. Romanticism vs Realism

Romantic individuals idealize love and relationships, believe in true love, expect intense emotions and constant affection by prioritizing feelings over practical concerns and view love as its own destiny, which is often influenced by movies, poetry and love stories.

Individuals view relationships as practical and meaningful partnerships that require continuous effort, mutual adjustment and a strong sense of shared responsibilities. They place more importance on compatibility, shared values and long-term goals, believing that these factors form the foundation of a stable relationship. Realistic individuals emphasize the importance of open communication, compromise and emotional stability in maintaining healthy relationships.

3. Religious vs. Secular Orientation

People with religious orientation base their views on marriage and relationships on religious beliefs, traditions and moral values. Individuals with this orientation believe that marriage is divinely sanctioned and governed by religious teachings, which emphasize commitment, fidelity and lifelong responsibility. They often support traditional marital roles, value religious marriage rituals and believe that moral and spiritual principles should guide relationships and family life.

Secular orientation on marriage views it as a social and legal institution rather than a sacred or religious bond. Individuals with this orientation view marriage as a personal choice, equality, mutual understanding, emotional compatibility

and shared responsibilities.

4. Individualism vs. Interdependence

Individualism emphasizes personal autonomy, self-fulfilment and individual goals within marriage. Partners value independence, personal space, and equal decision-making while maintaining their own identities. Conflicts are often addressed through open communication and negotiation, with an emphasis on personal rights and boundaries. Marriage is closely tied to how well the relationship supports individual happiness and freedom.

Interdependence perceives marriage as a long-term commitment with emotional intimacy, reciprocal support and joint decision making. They also value a sense of self that allows them and their partner to be themselves without any need to compromise who they are or their values system. Decisions are often made by considering the impact on the partner and the family as a whole. Emotional security, loyalty, and cooperation are central, and marital success is measured by mutual adjustment, shared responsibilities, and sustained support over time.

Influence on Parenting and Media

Both parenting and media strongly shape youth attitudes. Parenting plays a significant role in shaping youth attitudes on marriage and the ability to form a stable marital relationship. Parental warmth and supportive, communicative parenting help youth develop emotional maturity, self-esteem, and healthy relationship skills. Positive parenting develops realistic expectations about marriage and prepares them emotionally and socially for marital responsibilities. In contrast, authoritarian, neglectful or conflict-ridden parenting is associated with poor communication skills, insecure attachment. Whereas negative parenting heightens the likelihood of early marriage or unstable marital relationships.

Media strongly influences young people's perceptions by portraying stereotypical versions of marriage and relationships. Television shows, social media and online content often focus on idealized, romanticized or sometimes stereotypical ways emphasizing love, luxury or traditional gender roles. These portrayals can create unrealistic expectations about marital life, influencing how individuals define marital success. Media exposes youth and adults diverse cultural norms, peer lifestyles and societal trends which can reinforce challenge or reshape existing beliefs about marriage.

Conclusion

Marriage is shaped by personal, economic and career considerations as youth prioritize on financial stability over traditional expectations. It is no longer viewed as a fixed social obligation but as a thoughtful choice. Marriage is now often evaluated in terms of emotional compatibility, mutual respect and shared responsibilities rather than social pressure. Greater emphasis is placed on equality, open communication and personal growth within the relationship and exposure to media, cultural norms has increased acceptance of delayed marriage.

References

- APA. 2018. <https://dictionary.apa.org/marriage>
- Wilcox, W. and Wolfinger, N. H. 2016. Soul mates: Religion, sex, love, and marriage among African Americans and Latinos. *Oxford University Press*.
- Willoughby, B. Hall, S. and Luczak, H. P. (2015). Marital paradigms: A conceptual framework for marital attitudes, values, and beliefs. *Journal of Family Issues*, 36(2). 188–211.
- Changing attitudes of youths towards Marriage <https://www.sociologylens.in/2025/03/changing-attitudes-of-youths-towards-marriage.html>

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ARTICLE ID: 19

Smart Horticulture: Integrating Artificial Intelligence, IoT and Drone Technologies for Climate-Resilient Production

Abstract

Horticulture is rapidly transforming through precision and digital technologies that enable data-driven crop management. Artificial Intelligence (AI), Internet of Things (IoT), drone-based monitoring, smart sensors, and greenhouse automation are redefining how fruits, vegetables, flowers, and plantation crops are cultivated. AI-based disease detection models now achieve more than 90% classification accuracy (Mohanty *et al.*, 2016; Ferentinos, 2018). IoT-enabled irrigation improves water-use efficiency by up to 40% through real-time soil moisture monitoring (Adeyemi *et al.*, 2018). Drone-based multispectral imaging supports early stress detection and precision spraying (Zhang and Kovacs, 2012). Smart greenhouse automation stabilizes microclimatic conditions and improves yield reliability (Shamshiri *et al.*, 2018). Despite these advancements, adoption challenges such as high initial investment, limited rural connectivity, and lack of technical awareness persist (Ayaz *et al.*, 2019). This article discusses practical applications, benefits, constraints, and future prospects of digital horticulture in the Indian context. Precision horticulture represents a promising pathway toward sustainable intensification and climate-resilient crop production.

Keywords: Precision horticulture, AI in agriculture, IoT irrigation, Drone farming, Smart greenhouse, Digital farming

Introduction

Horticulture contributes significantly to India's agricultural GDP and plays a vital role in nutritional security and rural employment. High-value crops such as mango, banana, tomato, chilli, onion, cucumber, rose, and marigold require precise input management because they are highly sensitive to temperature, moisture, nutrient imbalance, and pest pressure.

Conventional horticulture often results in:

- Excess irrigation
- Nutrient leaching
- Pesticide overuse
- Yield variability
- Post-harvest losses

The emergence of digital agriculture technologies allows real-time monitoring, predictive analytics, and automated decision-making (Wolfert *et al.*, 2017; Liakos *et al.*, 2018). Artificial Intelligence (AI), Machine Learning (ML), IoT devices, drones, robotics, and sensor networks are enabling precision management of horticultural crops (Kamilaris and Prenafeta-Boldú, 2018).

Internet of Things (IoT) in Horticulture

IoT refers to interconnected devices and sensors that collect and transmit real-time data (Ayaz *et al.*, 2019). In horticulture, IoT systems monitor:

- Soil moisture
- Soil temperature
- Relative humidity
- Light intensity
- Nutrient levels
- Greenhouse microclimate

These data are analyzed to automate irrigation, fertigation, and climate control systems.

Smart Irrigation Systems

Water scarcity is one of the major constraints in horticulture. IoT-based soil moisture sensors integrated with automated drip irrigation systems trigger irrigation only when required, thereby improving water-use efficiency (Adeyemi *et al.*, 2018).

Field studies indicate:

- 20–40% water saving
- Reduced energy consumption
- Improved fruit size and uniformity

Such systems are especially useful in crops like tomato, capsicum, cucumber, and grapes.

Table 1. Practical IoT Applications in Horticulture

Technology	Application	Example Crop	Benefit
Soil moisture sensor	Automated drip irrigation	Tomato	Water saving up to 40%
EC and nutrient sensors	Precision fertigation	Cucumber	Improved NUE
Climate sensors	Greenhouse automation	Rose	Yield stability
Smart weather stations	Disease forecasting	Grapes	Reduced fungicide use

Precision Fertigation

IoT-enabled fertigation delivers nutrients

based on crop growth stage and real-time soil nutrient status (Zhang *et al.*, 2021). This reduces nutrient leaching and improves nutrient-use efficiency (NUE).

In greenhouse cucumber and tomato production, precision fertigation improves yield consistency and reduces fertilizer wastage.

Artificial Intelligence (AI) in Horticulture

AI enables machines to analyze data and make intelligent decisions. In horticulture, AI applications include:

- Disease identification
- Pest detection
- Yield prediction
- Fruit grading
- Harvest forecasting

According to Mohanty *et al.* (2016), deep learning models achieved 99% accuracy in controlled plant disease classification. Ferentinos (2018) reported over 95% accuracy across 25 crop species. AI-based mobile applications now allow farmers to capture leaf images and receive instant disease diagnosis, reducing dependency on manual scouting.

Yield Prediction and Quality Grading

Machine learning models analyze historical yield, weather data, and soil conditions to predict crop performance (Liakos *et al.*, 2018). AI-based sorting machines are widely used in apple, tomato, and citrus packing units to grade fruits based on size, color, and defects.

Drone Technology and Remote Sensing

Unmanned Aerial Vehicles (UAVs) equipped with RGB and multispectral cameras provide high-resolution imagery for crop monitoring (Zhang and Kovacs, 2012).

Drone applications include:

- Early detection of nutrient deficiency
- Pest hotspot identification
- Precision pesticide spraying
- Orchard mapping

- Canopy health assessment

Vegetation indices such as NDVI help detect crop stress before visible symptoms appear.

Drone-based precision spraying reduces pesticide use by 20–30% and minimizes environmental contamination.

Smart Greenhouse Automation

Protected cultivation is expanding rapidly in horticulture. Smart greenhouses integrate:

- Temperature sensors
- Humidity sensors
- CO₂ sensors
- Automated ventilation
- Fogging systems
- AI-based climate control

According to Shamshiri *et al.* (2018), greenhouse automation enhances microclimate stability and improves yield reliability under changing climatic conditions.

Such systems are particularly beneficial for crops like capsicum, cucumber, gerbera, and rose.

Economic and Environmental Benefits

Economic Benefits

- Reduced labor costs
- Higher productivity
- Improved produce quality
- Reduced input wastage

Environmental Benefits

- Lower water consumption
- Reduced fertilizer runoff
- Decreased pesticide application
- Reduced carbon footprint

Precision horticulture contributes to Sustainable Development Goals (SDGs) by promoting resource-efficient agriculture.

Challenges in Adoption

Despite technological benefits, challenges include:

- High installation cost
- Limited rural internet connectivity

- Lack of digital literacy
- Small landholdings
- Data security concerns

Government support, subsidies, digital training programs, and public-private partnerships are essential to promote adoption.

Future Prospects

Future research directions include:

- Affordable low-cost sensors
- Edge computing for real-time analytics
- AI integration with blockchain for traceability
- Crop-specific AI models for Indian horticulture
- Solar-powered IoT systems

Digital horticulture is expected to play a crucial role in climate-resilient and sustainable crop production.

Conclusion

Precision and digital horticulture represent the future of sustainable crop production. Integration of AI, IoT, drones, and smart greenhouse automation enhances productivity, improves resource-use efficiency, and strengthens climate resilience. With appropriate policy support and farmer training, digital technologies can transform horticulture into a more efficient and profitable sector.

References

- Adeyemi, O., Grove, I., Peets, S., Domun, Y., and Norton, T. (2018). Dynamic modelling of smart irrigation systems. *Computers and Electronics in Agriculture*, 154, 102–115.
- Ayaz, M., Ammad-Uddin, M., Sharif, Z., Mansour, A., and Aggoune, E. (2019). IoT-based smart agriculture: Architecture and challenges. *IEEE Access*, 7, 129551–129583.
- Ferentinos, K. P. (2018). Deep learning models for plant disease detection. *Computers and Electronics in Agriculture*, 145, 311–318.

- Kamilaris, A., and Prenafeta-Boldú, F. X. (2018). Deep learning in agriculture. *Computers and Electronics in Agriculture*, 147, 70–90.
- Liakos, K. G., Busato, P., Moshou, D., Pearson, S., and Bochtis, D. (2018). Machine learning in agriculture: A review. *Sensors*, 18, 2674.
- Mohanty, S. P., Hughes, D. P., and Salathé, M. (2016). Using deep learning for image-based plant disease detection. *Frontiers in Plant Science*, 7, 1419.
- Shamshiri, R. R., Jones, J. W., Thorp, K. R., Ahmad, D., Man, H. C., and Taheri, S. (2018). Advances in greenhouse automation. *Biosystems Engineering*, 165, 1–22.
- Wolfert, S., Ge, L., Verdouw, C., and Bogaardt, M. J. (2017). Big data in smart farming. *Agricultural Systems*, 153, 69–80.
- Zhang, C., and Kovacs, J. M. (2012). The application of small UAVs in precision agriculture. *Precision Agriculture*, 13, 693–712.
- Zhang, Y., *et al.* (2021). IoT-enabled precision fertigation systems. *Agricultural Water Management*.

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HYBRID COTTON:

TECHNOLOGY TRANSFORMING YIELDS

Cotton has long been known as “white gold,” a crop that not only fuels the textile industry but also sustains millions of farming families across the world. In many developing countries, cotton plays a dual role—serving as a vital fibre crop for industry and as a source of livestock feed through cottonseed and oilcake. Its contribution to rural livelihoods, trade, and national economies is immense. Yet cotton cultivation has never been free from challenges. Yield instability, pest outbreaks, rising input costs, and changing climatic conditions continue to test farmers’ resilience. In India, cotton productivity reached its highest level in 2013–14 after Independence. Since then, apart from a few exceptional seasons, the overall productivity trend has shown signs of decline. This situation has renewed attention toward technological interventions that can restore yield growth and strengthen farm profitability. Among these, hybrid cotton stands out as one of the most significant innovations in modern cotton breeding.

What Makes Hybrid Cotton Different?

Traditional cotton varieties are usually developed through open-pollinated breeding systems. Farmers often save seeds from their harvest to plant in the next season, expecting similar performance. While this approach offers seed independence, it may limit the scope for major yield breakthroughs. Hybrid cotton represents a different strategy. It is produced by crossing two carefully selected, genetically distinct parent lines. The first-generation offspring, known as the F_1 hybrid, expresses a phenomenon called **heterosis**, or hybrid vigor. This biological advantage allows the hybrid plant to outperform both parents in several important traits.

The benefits observed in the field commonly include:

- Higher yield potential
- Greater uniformity of plant growth
- Improved tolerance to environmental stresses
- Better overall economic returns per hectare

Hybrid cotton does not merely improve one characteristic—it enhances the overall performance package of the crop.

The Science behind the Yield Advantage

The success of hybrid cotton lies in the intelligent combination of complementary parental traits. One parent may possess superior fibre length and strength, while the other may contribute strong root systems, disease resistance, or improved boll retention. When these traits are brought together, the hybrid plant often shows enhanced physiological efficiency.

This synergy results in:

- Vigorous early growth
- Increased boll formation and retention
- Better nutrient and water utilization
- Improved adaptability to variable conditions

Modern breeding technologies have further strengthened hybrid development. Tools such as molecular markers and genomic analysis allow breeders to identify promising parent lines with greater precision. Instead of relying solely on visible traits, scientists now examine DNA-level information to predict performance. This integration of classical breeding with molecular tools accelerates the development of superior hybrids.

Why Farmers Prefer Hybrid Cotton

For farmers, the primary question is simple: Does it increase income? In many cases, hybrid cotton provides a clear affirmative answer. Under comparable management conditions, hybrids can produce significantly higher yields than conventional varieties. Even a 15–20 per cent increase in productivity can substantially improve profitability, particularly when market prices are favourable.

Hybrid cotton also offers practical field advantages:

- More synchronized flowering and maturity
- Reduced plant-to-plant variation
- Greater suitability for mechanical harvesting
- Enhanced responsiveness to fertilisers and irrigation

Uniform crop growth simplifies crop management and harvesting operations. Additionally, hybrids often respond better to improved agronomic practices such as balanced nutrient management and precision irrigation, further amplifying their yield potential.

Contribution to Sustainability

Hybrid cotton is sometimes viewed only through the lens of productivity, but its contribution extends beyond yield. Higher productivity per unit area reduces pressure to expand cultivation into forested or marginal lands. In this way, hybrid cotton can indirectly support land conservation. Many modern hybrids are also bred with improved pest and disease tolerance. This can reduce the frequency of chemical sprays, lowering production costs and minimising environmental contamination. Furthermore, hybrids developed for drought tolerance or efficient water use can perform better under erratic rainfall patterns—an increasingly important trait under climate change. While hybrid seeds alone cannot guarantee sustainability, they provide a technological foundation that, when combined with good agronomic practices, supports resource-efficient farming.

Challenges Associated with Hybrid Cotton

Despite its advantages, hybrid cotton is not without limitations. One of the most important concerns is seed dependency. The hybrid vigour that delivers superior performance is expressed only in the first generation. Seeds saved from hybrid crops do not maintain the same uniformity or yield potential. As a result, farmers must purchase new hybrid seeds every season. This recurring seed cost can be challenging, particularly for smallholder farmers. Ensuring the timely availability of quality seed at affordable prices is essential for the sustained success of hybrid technology. Another challenge is maintaining genetic diversity. Excessive reliance on a narrow range of parental lines may increase vulnerability to emerging pests or diseases. Continuous breeding efforts are therefore necessary to broaden the genetic base and introduce new traits.

The Future of Hybrid Cotton

The evolution of hybrid cotton is far from complete. Breeders are now integrating advanced tools such as genome-wide selection, gene editing, and digital phenotyping into their programs. These technologies enable more precise identification of genes responsible for fibre quality, yield stability, and stress tolerance. Gene editing techniques, for example, allow targeted modification of specific genes without altering the entire genetic structure of the plant. This opens new possibilities for improving traits such as heat tolerance, boll development, and fibre fineness.

At the same time, digital agriculture tools—such as remote sensing and data analytics—help monitor hybrid performance under real field conditions. This feedback loop between research and farm practice strengthens future breeding efforts. The goal is no longer limited to maximising yield alone. Modern breeding aims to develop hybrids that combine high productivity with resilience, input efficiency, and environmental sustainability.

Conclusion

Hybrid cotton represents a milestone in agricultural innovation. By harnessing the power of heterosis and combining complementary parental traits, breeders have significantly enhanced cotton productivity and profitability. For farmers facing the pressures of climate variability, pest challenges, and market fluctuations, hybrid cotton offers a pathway toward greater stability and income security. Although challenges related to seed cost and genetic diversity remain, continued research and responsible deployment of technology are addressing these concerns. As breeding science advances and integrates molecular tools with traditional expertise, hybrid cotton will continue to evolve. In a world where the demand for sustainable fibre is growing and agricultural land is limited, hybrid cotton stands as a powerful example of how science can transform a traditional crop into a high-performing, future-ready agricultural system. From seed to fibre, it is technology at work—reshaping yields and strengthening livelihoods.

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NUTRI-GARDEN: GROW HEALTH AT HOME

No farm? No problem.

Fresh vegetables can thrive in your backyard, balcony or even on the rooftop.

Malnutrition continues to be one of the most pressing challenges in India, especially among rural and vulnerable populations. As per ICMR report, intake of vegetables and fruits is extremely low. People in India eat merely 100g to 200g of vegetables and fruits per day while the recommendation is 500g per day. This nutritional gap highlights the urgent need for low-cost and accessible solutions. Vegetables and green leafy vegetables provide several vitamins and minerals and offer protection from micronutrients deficiencies and various diseases. Nutri Garden also known as kitchen garden or Poshan Vatika offers an innovative yet simple approach to overcome this challenge.

What is a Nutri-Garden?

A nutri-garden is a small, purposefully planned garden that prioritises nutritional variety over size. The concept is straightforward: cultivate a variety of leafy greens, vegetables, legumes, roots, and at least one fruit or perennial plant to add nutrients to each meal. To produce veggies all year round, these gardens make use of organic inputs whenever feasible, local seeds, and smart area planning. A household can secure their nutritional needs, enhance their health, and even create additional revenue by turning modest areas like their backyard, rooftop, terrace, or community allotment into a fruitful garden.

Why Does Nutri-Garden Matter?

- Create awareness on nutrition-sensitive agriculture among rural and urban households.
- Promote Nutri-garden, Nutri-thali and Nutri-village for improved diet diversity.
- Encourage the use of bio-fortified crop varieties for nutritional security.
- Develop entrepreneurship among women and youth through value-added nutrition-based products.
- Recycle home waste, greywater and organic residues for sustainable gardening.
- Integrate backyard poultry, dairy farming and beekeeping for better nutrient recycling and income.

Components of Nutri-Garden

A Nutri-garden includes a diverse range of crops and complementary elements to ensure balanced nutrition and sustainability:

- **Vegetables:** leafy greens (spinach, fenugreek, amaranth, mustard), roots and tubers (radish, carrot, turnip, beetroot), legumes (beans, peas, cowpea).
- **Fruits:** papaya, banana, mango, guava, pomegranate, citrus fruits.
- **Spices and herbs:** coriander, mint, turmeric, ginger, curry leaves.
- **Livestock integration:** poultry, goats, dairy and beekeeping for manure, milk, eggs and honey.

Models of Nutri-Gardens

- **Urban models:** rooftop garden, terrace garden, vertical gardening and container gardening.
- **Rural models:** backyard garden and community-based Nutri-garden.

Key inputs for setting up a garden are:

- A garden plan
- Available land.
- Some garden tools.

Small vegetable garden meets 13-18% of protein, 33-42% of Ca, 56-82% of Fe, 82-125% Vit A and 336-374% Vit. C.

Designing Your Nutri-Garden

1. Choose a **sunny site**, preferably oriented in the East-West direction and located close to the residence for easy access.
2. Divide the land into **small plots** (e.g., 2 × 3 m or 3 × 3 m), with size adjustable according to family needs.
3. Select **crop combinations** as per household requirements: plant short-statured vegetables in the front, medium-height vegetables behind them and climbers at the back. Borders can be lined with fruit trees, curry leaf or moringa.
4. By following scientific practices and crop rotation, two to three annual crops can be raised in the same plot. For effective utilization of plot accession cropping, intercropping and mixed cropping can be followed.
5. **Perennial vegetables** such as chayote (cho-cho), tree tomato, asparagus and greater yam should be planted along one side to avoid shading annual crops or disturbing crop rotation.
6. Once established, these perennial crops require **minimal care** and provide a

steady supply of vegetables year after year with little additional labor.

7. Maintain a separate nursery plot for seasonal seedlings. These seedlings can replace harvested crops and ensure continuity in production throughout the year.
8. Follow clean cultivation with minimal chemical use; rely on composting, vermicomposting and organic pest management.
9. Integrate poultry, dairy or beekeeping for nutrient recycling and added income.
10. Walking path should be provided at the center as well as along four sides.
11. Prepare a compost pit on one side of the garden to use kitchen waste and plant residues as organic manure.
12. Preference should be given to long duration and steady yielding crop varieties than high yielding ones.
13. Protect the garden with thorny fencing or wire, which can also support climber vegetables.

Classifications of Nutri-gardens

Nutri-garden can be classified into various types depending on the area, location, production etc.

1. Depending on the location, it can be classified into household/ home and community Nutri Garden.

- **Household Nutri-garden** - primarily for a family and is a planned space located either in household's front yard or backyard space to be utilized for cultivation.
- **Community Nutri-garden** - leveraged by a group of peoples like Self Help Groups (SHGs) etc. via utilization of a community owned land like panchayat lands etc. for cultivation.

2. Basis of the types of produce: vegetarian or non-vegetarian.
3. Based on the utilization of the produce of the Nutri-garden
e.g. self-consumption, selling, value addition etc.

Selection Criteria for Vegetable Crops

1. Choose vegetables that are hardy, easy to cultivate and well adapted to the local soil and climate.
2. Prefer crop varieties that show tolerance to common pests and diseases.
3. Select a diverse range of vegetables, because all have different nutritional qualities.
4. Use quality planting material (seeds, seedlings, tubers or cuttings) that are locally available and accessible to farm families.
5. Include a mix of improved varieties and traditional varieties to preserve agro biodiversity and cultural practices.
6. Promote family farming in homestead areas or Nutri-gardens to enhance crop availability and dietary diversity at the household level.
7. Encourage healthy food habit among children through regular access to fresh produce.
8. Support balanced nutrition as a strategy to tackle malnutrition.
9. Focus on diet diversification, supplementation and food fortification were necessary.
10. Supply fresh fruits and vegetables that are nutrient-rich and free from harmful chemicals.
11. **Kharif (Summer) Vegetables (February–March):** Ridge gourd, cowpea, cluster beans, okra, colocasia,

bitter gourd, bottle gourd, tomato, chili and pumpkin.

12. **Rabi (Winter) Vegetables (October–November):** Potato, brinjal, fenugreek, spinach, coriander, onion, garlic, cauliflower, carrot, radish and turnip.

Short duration vegetables for Nutri Garden:

Methi, Bathua (Chenopod), Mint, Amaranthus, Coriander, Lettuce spinach, Turnip, Radish, Vegetable mustard, Peas, Cabbage, Knol Khol, Broccoli

Suitable fruits for Nutri Garden: Mango, Papaya, Banana, Acid lime, guava, pomegranate, bilimbi and karonda.

The Benefits: More Than Just Food

- Improved nutrition: regular supply of diverse vegetables and fruits enhances dietary quality and addresses malnutrition.
- Supplementary income: surplus produce sold in local markets provides extra earnings.
- Food security: reduces dependency on markets and ensures household-level food sufficiency.
- Environmental sustainability: recycling organic waste, using greywater, conserving biodiversity and reducing chemical use.
- Health benefits: availability of chemical-free food reduces risks of anemia, micronutrient deficiencies and lifestyle-related disorders.
- Enhances women's role in nutrition decision-making and household economy.
- Climate resilience: acts as a buffer against erratic rainfall, crop failures and economic shocks.

Nutri-Gardens in Action: Stories of Change

Several successful initiatives across India have highlighted the role of Nutri-garden in improving nutrition and livelihoods:

- **Government Programs:** The Union Ministry of

Women and Child Development in collaboration with the Ministry of Ayush has established Nutri-gardens in over 4.37 lakh Anganwadi centers under Poshan Maah 2022. These gardens provide easy and affordable access to fruits, vegetables, medicinal plants and herbs.

- **Uttarakhand Hill Regions:** Demonstrations by ICAR-VPKAS, Almora, have established more than 65 Nutri-gardens in hill villages. These efforts showcased that even small, fragmented landholdings in hilly areas can address micronutrient deficiencies effectively through diversified fruit and vegetable cultivation.

A Climate-Smart Solution

Climate change has intensified the challenges of food and nutritional security. Erratic rainfall, rising temperatures and increased pest attacks adversely affect crop productivity. However, Nutri-garden offer resilience by diversifying food production at the household level. Practices such as mulching, rainwater harvesting, staggered planting and the use of climate-resilient crop varieties help reduce risks. For households in vulnerable regions, Nutri-garden provides a reliable safety net by ensuring year-round access to food and reducing dependence on volatile market.

Challenges Along the Way

- Limited awareness and training in nutrition-sensitive agriculture.
- Scarcity of quality seeds and planting material.
- Increased workload on women, adding to their household and farming responsibilities.
- Vulnerability to climate variability, pests and diseases.
- Lack of access to simple, affordable agricultural tools that reduce drudgery.

Way Forward

Nutri-garden requires a multifaceted strategy to scale up. Adoption can be promoted via awareness programs run by NGOs, self-help groups (SHGs), and Krishi Vigyan Kendras (KVKs). Government programs should provide training, basic tools, and seed kits to homes. Linking Nutri-gardens with school midday meals, Anganwadi programs and local markets can enhance their impact. The Sustainable Development Goals (SDGs) of the United Nations, especially SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-Being), SDG 5 (Gender Equality), and SDG 13 (Climate Action), are also in line with incorporating Nutri-gardens into national initiatives.

Conclusion

More than merely green spaces, nutri-gardens are effective means of combating malnutrition, empowering women, raising household earnings, and promoting climate resilience. by turning little landholdings into sources of varied, fresh, and chemical-free food. The secret to stronger communities and healthier families resides in nutri-gardens. The seeds of a sustainable and nutrition-secure future can be sown via Nutri-garden with increased awareness, appropriate legislation, and community involvement.

Every backyard can be a plate of nutrition- the first step is planting a seed.

References:

- Babu, P *et al.* (2023). Nutri-gardens: Nutritional needs of tribal community in Andhra Pradesh. *Just Agriculture*, 4(1): 317–321.
- Selvarani, K., & Subathra, B. (2024). Nutri-Gardens: A Way to Manage Malnutrition and Ensure Food Security. *International Journal of Environment and Climate Change*, 14(2): 23-29.

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RESILIENT WATER RESOURCES APPROACHES FOR SUSTAINABLE AND ADAPTIVE WATER MANAGEMENT

Abstract

Water resources across the globe are under increasing stress due to climate variability, rising water demand, land degradation, and unsustainable use practices. Ensuring resilience in water resources has become essential to maintain reliable water availability for agriculture, ecosystems, and human consumption. Resilient water systems are those capable of resisting disturbances, adapting to changing environmental conditions, and recovering from extreme events such as droughts and floods. This paper discusses the concept of water resource resilience, examines the major factors threatening water security, and highlights strategies for strengthening resilience through soil and water conservation, integrated management approaches, technological interventions, and effective governance. The role of conservation practices in enhancing adaptive capacity and long-term sustainability is emphasized.

Keywords: Resilient water systems, climate variability, soil and water conservation, sustainable development, water security

Introduction

Water is a critical natural resource that supports food production, economic development, and ecological balance. In recent decades, increasing population pressure, urban expansion, and climate change have placed severe stress on freshwater resources. Variability in rainfall patterns, frequent extreme weather events, and declining groundwater levels have made water management more complex and uncertain.

In this context, the concept of resilient water resources has gained importance. Water resilience focuses on the ability of water systems to function effectively despite disturbances and long-term changes. Soil and water conservation plays a central role in building resilience by improving water retention, reducing runoff, and supporting sustainable land and water use practices.

Understanding Water Resource Resilience

Resilience in water resources can be defined as the capacity of hydrological systems, infrastructure, and management institutions to absorb shocks, adjust to change, and continue delivering essential services. These systems must respond not only to short-term hazards such as floods and droughts but also to long-term pressures like climate change and land degradation.

A resilient water system is characterized by:

5. Strength to withstand extreme climatic events
6. Ability to adapt management practices over time
7. Availability of multiple water sources
8. Flexible and responsive institutional frameworks

3. Major Threats to Water Resource Resilience

3.1 Climate Variability and Change

Changes in temperature and precipitation patterns have intensified hydrological extremes, leading to prolonged droughts and sudden flooding events. These changes disrupt water availability and increase uncertainty in planning.

3.2 Increasing Population and Water Demand

Rapid population growth and urbanization significantly increase demand for domestic, agricultural, and industrial water, often exceeding the natural replenishment capacity of water sources.

3.3 Land Degradation and Soil Erosion

Poor land management practices result in soil erosion, reduced infiltration, and loss of soil moisture, which negatively affect surface and groundwater resources.

3.4 Groundwater Depletion

Excessive withdrawal of groundwater without adequate recharge has led to declining water tables, reduced well yields, and deterioration of water quality in many regions.

4. Importance of Soil and Water Conservation in Enhancing Resilience

Soil and water conservation measures are fundamental for improving the resilience of water resources. These practices enhance rainwater infiltration, minimize surface runoff, and promote groundwater recharge, especially in rainfed and dryland areas.

Common conservation practices include:

- Contour bunding and terracing

- Construction of check dams and recharge structures

- Use of vegetative cover and mulching

- Integrated watershed management programs

Such interventions contribute to sustainable agriculture, reduced land degradation, and improved water availability.

• Strategies for Strengthening Resilient Water Resources

◦ Integrated Water Resources Management

Integrated Water Resources Management (IWRM) emphasizes coordinated planning and management of water, land, and related resources to achieve economic efficiency, social equity, and environmental sustainability.

◦ Nature-Based and Ecosystem Approaches

Restoration of wetlands, forest cover, and natural drainage systems enhances the natural capacity of landscapes to store and regulate water, reducing disaster risks.

◦ Technological Interventions

Adoption of modern technologies can significantly improve water use efficiency. These include:

Rainwater harvesting systems

Micro-irrigation techniques such as drip and sprinkler systems

Use of remote sensing and GIS for water assessment and monitoring

◦ Institutional and Policy Support

Effective governance, community participation, and



adaptive policies are essential for successful implementation of resilience-building measures. Local involvement ensures long-term sustainability of water management initiatives.

• **Future Outlook**

Enhancing water resource resilience requires an interdisciplinary approach that integrates soil science, hydrology, engineering, and socio-economic planning. Future strategies should focus on climate-resilient agriculture, data-driven decision-making, and capacity building at the community level. Strengthening research and innovation in soil and water conservation will be crucial for addressing emerging water challenges

• **Conclusion**

Resilient water resources are vital for sustaining agricultural productivity, protecting ecosystems, and ensuring water security under changing climatic conditions. Soil and water conservation practices form the backbone of resilient water management by improving water storage, reducing degradation, and enhancing system adaptability. A combination of integrated management approaches, technological solutions, and supportive policies is necessary to build water systems capable of meeting future demands.

References

1. Falkenmark, M., & Rockström, J. (2004). *Balancing Water for Humans and Nature*. Earthscan.
2. IPCC. (2022). *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. Intergovernmental Panel on Climate Change.
3. FAO. (2018). *Water for Sustainable Food and Agriculture*. Food and Agriculture Organization of the United Nations.
4. Global Water Partnership. (2010). *Integrated Water Resources Management*. GWP Technical Advisory Committee.
5. Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability*, 7(5), 5875–5895.S
6. Rockström, J., et al. (2017). Sustainable agricultural intensification for global sustainability. *Ambio*, 46, 4–17.

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REPRODUCTION IN INSECTS

DIFFERENT TYPES OF REPRODUCTION IN INSECT

- a) **Oviparity:** Majority of female insects, are oviparous, lay eggs. Embryonic development occurs after oviposition by utilizing the yolk **e.g. Moths.**
- b) **Viviparity:** Unlike oviparous, here initiation of egg development takes place within the mother.

The life cycle is shortened by retention of eggs and even developing young within the mother. There are four main types:

1. **Ovoviviparity:**

Fertilized eggs containing yolk are incubated inside the reproductive tract of the female and hatching of egg occur just prior to or soon after oviposition **e.g. Thrips**

b) **Adenotrophic viviparity:**

This occurs when a poorly developed larva hatches and feeds orally from accessory gland (milk gland) secretion within the uterus of the mother. The full grown larva is deposited and pupates immediately **e.g. Tsetse flies**

2. **Pseudoplacental viviparity:**

This occurs when a yolk deficient egg develops in the genital tract of the female. The mother provides a special placenta-like tissue, through which nutrients are transferred to developing embryos. There is no oral feeding and larvae are laid upon hatching. **e.g. aphids.**

- d) **Haemocoelous viviparity:** This involves embryos developing free in the female's haemolymph with nutrients taken up by osmosis **eg. Strepsiptera** and some gall midges.
- c) **Parthenogenesis:** It is the ability of the females to reproduce without fertilization / copulation with males. This usually occurs due to the genetic characters, due to heredity, failure in finding a mate, hormonal changes within the body and weather factors **e.g. aphids.**
- d) **Paedogenesis (or) Neoteny:** It is a phenomenon where the immature insects or stages give birth to young ones. **Eg. Mustard sawfly.**
- e) **Polyembryony:** It is a type of reproduction where insects reproduce by giving birth to two or more young ones instead of a single one, as two or more embryos are produced from a single egg. **eg. Hymenoptera like platygaster.**

6. Hermaphroditism: It is a type of reproduction where both male and female gonads are present in the same individual. **eg. scale insect**

7. Castration: It is a type of reproduction where the separation of the individuals occurs mainly due to the development of the reproductive organs. The insects with well-developed ovaries develop in to females (queens), the insects with well-developed testis develop in to males (drones) and insects with underdeveloped ovaries develop in to workers **e.g. honey bees.**

MALE REPRODUCTIVE SYSTEM

The main functions of the male reproductive system are the production and storage of spermatozoa and their transport in a viable state to the reproductive tract of the female.

Male reproductive system consist of following organs-

- a) A paired testes
- b) A pair of vasa deferens
- c) Seminal vesicles
- d) Ejaculatory duct
- e) Accessory glands

1. A pair of testes

1. These are paired structures
2. Each testes contain a series of testicular tubes or **follicles** in which spermatozoa are produced.
3. Testes are well supplied with trachea and fat body tissues.
4. The entire follicle is covered by a **peritoneal membrane** whereas the testes are completely enveloped within a coat known as **scrotum**
5. **The functions of testes are production and storage of spermatozoa.**

2. A pair of vasa deferens

These are the long tubes which receives the sperms from testis and allow their **transport to the ejaculatory duct.**

3. Seminal vesicles

Each vasa deferens becomes enlarged posteriorly to form a sac like structure called seminal vesicle **for storage of spermatozoa** for some time

4. Ejaculatory duct

- a) Both the vasa deferens of the two testes unites posteriorly to form a common median ejaculatory duct.
- b) The terminal section of ejaculatory duct consists of

male copulatory organ or aedeagus or penis.

- c) **The function of aedeagus is that ejaculate the spermatozoa into the female genital tract.**

5. Accessory glands

- a) These are **1-3 pairs** of glands which open in to the ejaculatory duct
- b) In most cases their secretion mixed with spermatozoa.
- c) These glands are also called as **mushroom glands** in cockroaches and mantid because of their appearance as **mushrooms.**
- d) This secretion facilitates **sperm transmission from male to female**

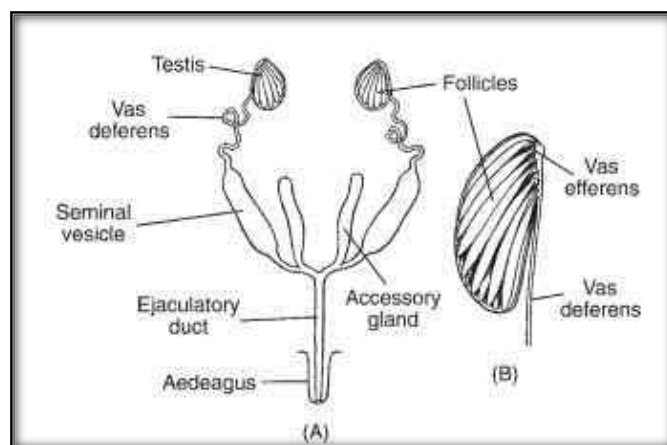


FIG. Male reproductive system

FEMALE REPRODUCTIVE SYSTEM

The main functions of the female reproductive system are egg production and storage of male's spermatozoa until the eggs are ready to be fertilized.

Female reproductive system consist of -

1. A pair of ovaries
 2. A pair of lateral oviducts
 3. A common oviduct / Median oviduct
 4. spermatheca
 5. A pair of accessory glands
 6. Bursa copulatrix/copulatory pouch/genital chamber/vagina
- a) **A pair of ovaries**
 - a) The functional unit of ovary is called ovarioles
 - b) A pair of ovaries are present on the either side of alimentary canal.
 - c) These organs are mainly covered with fat body and trachea.
 - d) Each ovary consists of eight ovarioles or egg tubes.

e) Each ovariole is differentiated into 4 parts namely; Terminal filament, germarium, vitellarium and Pedicel.

f) The functions of ovary are production of eggs or ova

b) A pair of lateral oviducts

a) It is the proximal end of the ovarioles of each ovary which joins to form a lateral oviduct on each side.

b) Function is to transfer the eggs from ovary to the median oviduct.

c) Median Oviduct:

Two lateral oviducts combine to form a median oviduct.

d) Vagina: (genital chamber)

a) The posterior part of median oviduct is modified into a sac like structure known as vagina or genital chamber.

b) Median duct opens in to a tubular genital chamber or vagina formed by invagination of body wall from VIII segment.

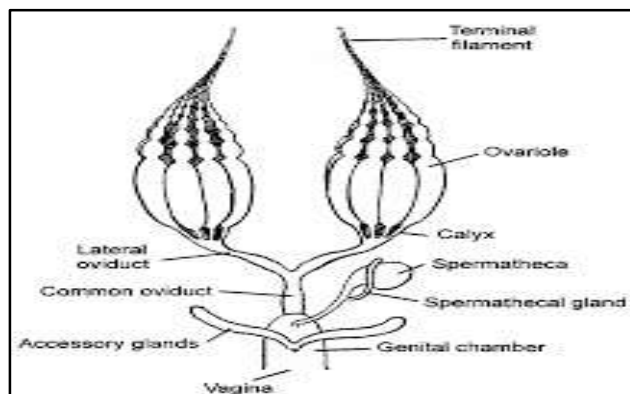


FIG. FEMALE REPRODUCTIVE SYSTEM

e) Bursa Copulatrix:

a) In some insects the genital chamber or vagina develops a separate pouch called Bursa Copulatrix in to which insects have two reproductive openings

One is vulva for receiving the sperms open on VIII sternum and another one is ovipore or gonopore on IX segment for discharging eggs. E.g.: Lepidoptera

f) Spermatheca:

a) It is a sac like structure consisting of a spermathecal gland and opens in to vagina through spermathecal duct.

b) Its function is of storage of sperms.

c) It also produces some fluids responsible for longevity of sperms cells for several hours.

g) Accessory glands: (collateral glands)

- These are a pair structured which open in to the distal portion of vagina.

- They secrete the sticky substance responsible for the formation of ootheca of cockroach.

f. In case of spittle bugs spittle around the immature stages is also a Malpighian secretion

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ARTICLE ID: 24

USING EDGE COMPUTING IN RURAL INDIAN AGRICULTURAL AREAS

ABSTRACT

A new era of precision farming and data-driven decision-making has been brought about by the incorporation of digital technologies into agriculture. However, rural Indian agricultural areas continue to face infrastructural limitations, including unstable internet connectivity, power shortages, and limited technical capacity, which restrict the effectiveness of centralized cloud-based agricultural systems. By processing data close to the data source, edge computing provides a decentralized computing architecture that lowers latency, bandwidth dependence, and operational delays. With a focus on its technical underpinnings, real-world applications, socioeconomic ramifications, integration with cutting-edge technologies like 5G and artificial intelligence (AI), implementation models for smallholder farmers, and policy considerations, this expanded review critically analyzes the role of edge computing in rural Indian agriculture. The article concludes that edge computing can significantly enhance agricultural productivity, sustainability, and rural livelihoods when supported by inclusive digital infrastructure and institutional frameworks.

Keywords: Edge computing, Digital agriculture, Precision farming, Rural India,

INTRODUCTION

Agriculture remains a cornerstone of India's economy, employing nearly half of the population and sustaining rural livelihoods. Productivity is nonetheless hampered by issues like climate variability, soil erosion, depleting water supplies, dispersed landholdings, and restricted access to timely advisory services. Opportunities for modernization are presented by the rise of Agriculture 4.0 technologies, such as robotics, artificial intelligence, big data analytics, and the Internet of Things (Wolfert et al., 2017).

Although digital agriculture platforms have historically benefited from cloud computing, rural India sometimes faces bandwidth limitations, excessive latency, and sporadic internet connectivity. These restrictions make it difficult to make decisions in real time during farming operations that are time-sensitive. An effective substitute for relying exclusively on centralized servers is edge computing, which is defined as processing data closer to the source (Shi et al., 2016; Satyanarayanan, 2017).

By enabling localized processing, edge computing ensures operational continuity even in low-connectivity environments. This makes it particularly relevant for rural Indian agricultural ecosystems characterized by infrastructural disparities.

Architecture of Edge Computing in Role in Climate-Smart Agriculture

Three main levels are involved in edge computing in agriculture:

- 1. Device Layer:** sensors, cameras, drones, wearables for livestock, and soil probes.
- 2. Edge Layer:** Edge servers, microprocessors, or local gateways set up at agricultural locations.
- 3. Cloud Layer:** Centralized systems for analytics, policy-level decision-making, and long-term storage.

Conceptual Illustration

Soil Sensors / Drones / Livestock Tags



[Edge Device]

(Local Processing & Decisions)



Limited Data to Cloud

(Storage & Advanced Analytics)

Combining Machine Learning and Artificial Intelligence

When edge computing is combined with AI algorithms, its power increases. Lightweight machine learning models can operate directly on edge devices rather than transferring raw data to cloud servers for model processing.

For instance:

- Local image analysis is possible with pest detection models.
- On-site processing of soil and climate data is possible with yield prediction models.
- Rule-based AI can be used by automated irrigation systems to take prompt action.

This method improves responsiveness and lessens the computational strain on cloud servers. Satyanarayanan (2017) asserts that edge-based AI greatly increases productivity in settings where latency is a concern.

Indian farmers are increasingly at danger from climate variability. Local monitoring of temperature, precipitation, humidity, and wind patterns is possible using edge-enabled weather stations and microclimate sensors.

Farmers can do the following with real-time local analytics:

- Modify irrigation timetables
- Change the dates of sowing
- Apply fertilizer as efficiently as possible.
- Get warnings about heat or frost.

In contrast to cloud-dependent systems, localized processing guarantees a quicker response. This promotes sustainable farming methods and climate resiliency.

Socio-Economic Implications for Rural Livelihoods

Enhancement of Income

Precision farming provided by edge technology maximizes resource utilization while lowering input costs for herbicides, fertilizers, and water. For farmers, increased net returns are a direct result of effective management.

Career Possibilities

Employment prospects in rural areas are created by the deployment and upkeep of edge technology in:

1. IoT installation
2. Upkeep of devices
3. Digital advice services for rural areas
4. Entrepreneurship in agri-tech

Strengthening Farmer Producer Organizations (FPOs)

FPOs allow groups of farmers to share edge infrastructure. Multiple farms may be served by a community-based edge server, which lowers the cost of individual investments and encourages group digital transformation.

Comparative Advantage Over Cloud-Only Systems

S.No	Parameter	Cloud-Based Model	Edge Computing Model
•	Internet Dependency	High	Low to Moderate
•	Latency	High	Low
•	Bandwidth Use	High	Reduced
•	Data Privacy	Centralized	Localized
•	Reliability in Rural Areas	Limited	Higher

Edge computing does not replace cloud computing but complements it. A hybrid architecture combining both offers optimal performance.

Implementation Models for Rural India

- **Edge Infrastructure Based in the Community**

Digital hubs at the village level can house edge servers that service several farmers. This lowers the cost of individual hardware

- **Digital Missions Supported by the Government**

Edge-based consulting systems can be integrated into national digital agriculture initiatives. IoT device subsidies can hasten adoption

- **Public-Private Collaborations**

State agricultural departments and agri-tech entrepreneurs can work together to implement scalable edge solutions designed for smallholder farmers.

Technical and Operational Challenges

Despite its advantages, several constraints persist:

- High initial capital investment
- Device durability in harsh field conditions
- Power supply instability
- Limited rural technical expertise
- Data standardization issues

Wolfert et al. (2017) emphasize the need for interoperability standards to ensure seamless integration of digital agricultural systems.

Cybersecurity and Data Governance

By reducing data transfer, edge computing improves data privacy. Local devices, however, need to be protected from infection and tampering.

Data integrity requires decentralized authentication mechanisms and robust encryption algorithms. Farm-generated data ownership and usage rights should be specified in policy frameworks.

Sustainability And Environmental Benefits

Edge computing indirectly contributes to environmental sustainability through:

- Reduced water wastage
- Efficient fertilizer application
- Lower greenhouse gas emissions from optimized inputs
- Reduced energy consumption from minimized data transfer

Precision resource management supports long-term soil health and ecosystem conservation.

Future Research Directions

Future studies should focus on:

1. Low-cost edge hardware tailored for smallholders
2. Energy-efficient edge devices powered by solar systems
3. Real-time multilingual advisory platforms
4. Impact assessment across different agro-climatic zones in India
5. Integration with 5G rural connectivity expansion

Empirical research measuring yield improvement and income change after edge adoption will strengthen policy advocacy.

CONCLUSION

By overcoming connectivity issues and facilitating real-time farm-level decision-making, edge computing is a game-changer for rural Indian agriculture. Its uses include supply chain optimization, climate resilience, agricultural monitoring, livestock health tracking, and irrigation management.

Even if there are still financial and infrastructure obstacles, India's digital agriculture mission can be fully realized with strategic integration, training, subsidies, and public-private cooperation. Edge computing enhances agricultural output, rural socioeconomic development, and environmental sustainability by providing farmers with decentralized intelligence.

REFERENCES

- Satyanarayanan, M. (2017). The emergence of edge computing. *Computer*, 50(1), 30–39. <https://doi.org/10.1109/MC.2017.9>
- Shi, W., Cao, J., Zhang, Q., Li, Y., & Xu, L. (2016). Edge computing: Vision and challenges. *IEEE Internet of Things Journal*, 3(5), 637–646. <https://doi.org/10.1109/JIOT.2016.2579198>
- Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big data in smart farming – A review. *Agricultural Systems*, 153, 69–80. <https://doi.org/10.1016/j.agry.2017.01.023>
- Zhang, Y., Wang, L., & Duan, Y. (2019). Agricultural information dissemination using ICTs: A review and analysis. *Information Processing in Agriculture*, 6(1), 1–10. <https://doi.org/10.1016/j.inpa.2018.11.002>

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ARTICLE ID: 25

SMART GODOWNS: IOT AND GIS-ENABLED REAL-TIME MONITORING OF ONION STORAGE

Abstract

India is a global titan in onion production, commanding a 30% share of the world's supply, yet it faces a "silent crisis" of post-harvest inefficiencies. Every third bulb is effectively lost to rotting and physiological weight loss, costing the sector approximately ₹11,000 Crores annually. This article introduces the "Smart Godown," a revolutionary storage solution that integrates Internet of Things (IoT) sensors and Geographic Information Systems (GIS) to transform passive sheds into active preservation units. By deploying affordable "Digital Sentinels" sensors like the DHT22 and DS18B20—farmers can monitor the internal micro-climate of onion stacks in real-time, detecting invisible threats like compression heat and fungal respiration. The system employs a "3-Zone Defence" strategy and GIS-enabled "Heat Maps" to pinpoint rot hotspots that manual inspections miss. Furthermore, automated ventilation governed by trigger logic and Vapor Pressure Deficit (VPD) optimizes curing while reducing electricity costs by 30%. This article shows that smart storage is a financially viable micro-investment that pays for itself in one season, offering a sustainable path to minimize the country's high post-harvest wastage.

Introduction

India stands as a titan in the global onion landscape, commanding a formidable 30% share of world production, second only to China (FAOSTAT). While the sector faced a climatic stress test in 2023-24 with output dipping to 242.67 Lakh Tonnes, the resilience of Indian agriculture is evident in the robust 2024-25 projection of nearly 289 Lakh Tonnes (GOI) for this much production onion is the undisputed '**Queen of the Kitchen**' for its flavour. This recovery is spearheaded by our production heavyweights Maharashtra, the undisputed '**Onion Bowl**' contributing over 86 Lakh Tonnes, followed by the rapidly expanding hubs of Madhya Pradesh and Karnataka, while Gujarat continues to set the national benchmark for per-hectare productivity.



Fig 01. Showing Conventional and Smart Godowns

However, this abundance faces a silent crisis; despite our massive output, we effectively lose every third bulb to post-harvest inefficiencies. With annual losses hovering between 30-40% valued at a staggering ₹11,000 Crores due to physiological weight loss, rotting, and sprouting, the narrative of Indian onions is currently one of high production, high wastage(ICAR-DOGR), underscoring an urgent need to shift focus from merely increasing harvest heaps to engineering smarter, loss-proof storage systems as a smart godown.

Smart Godown

A Smart Godown distinguishes itself from a standard shed through four revolutionary features that turn passive storage into active preservation. Unlike manual inspections, it offers 24/7 pulse monitoring, recording micro-climate data every 15 minutes to catch fluctuations that human checks often miss. This raw data is instantly converted into GIS-enabled 'Heat Maps', effectively providing the farmer with 'X-Ray vision' to visualize and locate invisible hot pockets of rot deep within the stack. Serving as a silent guard, the system triggers real-time SMS alerts the moment conditions drift into the danger zone (e.g., humidity >70%), while simultaneously engaging auto-pilot ventilation to run exhaust fans

only when the outside air is dry enough to cure the crop, thereby eliminating human error and preventing energy waste.

The technology stack – How to build a Smart Godown

Component I: The Nervous System (IoT Sensors)

If the godown is the body, IoT sensors are its nervous system. Traditional wall thermometers are useless because they measure the air around the stack, not inside it where rot begins. To fix this, we deploy a network of "Digital Sentinels" buried deep within the pile.

1. The Hardware: Accessible and affordable you don't need expensive machinery. We use robust, off the shelf components like the DHT22 (Temp/Humidity) or DS18B20 probes linked to microcontrollers like Arduino. These tiny brains work tirelessly, logging vital data every 15 minutes, 24/7.

2. Strategic Placement: The 3-zone defence random placement is futile. We use a 3D grid strategy to cover every risk vector:

- **Zone A (The Foundation):** Placed 1 foot from the floor to detect compression heat, warning if the sheer weight is crushing bulbs and causing wet rot.

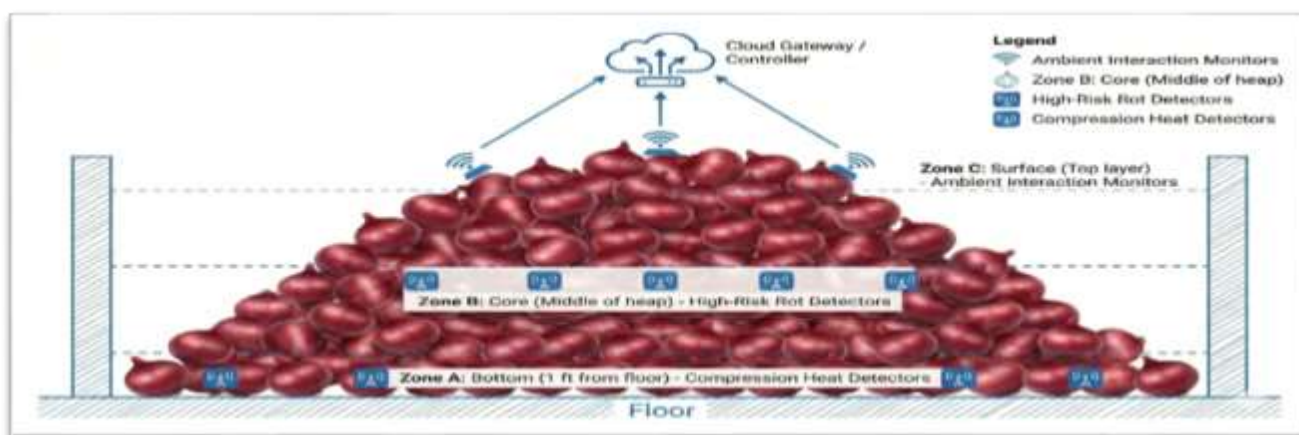


Fig.02.Showing the technology stack of godown

- Zone B (The Core): The dead zone sensors here act as spies, catching the heat generated by fungal respiration long before the smell reaches the surface.
- Zone C (The Surface): Monitors ambient interaction, instantly alerting if external humidity is penetrating the stack's protective layer.

2. Blue/Green (Safe Zones): Safe. Onions are dormant and happy. Action: No intervention needed.

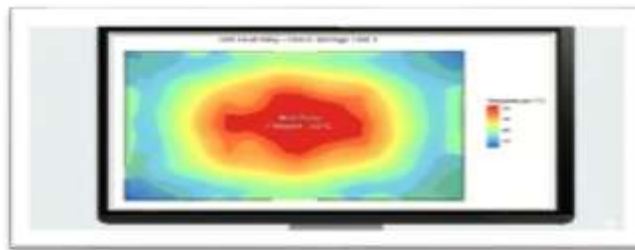


Fig 03. Showing the GIS heat map

3. Data Transmission: Cutting the cord forget messy wiring. Modern sensors use Wi-Fi or GSM modules to beam data directly to the cloud and the system updates the dashboard in real-time.

Component II: The Brain (GIS and Spatial Mapping)

1. Mapping the invisible sensors only provide data for specific spots, but rot hides in the gaps between them. GIS acts as the brain, using spatial interpolation algorithms like IDW (Inverse Distance Weighting). Think of it as mathematically connecting the dots the software takes discrete sensor readings and fills in the blanks to create a continuous, complete picture of the storage room.

2. The Visualization: A traffic light system, the output isn't a boring spreadsheet; it is an instant, color-coded "Heat Map" that anyone can read:

1. Red/Orange (Hotspots): Danger. Heat or humidity is trapped. Action: Ventilate immediately or remove the batch.

Real-Time Monitoring and Automation

1. The Dashboard (The Digital Cockpit) Farmers no longer need logbooks. The mobile app acts as a "Cockpit," displaying vital signs (Temperature, Humidity, Battery) in real-time. If a specific zone enters a danger threshold, the interface instantly flashes Red, pinpointing exactly where the rot is starting so the farmer can act.

2. Automated Action (Smart Logic) The system replaces guesswork

with strict code. It uses trigger logic to ensure fans only run when beneficial, preventing the common mistake of pumping moist air into the stack:

The Rule: If internal humidity > 75% (too wet) and External humidity < 60% (dry air) → Turn ON exhaust fans.

3. The benefit this automation eliminates human error and reduces electricity bills by 30%. By syncing with the Vapor Pressure Deficit (VPD),

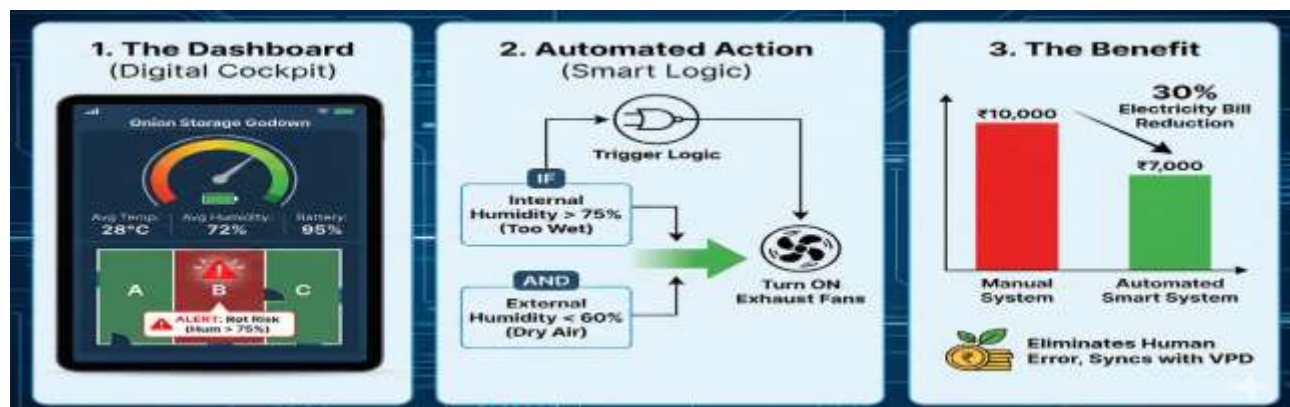


Fig 03. Showing the automation process

the system ensures every minute of energy spent actively cures the onions.

Increasing Storage Capacity: The "Vertical" Advantage

One of the most significant yet overlooked advantages of the Smart Godown is the ability to unlock vertical capacity. Traditionally, farmers are paralyzed by the fear of compression heat, limiting their stack heights to a safe 3-4 feet to prevent invisible rotting at the bottom. However, by embedding sensors in the foundation layer (Zone A), the system effectively removes this blind spot, acting as a real-time safety net that alerts the farmer instantly if pressure causes temperature spikes. This digital confidence allows farmers to safely increase stack height to 6 feet, effectively boosting total storage capacity by 50% within the existing infrastructure a massive economic win that maximizes profit per square foot without the capital expenditure of constructing new sheds.

Economics and Future Scope: The Cost-Benefit Analysis

The most common question from farmers is, "Is it affordable?" When analysing a standard 50-tonne onion chawl, the Smart Godown proves to be a financial necessity rather than a luxury.

The Setup Cost: A Micro-Investment Contrary to the myth that "smart" means expensive, upgrading a traditional shed is highly accessible. For a 50-tonne facility, the total bill of materials—including industrial sensors (DHT22/DS18B20), microcontrollers (Arduino/ESP32), and wiring ranges between ₹10,000 to ₹15,000. This one-time cost is roughly the price of a mid-range smartphone, a negligible fraction of the godown's infrastructure value.

The ROI: Breaking even in season one the system's value lies in "Loss Prevention". While

traditional methods accept 25–30% loss as unavoidable, the Smart Godown challenges this baseline. Even in a conservative scenario where the system saves just 5% (2,500 kg) of a 50-tonne crop, the revenue recovered at a distress price of ₹10/kg is ₹25,000.

The Verdict: Pure profit the math is undeniable: an investment of ₹15,000 yields a first-season saving of ₹25,000, paying for itself within months with a ₹10,000 surplus. With equipment lasting 3–5 years, every rupee saved in future seasons is 100% profit, making this the highest-yielding insurance policy a farmer can buy. This economic model is directly supported by recent research from Patel et al. (2026)

Success stories

1.ICAR-DOGR Model

The Model states that in comparative trials, the DOGR-Cold Storage (Sensor-Controlled) had a total loss of only 7.14%, whereas traditional Ventilated Storage saw losses of 54.89% after 4 months(ICAR).

2. The FPO Smart Network Model

The Model states that by connecting 50+ scattered smallholder sheds to a central Digital Cockpit, the FPO achieved 100% remote visibility of stock health this system reduced collective wastage by 20-25% and allowed farmers to hold stock for 60 extra days, resulting in a 150% increase in net income compared to unmonitored groups who panic-sold early(DoCA).

Conclusion

The Smart Godown represents a definitive shift from traditional, high-risk storage to data-driven precision agriculture. By addressing the "vertical limit" of stacking, the technology allows farmers to safely increase storage capacity by 50% without new infrastructure, simply by monitoring

compression heat in the foundation layer. The economic rationale is undeniable; for a standard 50-tonne chawl, a setup cost of ₹10,000–₹15,000 yields a full Return on Investment (ROI) within the first few months by saving just 5% of the crop. Real-world applications validate these benefits: the ICAR-DOGR model demonstrated a loss reduction to 7.14% compared to nearly 55% in traditional methods, while FPO "Smart Networks" increased farmer income by 150% through improved market timing. Ultimately, the Smart Godown serves not as a luxury expense but as a high-yielding insurance policy, proving that affordable hardware and smart logic can solve one of India's most persistent agricultural challenges.

References

- Department of Agriculture and Farmers Welfare. 2024. *Annual Report 2023-24*. Government of India.
- Department of Consumer Affairs (DoCA). Grand Challenge for Onion Storage 2024 and Godaam Innovations Impact Report.
- Diya Patel, Dimpal Jadhav, Sakshi Hande and Hemangi Jadhav. 2026. IoT-Driven Smart Warehouse for Post-Harvest Onion Loss Reduction. *International Journal of Scientific Development and Research* 11(1):459-462.
- Food and Agriculture Organization of the United Nations (FAO). 2024. *FAOSTAT Statistical Database*
- Indian Council of Agricultural Research (ICAR). *Onion Cold Storage - Potential to Stabilize Price Fluctuation*. Directorate of Onion and Garlic Research (DOGR).

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ARTICLE ID: 26

From Sanjivini Booti to Super food: Nutritional Profiling, Propagation, and Post-Harvest Value Addition of Sea Buckthorn

Abstract

Sea Buckthorn (*Hippophae rhamnoides*), a resilient shrub of the Elaeagnaceae family, has emerged as a critical bio-resource across the temperate and high-altitude regions of Europe and Asia. Historically revered as "Siberian Pineapple" and the mythical "Sanjivini Booti," the plant is deeply rooted in ancient Ayurveda and Tibetan medical systems (specifically the RGYud Bzi). In the Indian subcontinent, its distribution spans across Ladakh, Himachal Pradesh (notably Spiti Valley), Uttarakhand, and Sikkim. This "superfood" is characterized by an extraordinary nutritional profile, containing over 190 bioactive compounds, including a complete Omega profile (3, 6, 9, and the rare Omega-7), and high concentrations of Iron (116 mg/100g) and Calcium (150 mg/100g). Effective utilization of this resource requires sophisticated propagation techniques, ranging from seed stratification to high-efficiency softwood cuttings and tissue culture. Due to the berry's high moisture content (80%–90%) and susceptibility to rapid fermentation, post-harvest management necessitates immediate pre-cooling and advanced storage technologies such as Individual Quick Freezing (IQF) and vacuum freeze-drying. Value addition remains the cornerstone of its economic viability, transforming the astringent raw fruit into premium cosmetics, nutraceuticals, and functional beverages. Especially in the Spiti Valley, Sea Buckthorn serves as a vital engine for rural economic upliftment and women's empowerment, while simultaneously acting as an ecological shield against soil erosion and desertification in fragile mountain ecosystems.

Keywords: *Hippophae rhamnoides*, Spiti Valley, Bioactive Compounds, Sanjivini Booti, Omega-7, Value Addition, Post-harvest Management, Sustainable Development, Cold Desert Ecology, Nutraceuticals

Introduction

Sea Buckthorn (*Hippophae rhamnoides*) is a valuable plant that is widely cultivated in Europe and Asia. It is a shrub that belongs to the family Elaeagnaceae and can reach a height of 7 meters. Its name comes from the fact that in Greece horses were fed with sea buckthorn to have shiny and healthy hair. Sea buckthorn (*Hippophae rhamnoides* L.) has a characteristic sour-bitter taste with an aroma reminiscent of pineapple. For this reason, sea buckthorn is also known as Siberian pineapple. Sea buckthorn (*Hippophae rhamnoides* L.) that grows naturally in large areas of temperate parts of the world.

According to scientific investigations, the therapeutic characteristics of sea buckthorn are identical to the mythical Sanjivani Booti, which was used to revive Lord Ram's younger brother Lakshman. That is why it is also known as "Sanjivini Booti". In ancient Greek literature by Theophrastus and Dioscorides, the history of sea buckthorn is traced back to the ancient ethnobotanical and ethno-pharmacological use of plant species in the Ayurvedic system of medicine (a traditional ancient Indian medical system that was published around 5000–500 BC). Sea buckthorn designs have also been used in traditional Tibetan medical literature, such as the four volumes of Pharmacopoeia known as the *RGyud Bzi*, which date back to the Tang Dynasty (618–907 AD). Sea buckthorn has been characterized by many as a super food, while it has been used in traditional medicine since ancient times, in various parts of Europe and Asia, to stimulate and protect the body. In the rugged and high-altitude landscape of Spiti Valley, Himachal Pradesh, sea buckthorn (locally known as *Chharma* or *Tirku*) has emerged as a vital "wonder berry" for both ecological restoration and rural economic upliftment. Processing typically begins with the labor-intensive harvesting of these thorny, orange-yellow berries during the short window of September and

October, after which they are subjected to primary processing—such as high-pressure dewatering and centrifugation—to separate the nutrient-rich pulp, juice, and seeds. Value addition is the cornerstone of making this hardy shrub commercially viable, as the raw fruit's intense acidity and astringency make it difficult to market in its pure form. In Spiti, local entrepreneurs and women's self-help groups have successfully transformed these berries into a wide array of premium products including antioxidant-rich juices, herbal teas, jams, and even specialized oil capsules high in Omega-7. Furthermore, by-products such as dried leaf tea and cosmetic-grade oils are increasingly being developed, allowing the tribal communities of the cold desert to tap into the global demand for "super foods" while simultaneously preventing soil erosion and desertification in their fragile mountain ecosystem.

Different ways of propagation in Sea buckthorn

Seed: Easy and simple procedure, having physiological dormancy, requires stratification treatment for 25-90 days in alternate layers of moist sand. Then, sowing of seeds is done in the month of January and 1st week of February.

Hardwood cuttings: Inexpensive and simple procedure, but success rates are not as high as

Table 1: Distribution of Sea buckthorn in Indian Subcontinent

Species	Regions			
	Ladakh	Himachal Pradesh	Uttarakhand	North-East Regions
<i>H. rhamnoides</i>	Kargil, Nubra, Changthang, Suru and Indus valleys.	Upper Kinnaur Tinu, Morang, Jispa, Tabo, Kaza, Sumdoh, Shego-Lara, Kiamal, Lingthi, Shichling, Kiato, Darcha, Pangi, Gemur, Rangrik	-	Nathula (Sikkim)
<i>H. salicifolia</i>	-	Kaza, Upper Kinnaur, Lahaul	Harsil, Tambara-Kali, Yamunotri valley, Hanumanchatti, Gangotri, Badrinath, valley, Bogdiar, Gori valley, Niti valley, Budhi, Byanse, Darm, Gaurikund,	Lachen, Dormang, Zema (I -III), Lachung, (Sikkim)
<i>H. tibetana</i>	Zaskar	Sangrum, Takcha Kibbar	Niti valley, Ranimani, Nelong, Gomukh, Shinla, Milam	North Sikkim

(Source: Singh and Dogra 1996; Dwivedi et al. 2004)

rooting of softwood cuttings. A cutting from previous season's growth (2.9 ± 0.8 mm thickness) is taken preferably in March. IBA @500 ppm is used to facilitate easy rooting

Softwood cuttings: The method is inexpensive, easy and effective, although an initial capital investment is necessary. This approach is significantly faster than hard wood cuttings since it produces over 90% rooting with high root quality, especially under mist conditions.

Suckers: Although the procedure is simple and affordable, the available materials may be limited. Suckers have a low root mass and are vulnerable to transplant shock.

Tissue Culture: A difficult procedure. Techniques are not yet fully established. Rapid production of a huge number of plants is possible. 0.01 ppm IBA was proved to be optimal for shoot proliferation, whereas 2.0 ppm BA and 1.0 ppm NAA were found to be optimal for rooting. (Source: Schroeder 2017)

Table 2: Nutritional composition per 100 g of sea buckthorn fruit is

Moisture (%)	98.30	Calcium (mg)	150.00
Protein (g)	12.10	Phosphorus (mg)	50.00
Fat (g)	12.30	Iron (mg)	116.00
Carbohydrates (g)	9.40	Ascorbic acid (mg)	20.00

(Source: Rana and Verma 2011)

Post-harvest management and storage of sea buckthorn

Post-harvest management of sea buckthorn is a high-stakes race against time due to the berry's exceptionally thin skin and high moisture content 80%-90%, which make it prone to rapid fermentation and microbial spoilage within just 2–3 days at room temperature. The process begins with rigorous cleaning to remove thorns, leaves, and a naturally occurring waxy layer that can

harbor a strong musky odor. To preserve its delicate bioactive compounds, particularly Vitamin C and Omega-7, berries must be immediately pre-cooled to 4-6 degree Celsius subjected to Individual Quick Freezing (IQF) at -20degree celsius which allows the fruit to be stored for up to a year without significant nutritional loss. For long-term storage and value addition, drying is a preferred method, with vacuum freeze-drying being the gold standard as it removes moisture while retaining nearly 95% of the berry's original antioxidants and bright color. Alternatively, the fruit can be processed into a stable pulp or a traditional condensed black mass known as "Kali Khatai" in the Himalayas, which can be stored for over 14 months in food-grade containers. Throughout the storage cycle, maintaining a strict cold chain is vital, as any temperature fluctuation can cause the "super fruit's" oils to turn rancid or its vitamins to degrade, directly impacting its market value.

Nutritional Value and Uses: Sea buckthorn (*Hippophae rhamnoides*) is widely regarded as a "super food" due to its extraordinary density of over 190 bioactive compounds, including an exceptionally high concentration of Vitamin C that can be 10 to 15 times greater than that of citrus fruits. It is perhaps the only plant in the world to contain a complete profile of Omega 3, 6, 9, and the rare Omega-7 fatty acids, which are essential for cardiovascular health and tissue regeneration. The berries and seeds are also rich in powerful antioxidants like flavonoids, carotenoids (including lycopene and lutein), and Vitamin E, alongside a broad spectrum of minerals such as potassium, calcium, and iron. Sea buckthorn berries possess anti-inflammatory properties, antibacterial activity, pain relief, tissue regeneration stimulation, immune system activation, and protection against cancer and cardiovascular disease (Grey et al. 2010, Xu et al.

2011). Sea buckthorn is a desirable ingredient for use in a variety of commodities including cosmetics, medications and food due to its flavour and nutritional qualities as well as its health advantages. Leh-berry juice has recently become highly popular in metropolitan areas.

Uses in Value Addition: It has been used to produce a variety of goods such as tea made from leaves, drinks, jam; pickles made from fruits and fermented goods created from pulp as shown in Table 3. India's Defense Research and Development Organization set up a facility in Leh to produce a multi-vitamin medicinal beverage based on sea buckthorn juice for its troops to drink when they are exposed to extremely cold temperatures.

Table 3: Various Sea buckthorn based products

Types	Products
Cosmetics	Vanishing Cream, Sun Block, Face wash, Fragrances, Serums
Raw Materials	Pulp oil, Seed oil, Concentrated juice, Raw powder
Drinks	Fruit Juice, Soda water, Wine, Beer, Champagne, Syrups, Bubbling wine, Herbal Tea

(Source: Mir et al. 2018)

Conclusion: Sea Buckthorn (*Hippophae rhamnoides*) stands as a biological marvel of the Himalayas, bridging the gap between ancient ethno-pharmacology and modern industrial science. From its legendary origins as the "Sanjivini Booti" of Indian mythology and the "Siberian Pineapple" of the Greeks to its current status as a "super food," the plant offers a unique combination of high-density nutrients and ecological resilience. In regions like Spiti Valley, it has moved beyond a wild shrub to become a cornerstone of rural economy through sophisticated value addition, transforming into high-value products like Omega-7 capsules,

herbal teas, and specialized military health drinks. The future of Sea Buckthorn lies in the optimization of propagation techniques moving from simple seed sowing to high-efficiency softwood cuttings and tissue culture to meet growing industrial demand. As post-harvest management technologies like Individual Quick Freezing (IQF) and vacuum freeze-drying become more accessible, the tribal communities of the cold desert can ensure the long-term stability of the fruit's 190+ bioactive compounds. Ultimately, the sustainable cultivation of this "wonder berry" not only provides a robust livelihood for local entrepreneurs and women's self-help groups but also acts as a vital ecological shield against soil erosion and desertification in one of the world's most fragile mountain ecosystems.

Reference:

- **Dwivedi et al. (2004):** Dwivedi, S. K., Singh, R., and Raut, B. (2004). Present status and future thrust on sea buckthorn research in Ladakh. *Souvenir and Book of Abstracts of National Seminar on Cultivation, Harvesting and Scientific Exploitation of Sea buckthorn*. FRL (DRDO), Leh, India, pp. 136.
- **Grey et al. (2010):** Grey, C., Widen, C., Adlercreutz, P., Rumpunen, K., and Duan, R. D. (2010). Antiproliferative effects of sea buckthorn (*Hippophae rhamnoides* L.) extracts on human colon and liver cancer cell lines. *Food Chemistry*, 120: 1004-1010.
- **Rana and Verma (2011):** Rana, J. C., and Verma, V. D. (2011). Genetic resources of temperate minor fruits (Indigenous and Exotic). *National Bureau of Plant Genetic Resources*, 113-120.
- **Xu et al. (2011):** Xu, Y. J., Kaur, M., Dhillon, S. R., Tappia, S. P., and Dhalla, S. N. (2011). Health benefits of sea buckthorn for the prevention of cardiovascular diseases. *Journal of Functional Foods*, 3: 2–12.
- **Schroeder (2017):** Schroeder, W. R. (2017). *Sea buckthorn Propagation*. Agriculture and Agri-Food Canada, Indian Head, Saskatchewan, Canada.

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FROM BUDGET TO BHARAT: HOW INDIA'S BUDGET IS RESHAPING AGRICULTURE, HORTICULTURE, DAIRY, AND RURAL FINANCE

Introduction:

India's **Union Budget** has increasingly become more than an annual financial statement—it is now a **development blueprint for rural transformation**. In recent years, budgetary priorities clearly signal a shift from short-term subsidies to **long-term structural reforms**, particularly in **agriculture, horticulture, dairy, and rural finance**. Together, these sectors form the backbone of livelihoods for millions of households and are central to food security, nutrition, and inclusive growth.

This article examines how budgetary interventions are influencing these sectors and what they mean for farmers, cooperatives, and rural institutions on the ground.

Agriculture: From Input Support to Income Security: Traditional budget support for agriculture focused heavily on fertilizers, irrigation, and price support. While these remain important, recent budgets reflect a **broader development approach**:

- **Investment in agri-infrastructure** such as warehouses, cold chains, and rural roads
- Emphasis on **digital agriculture and technology-driven extension**
- Support for **climate-resilient and sustainable farming practices**

Field Reality: In rainfed regions, improved access to storage and logistics has reduced distress sales. Farmers are increasingly able to **hold produce longer**, negotiate better prices, and reduce post-harvest losses. This signals a shift from production-centric policy to **value-chain-oriented agriculture**.

Horticulture: Budgeting for Nutrition and High-Value Crops: Horticulture—fruits, vegetables, spices, and floriculture—has emerged as a **strategic focus area** in India's budget discourse. The rationale is clear: horticulture offers **higher returns per hectare**, generates more employment, and contributes directly to nutritional security.

Key Budget Signals

- Expansion of **cold storage and refrigerated transport**
- Support for **cluster-based horticulture development**
- Promotion of **export-oriented horticulture value chains**

Development Impact: Small and marginal farmers cultivating vegetables and fruits benefit from:

- Reduced spoilage
- Improved market access
- More stable prices

From a policy lens, horticulture represents a move towards **diversification away from cereal-centric agriculture**, aligning with both nutrition goals and climate adaptation strategies.

Dairy Sector: Strengthening the Rural Safety Net

Dairy continues to be one of the most resilient components of the rural economy. Budgetary allocations and reforms increasingly recognize dairy not just as an allied activity, but as a **primary income stabilizer**, especially for landless households and women.

Policy Focus Areas

- Strengthening milk cooperatives and producer institutions
- Investment in animal health, vaccination, and breed improvement
- Support for fodder development and feed security

On the Ground

In many villages, dairy income provides **daily cash flow**, unlike seasonal crop earnings. Budget support to cooperatives has improved:

- Milk procurement efficiency
- Cold-chain infrastructure
- Farmer payments through digital platforms

For women, especially, dairy has emerged as a **pathway to economic participation and decision-making**.

Financial Reforms: The Quiet Enabler of Rural Growth

Perhaps the most transformative—yet less visible—budgetary impact lies in **financial reforms**. Agriculture, horticulture, and dairy can only thrive when supported by **accessible, affordable, and timely finance**.

Key Reform Directions

- Expansion of **institutional credit** to farmers and FPOs
- Digital payment systems and Direct Benefit Transfers (DBT)
- Encouragement of fintech solutions in rural lending

Why This Matters

Improved financial access reduces dependence on informal moneylenders and enables farmers to:

- Invest in better inputs

- Adopt new technologies
- Withstand climate and market shocks

From a development perspective, financial reforms act as a **multiplier**, enhancing the effectiveness of every rupee spent on agriculture.

Policy Synergy: Why Integration Matters

The real strength of the budget lies not in isolated allocations, but in **policy convergence**:

- Agriculture reforms improve productivity
- Horticulture boosts diversification and nutrition
- Dairy stabilizes incomes
- Financial reforms ensure liquidity and resilience

Together, they create a **virtuous cycle of rural development**—linking production, value addition, markets, and finance.

Challenges That Remain

Despite positive intent, several challenges persist:

- Uneven implementation across states
- Limited awareness among small farmers
- Capacity gaps in local institutions
- Risk of digital exclusion in remote areas

Addressing these requires **strong state capacity, decentralized planning, and continuous monitoring**.

Conclusion: Budget as a Development Instrument

India's budgetary approach to agriculture, horticulture, dairy, and finance reflects a maturing policy vision—one that sees farmers not merely as beneficiaries, but as **economic agents and entrepreneurs**. The emphasis on infrastructure, diversification, and financial inclusion suggests a move towards **resilient and market-integrated rural livelihoods**.

If effectively implemented, these reforms have the potential to transform the countryside—not through headline subsidies, but through **systemic change that lasts beyond one budget cycle**.

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FROM SOIL TO SILICON: HOW AI IS REWRITING THE FUTURE OF INDIAN FARMING

Introduction:

India's agricultural transformation today is no longer driven only by seeds, fertilizers, and irrigation—but increasingly by **data, algorithms, and digital intelligence**. As climate variability, declining farm profitability, and extension gaps challenge rural livelihoods, digital public innovations are emerging as key policy instruments. Among these, the **Bharat VISTAAR AI Tool** stands out as a development-oriented, farmer-first initiative that aligns technology with national agricultural and rural development goals.

Why Policy Needs Digital Agriculture Now

Over 85% of Indian farmers are small and marginal. Traditional extension systems—though well intentioned—are constrained by manpower, reach, and timeliness. For policymakers, the core challenge is clear:

How can scientific knowledge reach millions of farmers, in real time, at low cost, and in local contexts?

AI-based advisory tools such as Bharat-VISTAAR respond directly to this challenge by converting complex agronomic and climatic data into **simple, actionable advice** delivered through mobile phones.

From Policy to Field: Farmer Stories from the Ground

1. Rice Farmers and Climate Risk Management (Eastern India)

In a flood-prone block of eastern India, small rice farmers traditionally depended on intuition and past experience to decide sowing dates. Erratic monsoons often led to crop damage or re-sowing costs.

Using Bharat-VISTAAR's **weather-linked sowing advisories**, farmers received alerts on delayed rainfall and were advised to shift nursery preparation by a week.

Outcome:

- Reduced seed loss
- Better crop establishment
- Lower vulnerability to early-season floods

This illustrates how **climate-informed digital advisories function as a risk-reduction tool**, directly supporting climate adaptation policies.

2. Pest Surveillance in Cotton Belts (Central India)

Cotton farmers frequently suffer from sudden pest outbreaks, leading to panic spraying and high pesticide expenditure.

Through AI-driven pest prediction alerts, Bharat-VISTAAR warned farmers about an impending pest incidence based on humidity and temperature trends. Farmers were advised on **threshold-based spraying**, rather than blanket chemical use.

Outcome:

- Reduced pesticide costs
- Lower environmental impact
- Improved yield quality

For policymakers, this highlights the tool's potential in promoting **integrated pest management (IPM)** and reducing chemical dependence.

3. Women Farmers and Digital Inclusion (Tribal & Semi-Tribal Areas)

In tribal-dominated regions, women play a central role in agriculture but are often excluded from formal extension services.

With **voice-based advisories in regional languages**, women farmers could access guidance on vegetable cultivation and soil nutrition.

Outcome:

- Increased participation of women in farm decision-making
- Better kitchen garden productivity
- Improved household nutrition

This aligns strongly with **gender-inclusive development policies** and rural empowerment goals.

Developmental Significance of Bharat-VISTAAR

From a policy and planning perspective, Bharat-VISTAAR contributes to multiple national priorities:

Climate-Smart Agriculture

- Encourages optimal input use
- Supports adaptation to climate variability
- Reduces resource wastage

Data-Driven Governance

Aggregated, anonymized farm-level data can:

- Inform district-level planning
- Improve crop forecasting
- Support evidence-based policymaking

Strengthening Extension Systems

Rather than replacing extension workers, the tool

augments human capacity, allowing field staff to focus on community engagement while AI handles scale and speed.

Income Stability

By reducing losses and improving efficiency, digital advisories contribute indirectly to **income stabilization**, a key rural development objective.

Policy Challenges That Need Attention

Despite its promise, effective scaling of Bharat-VISTAAR requires supportive policy action:

- **Digital literacy programs** for farmers
- **Affordable internet and device access**
- **Local validation of AI advisories**
- **Trust-building through extension workers and FPOs**

Without these, the digital divide may deepen rather than shrink.

The Way Forward: From Pilot to Public Good

For Bharat-VISTAAR to realize its full potential, it must be treated as a **digital public good**—integrated with:

1. State agriculture departments
2. Krishi Vigyan Kendras (KVKs)
3. Farmer Producer Organizations (FPOs)
4. Climate and disaster management systems

Such integration can transform the tool from an innovation into a **systemic solution**.

Conclusion

Bharat-VISTAAR represents a shift in agricultural development thinking—from generalized advice to **precision, personalization, and prevention**. Farmer stories from the field demonstrate that when AI is aligned with public policy and grassroots realities, it can significantly enhance resilience, sustainability, and equity in Indian agriculture.

In the coming decade, India's success in feeding its population and securing rural livelihoods may well depend on how effectively such **digital intelligence is translated into farmer empowerment**.

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ROOT REWIRED: Hacking the Rhizosphere to Build a Nematode-Proof Future

Abstract

Plant-Parasitic Nematodes (PPNs) like *Meloidogyne* and *Heterodera* cause \$157 billion in annual losses, driving an urgent "green revolution" within the 1–3 mm rhizosphere. This biological battleground recruits specialized bodyguards, including predatory fungi like *Arthrobotrys* and bacterial *Bacillus* species that deploy Cry protoxins and volatile organic compounds (VOCs) to dismantle pests. By merging lab-scale precision with high-tech field tools like drone-assisted mapping, these microbial solutions offer a sustainable, pesticide-free path toward global food security.

Introduction

Plant Parasitic Nematodes (PPNs) are a global agricultural crisis, draining \$157 billion from the economy every year. From the aggressive Root-Knot Nematode (*Meloidogyne* spp.) to the persistent Cyst (*Globodera*, *Heterodera*), these soil-borne invaders sabotage root health, blocking the flow of nutrients and water. In high-value crops like soybean and tomato, damage can soar to 90%, making PPN management the most critical frontier in modern food security. With global food demand rising, sustainable nematode management has moved from a "nice-to-have" to a necessity. Traditional chemical controls are vanishing under the weight of strict regulations and environmental concerns. This has sparked a "green revolution" in nematology, driving the development of innovative, eco-friendly alternatives that safeguard human health without sacrificing productivity. The rhizosphere is the narrow, dynamic zone of soil (typically extending 1–3 mm) immediately surrounding a plant root that is physically, chemically, and biologically altered by the root itself. It is characterized by rhizodeposition, the process where plants exude up to 20-40% of their photosynthetically fixed carbon (sugars, amino acids, and organic acids) into the soil. These exudates act as a biological "calling card," attracting a dense and diverse community of microorganisms, the rhizobiome, at concentrations 10 to 100 times higher than in the surrounding bulk soil. The rhizosphere is home to an elite squad of biological control agents (BCAs). "Heavy hitters" like *Bacillus thuringiensis*, *Trichoderma*, and *Pasteuria penetrans* don't just sit idle; they launch a multi-pronged assault on parasitic nematodes. Some act as direct assassins, using toxic metabolites and lytic enzymes to dissolve nematode shells, kill juveniles (J₂s), and prevent eggs from ever hatching. Others play the long game, acting as "immune trainers" that trigger the plant's own defense systems (ISR) or release chemical signals that confuse nematode feeding patterns and even mess with their breeding ratios.

In this feature, we dive into the world of microbial "bodyguards"- showcasing how specific bacteria and fungi are replacing toxic chemicals in the fight against nematodes. From current success stories to the hurdles of scaling up, we explore the roadmap to a truly sustainable, pesticide-free future for global farming.

The Fungal Frontier: Recruiting Microbes for Natural Nematode Control

In the hidden world of the soil, fungi act as nature's special operations team, hunting plant-parasitic nematodes (PPNs) with terrifyingly effective biological weapons. Researchers are now looking to these nematophagous fungi as the key to sustainable, pesticide-free farming. Here is how these fungal assassins get the job done:

1. The Four Tactics of Fungal Warfare:

Fungi don't just happen upon their prey; they utilize four distinct survival strategies:

A. Nematode-Trapping (Predatory) Fungi:

These fungi are the engineers of the soil. Species like *Arthrobotrys* and *Dactylellina* build intricate adhesive nets and knobs. Some, like *Drechslerella brochopaga*, use constricting rings that snap shut around a nematode in a fraction of a second.

B. Endoparasitic Fungi: These are the "silent" killers. *Drechmeria coniospora* attaches spores to a nematode's sensory organs. Even if the fungus doesn't kill the worm immediately, by "blinds" it, preventing it from ever finding the plant's roots.

C. Egg and Female Parasites: To stop the next generation, fungi like *Pochonia chlamydosporia* and *Paecilomyces lilacinus* target the source. They use specialized "pressure pads" called

appressoria or infection pegs to breach tough eggshells and sedentary females.

D. Toxin-Producing Fungi: *Coprinus comatus* uses chemical warfare. It features "spiny balls", a burr-like structures that release toxins to paralyze nematodes within hours before digesting them.

Bacterial Bodyguards: The High-Tech Chemists of the Soil

If fungi are the "assassins" of the rhizosphere, bacteria are the "chemical engineers." By producing a sophisticated pharmacy of toxins and enzymes, these microscopic allies dissolve plant parasitic nematode defenses and disrupt their life cycles before they can damage crops.

The Bacillus Arsenal: Multi-Purpose Defense:

The genus *Bacillus* is a powerhouse of biological control, using a variety of specialized "weapons" to suppress populations of *Meloidogyne* and *Heterodera* species.

1. The Gut-Buster (*B. thuringiensis*):

Widely known as Bt, it produces Cry and Cyt protoxins. Once a nematode eats these, they activate and form pores in the gut, causing osmotic lysis-essentially making the worm's digestive system explode.

2. The Immune Trainer (*B. subtilis*): This species works on three levels. It releases lipopeptides to pop nematode membranes, emits volatile organic compounds (VOCs) like 2,3-butanediol to paralyze them, and triggers the plant's own Jasmonic Acid (JA) and Salicylic Acid (SA) defense pathways.

3. The Armor-Dissolvers (*B. cereus*, *B. megaterium*, & *B. pumilus*): These species specialize in "melting" the nematode's skin (cuticle). They secrete enzymes like metalloproteinases (Npr, BlyA) and subtilisin, alongside siderophores (like

bacillibactin) that starve the nematodes of essential iron.

4. **The "Attract and Kill" Specialist** (*B. nematocida*): In a devious twist, this bacterium releases 2-heptanone, a chemical lure that smells like food. Once the nematode is close, the bacterium switches to lethal enzymes and lipopeptides to finish the job.
5. **The Egg-Crusher** (*B. amyloliquefaciens*): Using a blend of fengycin and iturin, this bacterium destroys nematode eggshells and impairs the development of juveniles.

Challenges in biocontrol of PPNs

While biocontrol offers a green future for agriculture, managing PPNs involves navigating a complex web of biological and logistical hurdles:

- **Biological Complexity**: The sheer diversity of nematode species and their intricate interactions with plants, microbes, and the environment make finding a "one-size-fits-all" BCA (Biological Control Agent) extremely difficult.
- **The Survival Challenge**: Many BCAs with high lab potency fail in the field because environmental variables, such as soil type, pH, moisture, and temperature hinder their long-term survival and efficacy.
- **Economic Barriers**: Bringing these solutions to market is often slowed by high production costs, short shelf lives for chemical formulations, and inconsistent performance in different climates.
- **Regulatory and Social Hurdles**: The path to registration is both expensive and time-consuming, while market adoption requires active effort to educate the public

and stakeholders on the safety of biocontrol technology.

Overcoming these obstacles is the vital next step in creating truly sustainable and efficient management systems for PPNs.

Conclusion and Future Prospects

The search for safe, eco-friendly ways to protect our food supply has led researchers to a promising new frontier: using beneficial microbes to manage crop diseases. This is particularly vital because PPNs (Plant Parasitic Nematodes) pose a massive threat to the productivity of major crops on a global scale. To address this, current research is focused on summarizing how both bacterial and fungal biocontrol strategies can be used as a primary defense to keep PPNs in check. As the climate shifts, our defense against PPNs (Plant-Parasitic Nematodes) must evolve. To keep agriculture sustainable, we need biocontrol agents that aren't just effective, but adaptable to unpredictable weather. Here is how we move these solutions from the lab to the field:

- **Commercial Hurdles**: Success depends on making biocontrol technologies economically viable and navigating complex regulatory frameworks.
- **Winning Public Trust**: Education is the bridge. By teaching farmers and legislators about the benefits of sustainable farming, we can accelerate the adoption of these methods.
- **The Tech Edge**: High-tech precision agriculture, including drones and remote sensing, now allows us to map nematode infestations in high resolution. This data ensures we apply treatments exactly where they are needed, optimizing resources and results.

Ultimately, combining climate-ready science with smart technology and public awareness is the only way to stay ahead of these microscopic threats.

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The Role of Indian Knowledge Systems in Promoting Holistic Education

Introduction

The development of students' intellectual, emotional, social, physical, artistic, creative, and spiritual potential is the goal of holistic education. In this educational paradigm, Indian Knowledge Systems (IKS), which comprise a wide range of knowledge, customs, and practices originating from the Indian cultural environment, can be very important. Holistic education is a teaching approach that places more emphasis on a student's overall development than just their academic achievement. It aims to develop a student's physical, emotional, spiritual, psychological, and moral attributes. The idea that integrating many courses enhances student learning is the basis of holistic education. Indigenous Knowledge (IK), which includes the abilities, insights, and experiences of people utilized to preserve or enhance their standard of living, is an essential resource for development. A third of the 900 million people living in extreme poverty in rural areas worldwide are indigenous peoples, who comprise around 5000 different tribes and approximately 4% of the global population. Seventy percent of their 70+ nations are in Asia. However, for historical and political reasons, they frequently experience discrimination and marginalization. In addition to having difficulty producing food, making a living, accessing healthcare, education, and legal rights to reside on their lands, they also have difficulty influencing institutions and policies. Eradicating poverty requires addressing the unique needs of these minority ethnic communities. An overview of IK, its effects on social development, how international initiatives are maintaining IK, and India's readiness to defend it are all covered in this study.

Understanding Indian Knowledge Systems (IKS)

IKS is defined as the philosophy, astronomy, mathematics, medicine, yoga, linguistics, and ethics are all included in Indian knowledge systems. Important writings that examine many facets of life, nature, and the cosmos include the Vedas, Puranas, and Aranyakas. These systems place a strong emphasis on harmony, sustainability, and interconnectedness—principles that are still applicable in today's educational environment.

Key Feature of IKS:-

1. **Holistic thinking:** The IKS places a strong emphasis on how everything is interrelated and how crucial it is to view the big picture. The IKS places a strong emphasis on observation and firsthand experience as knowledge sources.
2. **Tradition is important:** The IKS considers the transmission of knowledge from one generation to the next and the preservation of tradition to be very important.

3. Emphasis on spiritual growth: The IKS places a strong emphasis on the value of spiritual growth as well as the pursuit of knowledge and truth for their own sake.

4. Integration of knowledge from several disciplines: The IKS incorporates information from a number of disciplines, including as science, medicine, philosophy, religion, and the arts.

The IKS is a sophisticated and diverse body of knowledge that is still being researched and discussed by academics today. Nonetheless, it is evident that the IKS has significantly advanced human civilization and is still applicable in the contemporary era.

Here are some of the specific features of the IKS:

1. Emphasis on Interconnectedness

- **Holistic Approach:** IKS encourages people to see the cosmos and life as interdependent systems. For example, the idea of "Vasudhaiva Kutumbakam," which translates to "the world is one family," encourages students to feel like global citizens.
- **Curriculum Integration:** Traditional ecological knowledge can be included into subjects like environmental science to highlight the interdependence of humans and nature.

2. Promotion of Emotional and Spiritual Well-being

- **Yoga and Mindfulness:** Including IKS's yoga and meditation techniques helps improve students' mental and emotional well-being. These exercises encourage self-awareness, self-control, and stress reduction.

- **Cultural Values:** IKS promotes emotional intelligence by embodying values like gratitude, respect, and compassion that can be included into the educational ethos.

3. Development of Critical Thinking and Creativity

- **Philosophical Traditions:** Buddhist philosophy, Nyaya philosophy, Vedanta philosophy, and other Indian philosophical schools promote inquiry and critical thought. Through these readings, students can examine a variety of viewpoints and hone their analytical abilities.
- **Creative Expression:** Students can express their creativity and cultural identity by participating in traditional dance, music, and arts and crafts programs at schools.

4. Practical Knowledge and Skills

- **Traditional Practices:** By incorporating Ayurvedic medicine, traditional farming methods, and handicrafts into vocational education, students can gain useful skills that are applicable to their local communities.
- **Sustainability:** IKS promotes environmental stewardship and responsible citizenship by providing sustainable methods that students can learn.

5. Multilingualism and Cultural Diversity

- **Language Education:** By highlighting native tongues and dialects in the curriculum, teachers can encourage multilingualism and help pupils connect with their cultural background and comprehend different points of view.
- **Cultural Appreciation:** Learning IKS promotes pride in one's ancestry and respect for cultural diversity.

Conclusion

Promoting holistic education can be greatly aided by the incorporation of Indian knowledge systems into the educational system. IKS can contribute to the development of a more inclusive and stimulating learning environment by promoting interconnectedness, emotional and spiritual well-being, critical thinking, practical skills, and cultural variety. To guarantee that IKS is successfully included into the curriculum and in line with the objectives of holistic education, policymakers, educators, and communities must work together.

References

- National Education Policy (NEP) 2020, Government of India.
- Sharma, A. (2018). "The Role of Indian Knowledge Systems in Education: A Cultural Perspective." *Journal of Indian Education*, 44(3), 17-34.
- Mishra, R. (2020). "Integrating Indian Knowledge Systems in Modern Education." *Indian Journal of Education and Pedagogy*, 2(1), 45-56.
- Reddy, P. (2019). "Holistic Education: The Indian Perspective." *International Journal of Holistic Education*, 3(2), 23-30.
- Rao, Siriginidi Subba. "Indigenous knowledge organization: An Indian scenario." *International Journal of Information Management* 26.3 (2006): 224-233.

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BOTANICAL EXTRACTS AS BIOSTIMULANTS: NATURE'S BLUEPRINT FOR SUSTAINABLE AGRICULTURE

Introduction

The modern agricultural is confronted with a major challenge of providing adequate and nutritious food while minimizing environmental impact. According to reports from the United Nations, the global population, currently estimated at around 7.5 billion, is expected to exceed 9.7 billion by 2050. To meet this growing demand, agriculture has relied heavily on the extensive use of synthetic fertilizers and pesticides for several decades. However, improper and excessive application of these inputs has led to negative effects on human health and agroecosystems due to their high toxicity and residual effect in the environment. As a result, there is an urgent need to develop sustainable and efficient approaches to enhance crop yield and quality. In this context, plant biostimulants have emerged as a promising and environmentally friendly alternative, supporting the sustainability of agro-productive systems.

Plant Biostimulants

Although use of biostimulants is steadily increasing, a single, universally accepted definition of the term “plant biostimulant” has not yet been established. This lack of consensus arises from the heterogeneity of their sources, the complexity of their compositions, and the challenges involved in clearly identifying their modes of action. However, the scientific community generally agrees that plant biostimulants are substances or microorganisms which enhance physiological processes, improving nutrient uptake, nutrient use efficiency, tolerance to abiotic stresses, and crop quality, regardless of their nutrient content (Ricci et al. 2019). Importantly, classification as a biostimulant is based on its functional role in agriculture rather than on the nature of its constituents. In contrast to conventional fertilizers, the beneficial effects of biostimulants are not dependent on their nutrient composition.

Botanical extracts as biostimulant

Plants are emerging as a valuable local source of biostimulant extracts due to their abundant biomass and rich reservoir of bioactive compounds. Their wide availability from diverse sources, including weeds, invasive plants, and agro-industrial residues, further enhances their suitability for large-scale utilization. Botanicals are defined as substances derived from plant materials that are used in pharmaceuticals, cosmetics, food products, and agricultural applications (Seiber et al. 2014). These plant-derived products, commonly known as botanical extracts (BEs), consist of complex mixtures of primary and secondary metabolites such as polyphenols, phytohormones, organic acids, sterols, and terpenoids.

In agricultural research, the pesticidal properties of botanical extracts have been widely studied, whereas their function as biostimulants has received increasing attention only in recent years. Compared with conventional agrochemicals, botanicals are generally considered safer for human health and the environment, making them promising candidates for the development of innovative biostimulant formulations (Dimetry 2014). Bioactive constituents present in botanical extracts stimulate essential plant physiological processes ranging from seed germination to fruit development (Martínez-Lorente et al. 2024). Recent research has shown that crude botanical extracts and their organic fractions positively influence seed germination, vegetative growth,

flowering, and fruit set in several economically important crops, leading to improvements in yield and quality (keya Tudu et al. 2022). Application of these extracts often results in more uniform germination and vigorous seedling establishment, although plant responses depend on the type of extract used, the crop species or cultivar, and experimental conditions (Espinoza-Antón et al. 2025). When applied either individually or in combination as biostimulants, botanical extracts enhance growth parameters such as plant height, leaf number, chlorophyll index, biomass accumulation, yield, and product quality. The positive effects of botanical extracts are associated with the regulation of multiple physiological and biochemical pathways, including improved uptake of nutrients and

Table 1: Effects of botanical extracts on different plant or crops.

Source of botanical extracts	Plant/Crop	Effects	References
<i>Moringa oleifera</i> leaf extract	Cabbage	Enhanced growth, pigment concentration, vitamin C levels, and reduced nitrate accumulation	(Yaseen et al. 2023)
Henna Leaf Extract (<i>Lawsonia inermis</i> L.)	<i>Triticum aestivum</i>	Improved shoot and root development, enhanced biochemical traits, higher yield, and better grain quality	(Maksoud et al. 2023)
<i>Ocimum sanctum</i> leaf extract	Tobacco	Shoot regeneration doubled and in vitro stress adaptation was enhanced	(Vongnhay et al. 2024)
<i>Citrus sinensis</i> extract	<i>Pennisetum glaucum</i>	Enhanced seed germination and vigour; reduced fungal infection and improved field germination	(Anafo et al. 2023)
<i>Psidium guajava</i> , <i>Aloe vera</i> , <i>Allium sativum</i> , <i>Medicago sativa</i> extracts	Cucumber, Tomato, Kale, Lettuce	Increased shoot biomass and improved growth and metabolic activity in cucumbers, tomatoes, kale, and lettuce	(Ei et al. 2025)
Ginger Extract	<i>Salvia officinalis</i>	Increased plant height, branch number, herb yield, essential oil percentage and yield	(Moussa et al. 2024)

water, increased photosynthetic efficiency, modulation of phytohormone balance, activation of primary and secondary metabolism, and induction of stress-responsive genes (Martínez-Lorente et al. 2024). Their activity is attributed to the synergistic interaction of diverse bioactive compounds such as polyphenols, phytohormones, amino acids, sterols, terpenoids, and vitamins. These constituents exert direct effects following foliar or root uptake by influencing plant metabolic processes and indirect effects by improving soil properties, rhizosphere interactions, and the activity of beneficial microorganisms (Espinoza-Antón et al. 2025). Overall, botanical extracts function as multifunctional biostimulants with considerable potential to enhance crop productivity and sustainability in modern agriculture.

Preparation and Extraction Methods

The effectiveness of a botanical extract depends heavily on the selection of plant biomass and the extraction method used. The process typically involves several stages:

1. Pretreatment: Collected material is washed to remove surface impurities and then used fresh or dried. Drying can occur at room temperature (~26°C) or via freeze-drying (-80°C) to preserve delicate compounds like polyphenols and flavonoids.

2. Milling: The dried material is crushed to increase the surface-to-volume ratio.

3. Extraction: Common methods include maceration, autoclaving, or ultrasound-assisted extraction.

Solvent Selection: While organic solvents like methanol, ethanol, and acetone are used to selectively dissolve compounds, water-based extraction methods are the most common. Water extractions are simple, inexpensive, and reduce toxicity, although they may have lower selectivity for certain bioactive compounds.

Biological Processes: Some extracts are obtained through anaerobic fermentation, where microbial activity facilitates the release of bioactive compounds from the plant matrix.

Application Strategies for Maximum Efficacy

There are four primary ways to apply these extracts to crops, and their effectiveness is often determined by the method chosen. **Seed treatment (Priming):** Hydrating seeds with extracts optimizes germination capacity and promotes adequate seedling establishment. **Foliar application:** This method allows for immediate interaction with plant tissues through rapid absorption via stomata and cuticles. Foliar application is most effective when performed in the morning hours.

Soil Drenching/Irrigation: Delivering extracts to the base of the crop promotes root development and stimulates microbial activity in the rhizosphere.

The Regulatory Landscape and Future Directions

A significant challenge to the adoption of biostimulants is the lack of a specific, harmonized regulatory framework. The European Union established Regulation (EU) 2019/1009 as the first legislative text for marketing these products. In contrast, the majority of the countries still lack specific regulations, often regulating biostimulants under existing laws for fertilizers or soil improvers. Future research should prioritize bioprospecting efforts aimed at the systematic identification of new plant species with biostimulant potential. In addition, the expansion of field-based studies, moving beyond controlled laboratory conditions to validate the effectiveness of these biostimulants under natural environments and diverse abiotic stress conditions.

Conclusion

Botanical extracts represent a "win-win"

for modern agriculture. By replacing or reducing the need for synthetic chemicals with natural bioproducts, we can protect land fertility and promote food sovereignty without damaging the ecological balance.

References

- Anafo, M. A., Sugri, I., Asungre, P. A., Ankamah-Yeboah, T., Eleblu, J. S. Y., & Danquah, E. Y. (2023). Citrus Extract Found Potent in the Control of Seed-Borne Fungal Pathogens of Pearl Millet—A Recommendation for Farmers' Seed Saving Systems. *Horticulturae*, 9(10), 1075.
- Dimetry, N. Z. (2014). Different plant families as bioresource for pesticides. *Advances in plant biopesticides*, 1-20.
- Ei, E., Park, H. H., & Kuk, Y. I. (2025). Growth Promotion and Secondary Metabolites of Vegetables by Spraying Soil with Psidium guajava, Aloe vera, Allium sativum and Medicago sativa Extracts at Various Stages of Growth. *Plants*, 14(2), 237.
- Espinoza-Antón, A. A., Hernández-Herrera, R. M., Pizano-Andrade, J. C., & Salcedo-Perez, E. (2025). Botanical extracts with biostimulant potential for agriculture in Mexico: a review. *Biotechnia*, 27.
- keya Tudu, C., Dey, A., Pandey, D. K., Panwar, J. S., & Nandy, S. (2022). Role of plant derived extracts as biostimulants in sustainable agriculture: a detailed study on research advances, bottlenecks and future prospects. *New and future developments in microbial biotechnology and bioengineering*, 159-179.
- Maksoud, S. A., Gad, K. I., & Hamed, E. Y. (2023). The potentiality of biostimulant (*Lawsonia inermis* L.) on some morpho-physiological, biochemical traits, productivity and grain quality of *Triticum aestivum* L. *BMC Plant Biology*, 23(1), 95.
- Martínez-Lorente, S. E., Martí-Guillén, J. M., Pedreño, M. Á., Almagro, L., & Sabater-Jara, A. B. (2024). Higher plant-derived biostimulants: mechanisms of action and their role in mitigating plant abiotic stress. *Antioxidants*, 13(3), 318.
- Moussa, M. M., Mansour, M. M. F., El-Sharnouby, M., & Hassan, F. A. (2024). Foliar Application of Bee Honey or Ginger Extract Enhanced *Salvia officinalis* L. Growth and Productivity by Improving Phytohormones, Antioxidants, Chlorophylls, and Nutrients. *Agronomy*, 14(8), 1819.
- Ricci, M., Tilbury, L., Daridon, B., & Sukalac, K. (2019). General principles to justify plant biostimulant claims. *Frontiers in plant science*, 10, 494.
- Seiber, J. N., Coats, J., Duke, S. O., & Gross, A. D. (2014). Biopesticides: state of the art and future opportunities. *Journal of agricultural and food chemistry*, 62(48), 11613-11619.
- Vongnhay, V., Shukla, M. R., Ayyanath, M. M., Sriskantharajah, K., & Saxena, P. K. (2024). Enhanced In Vitro Plant Morphogenesis of Tobacco: Unveiling Indoleamine-Modulated Adaptogenic Properties of Tulsi (*Ocimum sanctum* L.). *Plants*, 13(10), 1370.
- Yaseen, A. A., Madar, Á. K., Vojnović, Đ., & Takács-Hájos, M. (2023). Examining the optimal amount of moringa leaf extract to improve the morphological and inner quality of cabbage (*Brassica oleracea* var. capitata). *Journal of Food Quality*, 2023(1), 3210253.

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EMPOWERING ENTREPRENEURS: A COMPREHENSIVE OVERVIEW OF THE PMFME SCHEME

INTRODUCTION

The Prime Minister Formalisation of Micro Food Processing Enterprises (PMFME) scheme is a visionary initiative by the Indian government aimed at transforming the informal food processing sector into a formal and organised industry. Launched as a part of the "Atmanirbhar Bharat Abhiyan" (Self-Reliant India Mission), the PMFME scheme focuses on promoting entrepreneurship, enhancing market access, and ensuring the financial and technical support for micro food processing enterprises. The Pradhan Mantri Formalisation of Micro Food Processing Enterprises (PMFME) scheme is a flagship initiative by the Government of India aimed at transforming the food processing sector by providing support and incentives to micro-enterprises. Launched on June 29, 2020, under the 'Atmanirbhar Bharat Abhiyan,' the PMFME scheme focuses on formalising and strengthening the unorganised food processing sector, thereby enhancing income opportunities for small-scale entrepreneurs and ensuring the availability of quality processed food for consumers.

KEY OBJECTIVES:

- 1. Formalisation of Enterprises:** The primary goal of the PMFME scheme is to encourage the formalisation of micro food processing enterprises, which often use in the unorganised sector. By providing support and incentives, the scheme aims to bring these enterprises into the formal economy, leading to better regulation and growth.
- 2. Financial Assistance:** Under the PMFME scheme, financial assistance is extended to eligible entrepreneurs to boost their production capacities, upgrade technology, and improve infrastructure. This financial aid is crucial for small businesses to compete effectively in the market and meet quality standards.
- 3. Capacity Building and Skill Development:** The scheme emphasises skill development and capacity building by providing training to entrepreneurs in areas such as food safety, hygiene, and business management. This helps enhance the overall competency of micro food processing enterprises.
- 4. Market Access:** PMFME facilitates market linkage for the beneficiaries, ensuring that their products reach a wider audience. Through the establishment of common processing centres and technology up gradation, the scheme aims to connect micro enterprises with mainstream markets and enhance their competitiveness.

COMPONENTS OF PMFME SCHEME:

1. Micro Food Processing Enterprises (MFPEs):

The scheme targets individual entrepreneurs, self-help groups, and cooperatives engaged in food processing activities. It covers a diverse range of activities such as fruits and vegetable processing, fisheries, poultry, meat processing, and more.

2. Credit Linked Subsidy:

PMFME provides credit-linked subsidies to eligible beneficiaries, reducing the financial burden on entrepreneurs. This ensures that micro food processing units have access to affordable credit for their business operations.

3. Infrastructure Development:

The scheme supports the creation of infrastructure like Common Processing Centres (CPCs) equipped with modern machinery and technology. These centres serve as shared facilities for multiple entrepreneurs, promoting cost-effective and efficient operations.

4. Brand Building and Marketing:

To enhance market visibility and consumer trust, the scheme encourages brand building for micro food processing enterprises. Marketing support is provided to help these enterprises establish a presence in both domestic and international markets.

BENEFITS AND IMPACT:

1. Employment Generation:

The PMFME scheme is expected to generate employment opportunities, particularly in rural areas, as more micro enterprises formalise and expand their operations.

2. Economic Growth:

By formalising the micro food processing sector, the scheme contributes to the overall economic growth of the country. It also aligns with the government's broader goal of making

India self-reliant in various sectors.

3. Quality Improvement:

Through capacity building and technology up gradation, the scheme aims to improve the quality of products from micro food processing enterprises, ensuring compliance with food safety standards.

Financial aspects play a pivotal role in the success of micro food processing enterprises under the PMFME scheme. The scheme provides various forms of financial assistance to beneficiaries, aiming to alleviate financial constraints and promote sustainable growth.

Here are more details about the financial aspects for beneficiaries:

1. Credit Linked Subsidy:

One of the key financial components of the PMFME scheme is the provision of credit-linked subsidies. Beneficiaries can avail themselves of loans at subsidised interest rates, making credit more accessible and affordable for micro food processing enterprises. This helps in meeting working capital requirements, investing in technology, and expanding production capacities.

2. Loan Amount and Subsidy Percentage:

The scheme defines the maximum loan amount that can be availed by beneficiaries based on their project requirements. The subsidy percentage is also predetermined, ensuring that a portion of the interest payable on the loan is subsidised. This makes the cost of borrowing more manageable for entrepreneurs.

3. Term Loans for Technology Up gradation:

Beneficiaries can use the financial support for technology up gradation, allowing them to invest in modern machinery and equipment. This not only improves efficiency but also enhances the quality of the processed food products. Term loans for technology up gradation are instrumental in keeping the enterprises

competitive in the market.

4. Working Capital Support:

Micro food processing enterprises often face challenges related to working capital management. The PMFME scheme addresses this by providing working capital support to beneficiaries. This ensures a smooth flow of operations, from procurement of raw materials to the production and distribution of finished goods.

5. Insurance Coverage:

The financial assistance provided under the scheme may include insurance coverage for assets and products. This protects the interests of beneficiaries against unforeseen events such as natural disasters, accidents, or damages to equipment, mitigating financial risks associated with business operations.

6. Margin Money Assistance:

To encourage beneficiaries to invest their own capital in the projects, the scheme may provide margin money assistance. This ensures that entrepreneurs have a stake in the success of their enterprises and promotes responsible financial management.

7. Revolving Fund:

Some components of the PMFME scheme may incorporate a revolving fund, where the interest and principal repayments from previous beneficiaries are recycled to provide financial assistance to new entrepreneurs. This sustainable approach ensures the continuous availability of funds for future beneficiaries.

8. Financial Literacy and Training:

Alongside financial assistance, the scheme emphasises financial literacy and training for beneficiaries. This equips entrepreneurs with the knowledge and skills needed to manage their finances effectively, enhancing their ability to make informed financial decisions for the growth of their enterprises.

By addressing the financial needs of micro food processing enterprises comprehensively, the PMFME scheme aims to create a supportive ecosystem that enables entrepreneurs to scale up their businesses, improve productivity, and contribute significantly to the formalised and organised growth of the food processing sector.

CONCLUSION:

The PMFME scheme stands as a crucial step towards transforming the landscape of micro food processing enterprises in India. By providing financial support, technical assistance, and market access, the scheme empowers entrepreneurs to thrive in a competitive environment while contributing to the nation's economic growth and self-reliance.

The Pradhan Mantri Formalisation of Micro Food Processing Enterprises (PMFME) scheme is a comprehensive and strategic initiative aimed at transforming the unorganised food processing sector in India. By providing financial support, capacity building, and marketing assistance, the scheme empowers micro-enterprises, fosters economic growth, and ensures the availability of safe and high-quality processed food products for consumers. As the scheme progresses, it is expected to contribute significantly to the vision of an 'Atmanirbhar Bharat' in the food processing sector.

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PLANT GROWTH REGULATORS: PRECISION TOOLS FOR ENHANCING YIELD AND QUALITY IN VEGETABLE CROPS

Abstract

Vegetables are an important component of a balanced diet providing essential micronutrient, antioxidants and dietary fibers. As the global population expands, increasing vegetable productivity has become a primary mandate for agriculture. Plant Growth Regulators (PGRs), both naturally occurring and synthetic compounds help in optimizing yield of vegetable crops. These “bioregulators” act in very minute concentrations and influence various processes in plants from cell division and germination to fruit ripening and stress response. Evidence from various studies demonstrates that strategic PGR application enhances growth and quality parameters in vegetable crops as well as provide tolerance to stress in some cases. GA₃ application in tomato and brinjal has shown to increase fruit weight and number of fruits, while Ethrel application has proved to manipulate sex expression in cucurbits to favour female flower production and higher yields. Use of PGR has achieved significant results within protected cultivation systems also, where controlled conditions allow these compounds to act as precision tools for maximizing return on investment and achieving higher productivity. Ultimately, judicious use of PGRs offers a pathway to enhance yield, quality and tolerance to stress in vegetable crops.

Keywords: Plant Growth Regulators, Vegetable Productivity, Protected Cultivation, Phytohormones, Yield Enhancement, Stress Resistance

Introduction

Vegetables are herbaceous, succulent plants which are annual, biennial or perennial, where the whole plant or any part of the plant is consumed either cooked or in raw form. Vegetables are nutritionally dense crops that play a vital role in ensuring food and nutritional security. According to the final advance estimates, vegetable production in India is reported to be 207.21 million tonnes in financial year 2024 (Ministry of Agriculture and Farmers' Welfare). In view of a rapidly expanding population, it is necessary to enhance the productivity of vegetable crops using efficient tools like plant growth regulators.

Plant growth regulators (PGRs) are a group of naturally occurring or synthetic compounds which influence the biochemical and physiological process in plants like cell division, cell elongation, cell differentiation, etc. They also regulate important physiological process like fruit ripening, flowering, germination, dormancy, abscission, etc, so they can also be termed as plant bioregulators. Contrary to the nutrients, which are required in relatively large quantities, PGRs act in minute concentrations to influence the plant morphology and physiology. By manipulating the internal metabolic system through precise and careful use of plant growth regulators, yield and productivity can be significantly enhanced to meet their rising demand.

Plant Growth Regulators

Broadly, plant hormones can be classified based on their ability to induce growth or inhibit it. Those hormones which encourage growth-related activities are called growth-promoting hormones, which include auxin, gibberellin and cytokinin while those which inhibit the growth-related activities are called growth retarding hormones and include abscisic acid and ethylene. These five hormones are considered as the “Big Five”.

Table 1: physiological roles of plant growth regulators

PGR Type	Major Functions
Auxin	Cell elongation, Apical dominance, Root initiation, Vascular differentiation, parthenocarpy, Prevention of Abscission, Callus formation
Gibberellins	Stem elongation, Bolting, Breaking of dormancy, Maleness in cucurbits, Fruit growth, Seed germination
Cytokinins	Cell division, Delay senescence (anti-aging hormone), Shoot initiation, Nutrient mobilisation, bud differentiation, Promotes lateral bud growth
Absciscic Acid	Stomatal regulation, Leaf abscission, Seed and bud dormancy, Mediates stress response
Ethylene	Fruit ripening, Abscission of fruits and flowers, Flowering, Sex expression, Senescence of leaf

In addition to the above-mentioned five major phytohormones, there are other important PGRs which significantly affect the growth process in plants: Brassinosteroids, Jasmonic acid, Strigolactones, Anthesin, Florigen, etc.

Role of PGRs in enhancing growth parameters

Higher overall productivity can be achieved by increase in growth parameters. Research across various vegetable crops demonstrates that applying PGRs significantly improves key growth parameters, such as fruit size, quantity, and length. In Tomato cultivation, the application of GA₃ notably increases the number of fruits per plant, fruit size, and overall weight. Similarly, in Brinjal, the use of NAA results in increase in fruit size and more number of fruits per plant. Furthermore, in Bottle gourd, the application of Ethrel has been shown to boost total yield by almost 40% (Duhan *et al*, 2022). Collectively, these findings show that optimized application of PGRs have shown substantial improvements in crop performance.

Role of PGRs on quality parameters

Plant growth regulators not only enhances yield, but also improves qualitative attributes of the produce. Quality improvement is a critical parameter that dictates market value. Farmers can get premium prices by producing vegetables that align with consumer preferences for superior taste, texture, and nutritional profiles. PGRs like GA₃ significantly improves the Total Soluble Solids (TSS) and acidity in Tomatoes, which improves the overall taste and preferred by consumers. Pod vegetables like Garden pea are valued for their high protein content, the use of Kinetin has been shown to increase the protein content in garden peas by up to 20%.

Cucurbitaceous crops exhibit good responsiveness to PGRs. For instance, GA₃ can nearly double the TSS in Cucumbers (Dinesh *et al*, 2024). Similarly, in Bottle gourd, GA₃ enhance the ascorbic acid (Vitamin C) content and optimize the seed-to-pulp ratio, directly increasing the vegetable's nutritional and commercial appeal.

Effect of plant growth regulators in protected cultivation

The practice of growing crops in a controlled environment inside specialised structures is called protected cultivation. The conditions inside the structure like light intensity, humidity, temperature, etc can be altered according to the requirements of the crop and at the same time protects it from adverse weather conditions, pests and diseases. Inside these protected structures, PGRs will act as precision tools as they become more effective compared to open field conditions due to favourable conditions inside the structure.

The application of specific plant growth regulators has demonstrated significant physiological benefits for Solanaceous crops in protected environments. In Pepper cultivation under plastic tunnels, the exogenous application of GA₃, CPA, and NAA notably enhanced fruit set, total yield, and other parameters, including fruit size and weight. Similarly, in greenhouse Tomato production, inflorescence dipping with 30 ppm of 4-CPA proved highly effective, resulting in superior fruit set percentages and a substantial increase in fruit yield per square meter (Jasmin *et al*, 2018).

Under protected conditions, PGR application proves to be more effective due to:

1. No spray washoff due to rainfall
2. Predictable response due to uniform climate
3. Greater hormone efficiency due to reduced stress

Protected cultivation involves a very high initial investment, which necessitates the efficient use of plant growth regulators to optimize resource utilization, maximize productivity per unit area and accelerate return on investment.

Table 2: crop-wise summary table

Crop	PGR and Dose	Major Effects	Reference
Tomato	GA ₃ (40 ppm)	Increased fruit size, number and achieved higher TSS and Acidity	Singh <i>et al</i> , 2024
	Ethephon (500 ppm)	Improved frost tolerance	Swamy <i>et al</i> , 2021
Tomato (Green house)	4-CPA (30 ppm)	Higher fruit set percentage and yield per m ²	Jasmin <i>et al</i> , 2018
Brinjal	NAA (25-75 ppm)	Increased fruit size, number and yield	Verma <i>et al</i> , 2025
Bottle Gourd	Ethrel (200 ppm)	40% yield increase	Duhan <i>et al</i> , 2022
	GA ₃ (40 ppm)	Higher seed-pulp ratio and ascorbic acid content	Wamiq <i>et al</i> , 2022
Cucumber	GA ₃ (150 ppm)	Increased TSS	Dinesh <i>et al</i> , 2024
Garden Pea	Kinetin (200 ppm)	Higher protein content	Singh <i>et al</i> , 2018
Potato	NAA/PCP A (10-50 ppm)	Heat Tolerance	Swamy <i>et al</i> , 2021

Effect of plant growth regulators on stress tolerance

Vegetable crops are prone to a number of biotic and abiotic stresses, which significantly limit their growth and yield potential. Abiotic and biotic stresses affect in achieving optimal marketable yield, leading to substantial economic loss to the farmers. However, strategic and judicious use of PGRs can overcome this problem.

In Tomato cultivation, the application of Ethephon or Cycocel is found to induce frost tolerance and cold hardiness, allowing the plants

to withstand sub-optimal thermal conditions. In Potato, foliar applications of either PCPA or NAA have been found to improve tolerance to high temperatures. The use of Daminozide has proven effective reducing the incidence of common scab, thereby improving both the health and marketability of the tubers.

Future Prospect

In the coming time, the successful use of PGRs depends upon their integration with precision farming techniques. Although a significant progress has been made towards understanding the physiological roles of PGRs in vegetable production, there is a scope for refining their stage-specific applications. Standardisation of their optimal concentrations, time and method of application for different vegetable crops is essential to maximise benefits and avoid adverse effects.

Conclusion

Plant growth regulators have become highly significant in management and optimizing crop performance when applied judiciously. In the era of climate variability and intensive cultivation systems, PGRs offer a scientific approach to regulate plant growth and improve production efficiency. Furthermore, their strategic use holds potential for increasing the production of underutilized vegetable crops. However, the effectiveness of PGRs largely depends on factors such as crop species, growth stage, concentration, method of application and environmental conditions. Indiscriminate use may lead to adverse effects and economic losses; therefore, it is of utmost importance to standardise their application.

References:

1. Ahmed, I.H.M., Ali, E.F., Gad, A.A., Bardisi, A., El-Tahan, A.M., Esadek, O.A.A., El-Saadony, M.T., and Gendy, A.S. 2022. Impact of plant growth regulators spray on fruit quality and quantity of pepper (*Capsicum annum* L.) cultivars grown under plastic tunnels. *Saudi Journal of Biological Sciences* **29**(4):2291-2298. <https://doi.org/10.1016/j.sjbs.2021.11.062>
2. Agricultural and Processed Food Products Export Development Authority (APEDA). 2024. Fresh Fruits & Vegetables. <https://apeda.gov.in/FreshFruitsAndVegetables>
3. Dinesh, A., Parasanth, P., Lakshminarayana, D., Nagaraju, K., and Gouthami, P. 2024. Efficacy of plant growth regulators on quality and yield of Cucumber cv. Malini under shade net conditions. *Asian Journal of Soil Science and Plant Nutrition* **10**(3):121-125. <https://doi.org/10.9734/AJSSPN/2024/v10i3323>
4. Duhan, D.S., Singh, J., Panghal, V.P.S., and Raj, H. 2022. Influence of plant growth regulators on growth, flowering and fruit yield of bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. *Vegetable Science* **49**(1):69-74. <https://doi.org/10.61180/vegsci.2022.v49.i1.11>
5. Jasmin, B.L., Kumar, S., and Modi, S. 2018. Influence of plant growth regulators on growth and yield of greenhouse tomato (*Solanum lycopersicum* L.). *International Journal of Current Microbiology and Applied Sciences* **7**(8):1603-1609. <https://doi.org/10.20546/ijcmas.2018.708.183>
6. Mishra, S., Kumar, S., Wani, A.W., Mhaske, T., Hanmant, M.S., Saran, R., Magray, A.R., Zarina, and Gupta, A. 2024. Exploring Plant Growth Regulators (PGRs): Classification, Structural Features, and Functional Significance. *International Journal of Research in Agronomy* SP-7(4):315-325. <https://doi.org/10.33545/2618060X.2024.v7.i4Sd.645>
7. Morales, C.E., Lerma, T.A., Martínez, J.M., Palencia, M., and Combatt, E.M. 2021. Phytohormones and Plant Growth Regulators – A Review. *Journal of Science and Technological Applications* **4**(2):1-16. <https://doi.org/10.32463/jsta.2021.02.01>
8. Patel, T.V. 2008. Influence of PGRs on regulation of sex expression and their effect on growth, fruit yield and quality of

- Cucumber (*Cucumis sativus* L.) cv. Gujarat Cucumber-1. M.Sc.(Ag) thesis. Anand Agricultural University, Anand, Gujarat, India.
9. Rademacher, W. 2015. Plant Growth Regulators: Backgrounds and Uses in Plant Production. *Journal of Plant Growth Regulation* **34**(4):845–872. <https://doi.org/10.1007/s00344-015-9541-6>
 10. Singh, S., Fatmi, U., and Deepanshu. 2024. Effect of plant growth regulators on growth, yield and quality of tomato (*Lycopersicon esculentum* L.). *Asian Journal of Soil Science and Plant Nutrition* **10**(2):375-381. <https://doi.org/10.9734/AJSSPN/2024/v10i2295>
 11. Singh, S.K., Tomar, B.S., Anand, A., Kumari, S., and Prakash, K. 2018. Effect of growth regulators on growth, seed yield and quality attributes in garden pea (*Pisum sativum* var *Hortense*) cv. Pusa Pragati. *Indian Journal of Agricultural Sciences* **88**(11):1730-1734. <https://doi.org/10.56093/ijas.v88i11.84914>
 12. Swamy, G.N., Meghana, D., Kowsalya, K.B., Sudeshna, K., and Nair, K.A.K. 2021. History, mechanism and functions of plant growth regulators in vegetable crops. *The Pharma Innovation Journal* SP-**10**(7):556-567.
 13. Verma, S., Minz, R.R., Pankaj, P., Pandal, B., and Upadhyay, S. 2025. Effect of plant growth regulators on growth and yield attributes of Brinjal (*Solanum melongena* L.) cv. Pusa Purple Long Cluster under Chattisgarh plains. *International Journal of Advanced Biochemistry Research* SP-**9**(10):226-230. <https://doi.org/10.33545/26174693.2025.v9.i10Sc.5868>
 14. Wamiq, M., Kumar, D., Gangwar, V., Singh, N., Veersain., Gaur, M., and Prasad, V.M. 2022. Effect of plant growth regulators on yield contributing traits and quality attributes of Bottle gourd (*Lagenaria siceraria*) cv. MGH-4. *International Journal of Environment and Climate Change* **12**(11):2448-2453. <https://doi.org/10.9734/IJECC/2022/v12i1131239>
 15. Wang, J., Song, L., Gong, X., Xu, J., and Minhui Li. 2020. Functions of Jasmonic Acid in Plant Regulation and Response to Abiotic Stress. *International Journal of Molecular Sciences* **21**(4):1446. <https://doi.org/10.3390/ijms21041446>

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E-LIBRARY

Introduction and History

An e-library, i.e. an electronic library is a digital platform that provides access to books, journals, research papers, magazines, newspapers, theses, and multimedia resources in electronic format through the internet. It is a collection of digital resources that can be accessed electronically using computers, tablets, or smartphones without the need for physical presence in a traditional library.

The theory behind the first e-library was unclear until late 1980's. The beginning and expansion of e-libraries at this phase were driven by two main services. First was the electronic technology development, particularly in the multimedia and networking, obtaining more efficient and new ways in information processing and management. Second, societies required well share of vital information like library resources, scientific databases in academic and research. So, e-library schemes arose into actually. It allows flexible learning and distant education accessing online. History of e-library is the history of different type of information system and technologies that have been considered as 'digital libraries'. The progression of e-library cannot follow the single track.

It roots in 1980s with CD-ROMs and networking advancements. Expansion via internet and digitization projects in 1990s. In 2004, Google books project digitized billions of books.

Features

The key features of e-library includes :

1. 24X7 availability
2. Remote access
3. Quick search and retrieval
4. Large storage capacity
5. Multiple users can access the same resource simultaneously
6. User-friendly interface

Role of e-library

1. Support online education which is prevalent in the modern education.
2. Helps students access global resources easily and instantly.
3. Encourages independent learning without the frequent need of an advisor.
4. Improve research quality through various resources at one's fingertips.

Need of e-library in India

- e-library helps bridge gap between demand and availability of quality resources
- Large student and researcher population
- Limited physical library infrastructure
- Increasing demand for online education
- Cost-effective access to learning materials

Growth and scope

- Increased internet penetration
- Government digital initiatives
- COVID-19 speeded up online learning
- Availability of free digital resources

Advantages and Disadvantages

The advantages are :

- Saves time and space
- Cost-effective in the long run
- Supports learning and research
- Environment friendly
- Updated information available regularly

And the disadvantages are :

- Requires internet and electronic devices
- Eye strain due to long screen time
- Limited access for people without digital skills
- Copyright and licensing restrictions
- Technical issues like server failure

Major e-libraries initiatives in India

- NDLI(National Digital Library of India)** : It is a national digital repository of educational resources operated by the IIT Kharagpur. The library is sponsored by the Indian Ministry of Education.
- INFLIBNET(Information and Library Network Centre)** : It is an autonomous Inter University Centre(IUC) of the University Grants Commission(UGC) of India, established in 1991. It includes e-Shodhanga and Shodhaindhu is a premier digital repository of Indian electronic

theses and dissertations(ETDs, maintained by the INFLIBNET Centre under the UGC. It provides open access to thousands of Ph.D. theses, aiming to reduce research duplication, showcase Indian academic work and make scholarly content freely available globally.

- e- PG pathshala** : It is an Indian Government initiative providing high quality, curriculum based interacted e-content for PG students.
- CeRA(Consortium for e-Resources in agriculture)** : It is a premier e-consortium of agricultural libraries in India, established in 2007 under the Indian Council of Agricultural Research(ICAR).
- KrishiKosh** : It is Indian's national digital repository for agricultural knowledge, serving the Indian National Agricultural Research and Education System(NARES), providing access to theses, journals, books, and publications from ICAR institutes and State Agricultural Universities.
- SWAYAM(Study Webs of Active-learning for Young Aspiring Minds)** : It is a Government of India initiative offering free, high-quality online courses(MOOCs) from Class 9 to Post Graduation.

Challenges

e-library has some significant challenges that are yet to overcome.

- **High Initial Cost** : Setting up an electronic library requires expensive hardware, software, servers, digitization tools, and internet infrastructure.
- **Technological Obsolescence** : Rapid changes in technology make hardware, software, and file formats outdated quickly, requiring frequent upgrades.

- Lack of Technical Skills : Library staff and users may not have sufficient IT skills to effectively use or manage electronic resources. Not all users have access to computers, smartphones, or high speed internet, specially in the rural areas.
- Data Security and Privacy Risks : Electronic libraries face risks such hacking, data theft, malware attacks, and unauthorised access.
- Preservation of Digital Content : Long-term preservation of digital materials is difficult due to format changes, media degradation, and dependency on technology.
- User Resistance to Change : Some users prefer traditional print libraries and may resist shifting to electronic resources.
- Integration with Artificial Intelligence and smart search tools. There may be AI recommendations based on user's reading history and preferences.
- Inclusion of contents in more regional language to increase familiarity and inclusivity.
- Increased mobile-based access, by making it user-friendly and attractive with audio visual contents.

Conclusion

Therefore, we can conclude that the e-library is the future of learning in India. It is not the end of traditional library, but its evolution. More than a change in medium, it's a democratization of information. It is a vital tool for lifelong learners in an increasingly digital world. By removing barriers of time, effort and location, e-libraries ensure that quality resources are available to everyone, everywhere. With proper infrastructure and proper steps taken to mitigate the challenges, their impact will grow further.

Future of e-library in India

- Expansion of e-libraries to rural areas by bridging the internet connection gaps.

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ARTICLE ID: 35

Biochar for Sustainable Agriculture: Impacts on Soil Properties, Crop Productivity and Environmental Protection

Abstract

Biochar is a stable, carbon-rich material produced from biomass through pyrolysis under limited oxygen conditions and is increasingly recognized as a sustainable soil amendment. Its porous structure and large surface area enhance soil aggregation, improve water-holding capacity, and increase nutrient retention, thereby reducing nutrient leaching losses. Biochar also promotes beneficial microbial activity, which supports soil biological health and improves crop productivity. In addition to agronomic benefits, it contributes to environmental protection by immobilizing heavy metals, adsorbing pollutants, and facilitating long-term carbon sequestration for climate change mitigation. However, excessive or improper application may alter soil pH and nutrient balance. Therefore, optimized production methods and appropriate application rates are essential for sustainable agricultural systems.

INTRODUCTION

Biochar is made by heating crop residues or other organic materials at high temperature in a low-oxygen condition (a process called pyrolysis). This process converts biomass into a stable, carbon-rich material similar to charcoal. Biochar is important because it helps in reducing climate change and improving soil health. It stores carbon in a stable form for a long time, which lowers greenhouse gas emissions. Some studies suggest that biochar production may reduce global GHG emissions by around 12%.

Due to its stable structure, carbon remains locked in the soil for many years. When added to soil, biochar improves soil fertility. It increases water-holding capacity, improves nutrient retention, and supports beneficial soil microorganisms. It also reduces nutrient and pollutant leaching, helping to protect water quality. Biochar creates a better environment for plant growth and can reduce the need for chemical fertilizers.



Using agricultural waste to produce biochar is also a sustainable waste management method. Instead of burning or discarding crop residues, they can be converted into a useful soil amendment. Overall, biochar supports sustainable agriculture, reduces carbon emissions, and improves long-term soil productivity.

Origin of Biochar Production

The idea of biochar is very old. Thousands of years ago, ancient people used charcoal to improve soil fertility. One famous example is **Amazon Basin**, where indigenous communities created very fertile black soil known as **Terra Preta**. This soil contained charcoal, organic matter, and nutrients, which made it more productive than nearby soils. The presence of terra preta near old human settlements shows that people intentionally added charred materials to the soil to improve crop growth.

Although the practice is ancient, the term “biochar” is modern. Today, biochar is produced through a process called pyrolysis. In this method, organic materials such as crop residues are heated in the absence of oxygen, usually at 400–700°C. During heating, gases and bio-oil are released, and the solid carbon-rich material left behind is biochar. Biochar can be made using

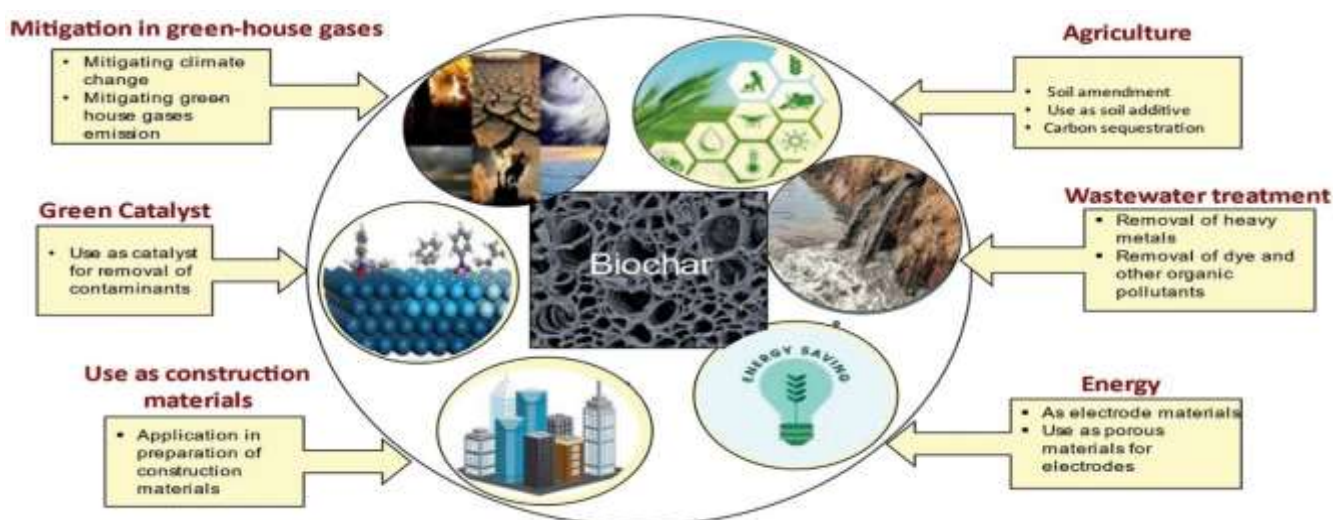
simple traditional methods like pit burning or modern pyrolysis reactors. The method chosen depends on the scale of production, type of raw material, and desired quality. In recent years, interest in biochar has increased because of its ability to store carbon and improve soil health. Researchers are working to improve production methods by studying temperature, heating time, and different raw materials to produce high-quality biochar for agricultural use.

Production of Biochar

Biochar can be produced using different thermochemical technologies such as pyrolysis, gasification, and carbonization. These methods mainly differ in temperature, heating rate, and oxygen supply.

1. Slow Pyrolysis: Slow pyrolysis is the most common method for producing biochar. In this process, biomass is heated slowly in the absence of oxygen. It produces a higher amount of biochar compared to other methods and helps save up to 50% of the carbon from the raw material. It is widely used for making charcoal, activated carbon, methanol, syngas, and other useful products.

2. Intermediate Pyrolysis: In intermediate pyrolysis, biomass is heated at a moderate rate with little or no oxygen. This method produces both biochar and bio-oil in balanced amounts.



The final products depend on factors like temperature, heating speed, and residence time. It is suitable when both biochar and bio-oil are required.

3. **Fast Pyrolysis:** Fast pyrolysis occurs very quickly, often within seconds. It mainly aims to produce bio-oil, but it also generates some biochar and gases. Proper control of temperature, heating rate, and gas flow is important in this process.
4. **Gasification:** Gasification takes place at high temperatures (above 700°C) with a controlled amount of oxygen. It mainly produces syngas, which contains carbon monoxide (CO), hydrogen (H₂), and small amounts of methane (CH₄). This gas can be used for energy production or in fuel cells. A small amount of biochar is also formed as a by-product.
5. **Carbonization:** Carbonization is a traditional method similar to charcoal making. Biomass is heated at temperatures between 280°C and 500°C, converting it into carbon-rich material along with some gases. Biochar in Environmental Sustainability

Biochar provides many environmental benefits and supports sustainable development. Its main advantages are explained below in simple words.

Applications of Biochar

Soil

Amendment

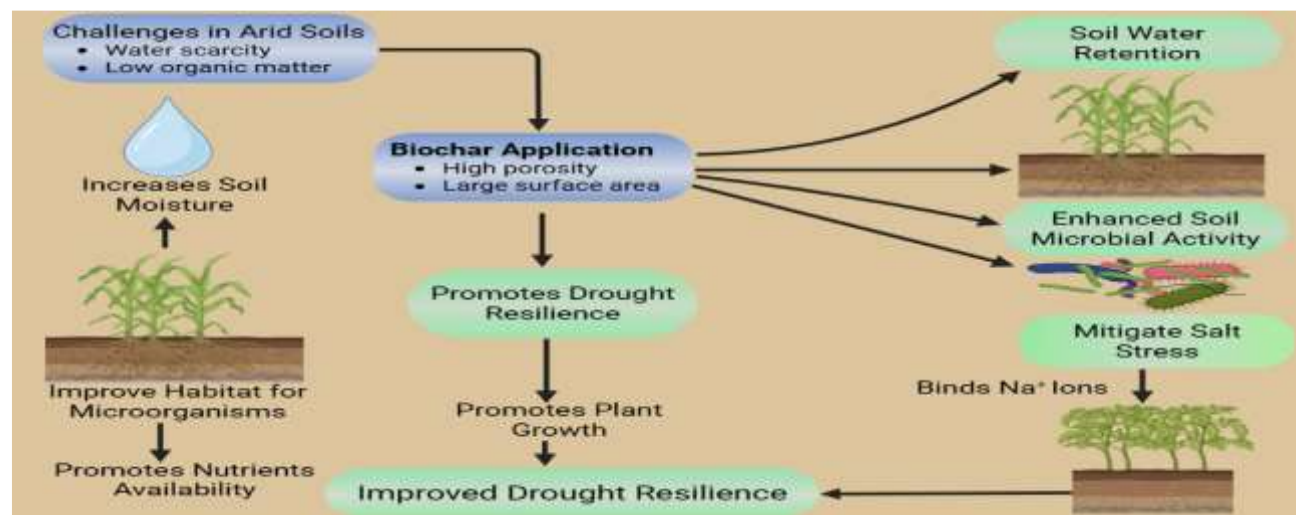
Biochar improves soil physicochemical and biological properties. It enhances cation exchange capacity (CEC), increases soil porosity, and improves aggregate stability. These changes promote better root growth, aeration, and nutrient availability. Biochar also stimulates beneficial microbial communities and increases soil organic carbon, leading to improved crop productivity.

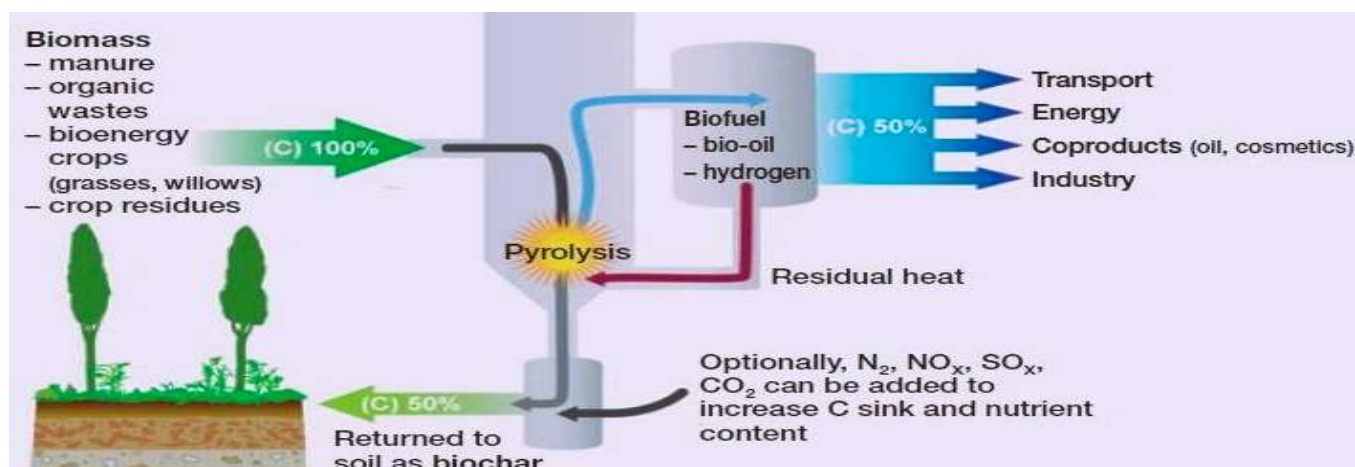
2. **Carbon Sequestration:** Biochar contains stable aromatic carbon structures that resist microbial decomposition. This recalcitrant carbon can remain in soil for hundreds to thousands of years. Therefore, biochar acts as a long-term carbon sink and contributes to greenhouse gas mitigation by reducing CO₂ emissions from biomass decomposition.

5. **Environmental Remediation:** Biochar has strong adsorption capacity for heavy metals (e.g., Cd, Pb, Zn) and organic pollutants (e.g., pesticides, hydrocarbons). It immobilizes contaminants by surface adsorption, ion exchange, and complexation, reducing their bioavailability and toxicity in soil and water systems.

Sustainable Land Use and Ecosystem Services:

Biochar application enhances soil resilience, increases biodiversity of soil microorganisms, and improves ecosystem stability. Its long-term carbon storage capacity and ability to restore





degraded lands make it a promising tool for sustainable land management and climate-smart agriculture.

Biochar is made by heating organic materials in low oxygen (pyrolysis). Common feedstocks include:

- **Agricultural waste** – rice husk, wheat straw, corn stalks
- **Wood materials** – hardwood, sawdust, bamboo
- **Animal manure** – chicken litter, cow dung
- **Urban organic waste** – food and garden waste
- **Industrial residues** – paper sludge, biosolids
- **Agroforestry waste** – coconut and nut shells

Production(pyrolysis) Biochar yield and quality mainly depend on two things: the type of raw material (feedstock) used and the processing conditions during production. These factors decide how effective biochar will be for improving soil health, soil remediation, and crop productivity.

Biochar is made when organic materials such as crop waste or biomass are heated in an environment with very little or no oxygen. This heating process changes the material into a stable, carbon-rich product called biochar. There are several thermal methods used to produce biochar, including pyrolysis, hydrothermal carbonization, gasification, flash carbonization, and torrefaction. Among these methods, pyrolysis is the most

commonly used because it is cost-effective, efficient, and easy to control.

During pyrolysis, biomass does not only produce biochar. It also releases bio-oil, which can be used as an energy source, and gaseous by-products such as carbon monoxide (CO), carbon dioxide (CO₂), hydrogen (H₂), methane (CH₄), water vapor, and other volatile compounds. The final properties and yield of biochar depend strongly on pyrolysis conditions, especially the temperature, pressure, heating time, size of the biomass particles, and the time the material stays inside the kiln or furnace. Changes in these conditions can significantly alter biochar structure, carbon content, and surface properties.

Methodology

Biochar enhances soil carbon storage through multiple linked processes. Its stable, aromatic carbon structure resists decomposition, allowing carbon to remain in the soil for a long time. Biochar can bind with easily degradable organic compounds, reducing their availability to microbes and slowing their breakdown. It also influences soil microbial communities by promoting slow-growing (K-strategist) microbes and reducing rapid decomposition activity, creating a negative priming effect. Additionally, biochar improves soil properties such as aggregation, water retention, and nutrient-holding capacity. Its charged surface interacts

with organic matter and soil minerals, further stabilizing carbon and protecting it from mineralization.

Challenges in Biochar Use: Biochar production requires controlled pyrolysis, and variations in feedstock can affect its quality and field performance. In some cases, biochar may be lost by wind or disturb soil structure. Heavy metal contamination is another concern, especially when produced from sewage sludge or polluted materials. Metals such as cadmium, lead, zinc, chromium, and copper can remain in biochar and pose environmental risks. Proper feedstock selection and correct application rates are essential.

Advanced Developments in Biochar: To address these challenges, modified biochar materials such as MOF-based biochar composites are being developed. These advanced materials have high porosity, improve nutrient release, capture heavy metals, and enhance long-term carbon storage. However, more long-term field research is needed to ensure their safety and large-scale applicability

Conclusion

Biochar is a sustainable soil amendment produced from organic wastes that supports environmental protection and resource recycling. It plays an important role in carbon sequestration by storing stable carbon in the soil, which helps reduce greenhouse gas emissions and mitigate climate change. In addition, biochar improves soil structure, enhances water and nutrient retention, and supports beneficial soil microorganisms. It can also reduce environmental pollution by immobilizing heavy metals and decreasing nutrient losses. When produced and applied properly, biochar contributes to soil restoration, sustainable agriculture, and long-term environmental conservation.

References

- Bai, X., Zhang, H., Wang, J., & Liu, Y. (2024). Biochar influences on soil microbial community structure and carbon cycling processes: A review. *Soil Biology and Biochemistry*, 186, 109123.
- Jeffery, S., Verheijen, F. G. A., van der Velde, M., & Bastos, A. C. (2011). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, Ecosystems & Environment*, 144(1), 175–187.
- Jeffery, S., Abalos, D., Prodana, M., Bastos, A. C., van Groenigen, J. W., Hungate, B. A., & Verheijen, F. (2017). Biochar boosts tropical but not temperate crop yields. *Environmental Research Letters*, 12(5), 053001.
- Lehmann, J., & Joseph, S. (Eds.). (2015). *Biochar for environmental management: Science, technology and implementation* (2nd ed.). Routledge.
- Lehmann, J., & Rondon, M. (2006). Bio-char soil management on highly weathered soils in the humid tropics. In N. Uphoff et al. (Eds.), *Biological approaches to sustainable soil systems* (pp. 517–530). CRC Press.
- Niu, Y., Chen, L., Zhao, X., & Li, Q. (2024). Biochar-mediated enhancement of soil carbon sequestration in urban and agricultural ecosystems. *Journal of Environmental Management*, 350, 119563.
- Wang, J., Xiong, Z., & Kuzyakov, Y. (2016). Biochar stability in soil: Meta-analysis of decomposition and priming effects. *Global Change Biology Bioenergy*, 8(3), 512–523.
- Wang, S., Gao, B., Li, Y., Zimmerman, A. R., Cao, X., & Harris, W. (2019). Impact of biochar on soil properties and crop yield: A global meta-analysis. *Geoderma*, 353, 191–202.
- Weng, Z., Van Zwieten, L., Singh, B. P., Tavakkoli, E., Joseph, S., & Macdonald, L. M. (2022). Interactions between biochar and soil organic matter and their role in carbon stabilization. *Science of the Total Environment*, 806, 150–160.
- Yang, H., Luo, Y., Li, D., & Wu, J. (2024). Biochar regulates soil microbial functional groups and improves carbon persistence under agricultural systems. *Applied Soil Ecology*, 195, 104786.

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ARTICLE ID: 36**Soil Erosion Dynamics and Integrated Management Strategies for
Sustainable Agriculture in India**

Soil is a dynamic complex of minerals and organic matter that serves as the fundamental base for life on Earth. While soil formation is an extremely slow process, soil erosion—the detachment and transportation of soil particles by geomorphic agents—is occurring at an accelerated pace due to increased anthropogenic interferences. This review explores the multifaceted causes, types, and extent of soil erosion in India, alongside the severe socio-economic and environmental consequences. It highlights the primary drivers, including intense rainfall, deforestation, overgrazing, and faulty agricultural practices like shifting cultivation. Utilizing the Universal Soil Loss Equation (USLE) framework, this paper examines how rainfall erosivity, soil erodibility, and topography interact to determine erosion rates. Furthermore, the article details integrated management strategies, categorizing them into mechanical, agronomical, and structural interventions such as contour bunding, terracing, and agroforestry. Achieving sustainable development in the face of climate change necessitates a shift toward watershed management and the adoption of conservation-oriented land use practices to preserve the nation's fertile productive base.

Keywords: Soil Erosion, USLE, Conservation, Watershed Management, Sustainable Agriculture, India.

1. Introduction

Soil is far more than a simple substrate for plant growth; it is a living, dynamic natural body composed of minerals, organic materials, and diverse life forms. It functions as a critical reservoir of water and minerals essential for plant development and provides habitat for countless organisms. In India, soil is arguably the most significant resource, serving as the fundamental base for life and the primary driver of agricultural productivity. However, the delicate equilibrium between soil formation and soil loss has been severely disrupted by human activity. While the natural formation of soil is an incredibly slow process—taking thousands or even millions of years to regenerate a lost layer—accelerated erosion can deplete this fertile productive base in a matter of decades.

Soil erosion is defined as a three-step process involving the detachment of soil particles from the main soil mass, their transportation by agents such as water or wind, and their eventual deposition elsewhere. Globally, human-induced soil degradation affects approximately 2 billion hectares, with water erosion alone accounting for 1,100 million hectares.

In India, water is the primary agent, responsible for nearly 90% of the soil loss, occurring in progressive stages from splash and sheet erosion to the formation of destructive rills and gullies. The problem is widespread across India, manifesting in forest lands, agricultural fields, and arid regions, threatening both food security and the national economy. Soil erosion results in a qualitative loss of the productive topsoil, leading to nutrient depletion and a drastic fall in agricultural yields. To mitigate what has been called the "greatest single evil" to Indian agriculture, comprehensive conservation measures and a shift toward sustainable watershed management are required. Strategies include mechanical interventions like contour bunding and terracing, alongside agronomical practices such as mulching, cover cropping, and agroforestry to protect the soil's structural integrity.

2. Conceptualizing Soil Erosion: Types and Agents

Erosion can be broadly categorized based on its origin and the agents involved.

2.1 Geological vs. Accelerated Erosion

Geological Erosion: Also known as natural erosion, it occurs when the land is in natural equilibrium under vegetative cover. Here, the rate of soil loss is compensated by the formation of new soil through natural weathering.

Accelerated Erosion: This occurs when human or animal interference, such as deforestation or faulty tillage, destroys the natural balance, leading to soil loss that far exceeds the rate of formation.

2.2 Water Erosion Dynamics

Water is the dominant agent of erosion in India, responsible for nearly 90% of soil loss. It manifests in several progressive stages:

Splash Erosion: The initial stage where falling raindrops strike unprotected soil, breaking down aggregates and displacing particles up to 1.5 meters vertically.

Sheet Erosion: The uniform removal of thin layers of topsoil across a large area. It is often "subtle" and can go unnoticed until a significant decline in crop yields occurs.

Rill and Gully Erosion: As water flow

concentrates, it forms finger-shaped grooves (rills) which, if left unchecked, deepen and enlarge into gullies. Gullies deeper than 30 cm cannot be obliterated by normal tillage and can turn entire landscapes into unproductive "badlands".

Special Forms: These include littoral erosion along coasts (most intense in Kerala) and glacial erosion in high-altitude Himalayan regions.

2.3 Wind Erosion

Active primarily in the arid and semi-arid regions of Rajasthan, Gujarat, and Haryana, wind erosion occurs through deflation and attrition. The process involves three distinct movements:

Suspension: Very fine dust particles (less than 0.1 mm) lifted high into the atmosphere and transported over long distances.

Saltation: Particles (0.1 to 0.5 mm) moving in short bounces, accounting for 50-75% of total wind-driven soil movement.

Surface Creep: Coarse particles (0.5 to 1.0 mm) that roll or slide along the surface.

3. Factors Influencing Erosion: The USLE Framework

The rate of soil erosion is a function of complex interactions between climate, soil, and management. To predict long-term average annual soil loss (\$E\$), the Universal Soil Loss Equation (USLE) is employed:

$$E = R \times K \times L \times S \times C \times P$$

3.1 Rainfall Erosivity (R)

Erosion is closely linked to rainfall intensity and kinetic energy rather than just total volume. High striking velocities (up to 9m/sec) generate the hydro-dynamic force needed to detach soil. In India, the R-factor varies significantly, from 120 at Bhuj (Gujarat) to 1457 at Mangalore.

3.2 Soil Erodibility (K)

This factor represents the inherent susceptibility of soil to detachment. It is influenced by texture, structure, and organic matter content. For instance, sandy soils are highly prone to wind erosion, while red, laterite, and black soils in India are particularly vulnerable to water erosion.

3.3 Topography (LS) and Surface Cover (C)

Steeper and longer slopes increase the velocity and erosive power of runoff. Conversely, a good

canopy or mulch cover (C factor) significantly reduces erosion by intercepting raindrops and retarding surface flow.

4. Major Causes of Accelerated Erosion in India

While erosion is a natural process, human activities have accelerated it to a "threatening" level.

Deforestation: Trees protect soil by binding it with roots and adding organic moisture. Their removal leads to increased floods and severe gully erosion, as seen in the Siwalik foothills.

Overgrazing: Continuous grazing by livestock removes vegetative cover and pulverizes the soil with hooves, making it easily washable during rains. This is common in the hilly areas of Madhya Pradesh and Himachal Pradesh.

Faulty Agricultural Practices: Ploughing along the slope instead of the contour creates ready-made channels for water flow, increasing runoff velocity.

Shifting Cultivation (Jhoom): Practiced extensively in North-Eastern states, this "slash and burn" method leaves steep slopes bare and exposed to heavy rainfall, leading to sterile soils and massive erosion.

Developmental Factors: Rapid urbanization, road construction in fragile mountain ecosystems, and unscientific mining further exacerbate soil instability.

5. Extent and Consequences of Soil Erosion in India

Research suggests that India loses approximately 5334 million tonnes of soil annually.

5.1 Regional Extent

The National Bureau of Soil Survey & Land Use Planning (2005) reported that 119.2 million hectares of land in India suffer from erosion.

Very Severe Erosion: Areas like the Shiwalik hills experience erosion rates exceeding 80 tonnes/ha/yr.

Regional Hotspots: Significant issues are noted in the Himalayas (steep slopes/heavy rain), Western Ghats (deforestation), and the arid regions of Rajasthan (wind).

5.2 Socio-Economic Impacts

On-Site Effects: Loss of topsoil leads to nutrient depletion (estimated loss of 74 million tonnes of major nutrients per year) and a subsequent 5% to 50% fall in agricultural productivity.

Off-Site Effects: Siltation in reservoirs reduces their water-holding capacity and lifespan. For example, the Mayurakshi reservoir's siltation rate is nearly six times the pre-project estimate. Furthermore, erosion increases the frequency of landslides and floods in river basins like the Ganga and Brahmaputra.

Soil Erosion in Maharashtra: A Regional Perspective

Maharashtra faces significant soil erosion issues due to a combination of topography, climate, and land-use changes.

Regional Context: Areas in Maharashtra face erosion due to improper land management, deforestation, and unsustainable agricultural practices.

Vulnerability of Black Soils: Maharashtra is characterized by extensive areas of black soils, which are relatively more prone to erosion. Sheet erosion is notably serious in these black soil regions, occupying millions of hectares.

Hilly Terrain Impact: Erosion due to overgrazing is very common over the hilly areas of the state. The Western Ghats region, in particular, experiences accelerated erosion due to heavy rainfall and land-use changes.

Nutrient Loss: Soil erosion in the state contributes to the significant national loss of major nutrients, which is estimated at 74 million tonnes per year for the country.

6. Integrated Management and Conservation Strategies

6.1. Mechanical (Engineering) Measures

Mechanical measures involve physical changes to the land surface to manage runoff and are primarily used on **sloping lands** where agronomical measures alone are insufficient.

Contour Bunding

- **When to Apply:** Best suited for low-rainfall areas on slopes where the primary goal is to retain runoff and allow it to infiltrate the soil.

- **How to Apply:** Construct earthen barriers (bunds) across the slope along contour lines. Over time, the area between bunds levels out to form a riser.
- **Maintenance:** Risers should be planted with grasses to stabilize the structure and prevent their own erosion.

Graded Bunding

- **When to Apply:** Recommended for areas with **heavy rainfall** (exceeding \$800~mm\$ annually) and on clayey or black soils with poor drainage. They are effective on slopes up to 10% but work best under 4%.
- **How to Apply:** Construct bunds with a slight longitudinal grade (slope) across the main hill slope.
- **Function:** Unlike contour bunds, these are designed for the **safe disposal** of excess runoff rather than just retention, reducing the water's velocity to minimize damage.

Bench Terracing

- **When to Apply:** Essential for **hilly terrain** where agricultural crops are grown on slopes steeper than 15 degrees.
- **How to Apply:** Excavate the slope to create a series of flat platforms or "steps". The width of the bench depends on the steepness of the slope, and risers should generally not exceed one meter in height.
- **Types:** Depending on rainfall, they can be level (table-top), inward sloping (to collect water), or outward sloping (to drain water).

Gully Control Structures

- **When to Apply:** Applied when erosion has advanced to the gully stage, which cannot be fixed by normal plowing.
- **How to Apply:**

- **Loose Boulder Check Dams:** Used in gullies with lower runoff volumes to trap silt and stabilize the bed.
- **Permanent Structures:** Masonry or concrete dams built at gully heads to control overfalls and prevent the gully from extending further.

6.2. Agronomical Measures

These practices focus on using **vegetation and tillage techniques** to protect the soil surface and are often the most cost-effective methods for agricultural lands.

Contour Tillage and Cultivation

- **When to Apply:** Applicable to almost any sloped agricultural field.
- **How to Apply:** Perform all farming operations—ploughing, sowing, and tilling—**across the slope** along contour lines rather than up and down the hill.
- **Function:** The ridges and furrows created act as mini-dams that retard runoff velocity and increase water infiltration.

Strip Cropping

- **When to Apply:** Useful on rolling topography to break the momentum of wind or water.
- **How to Apply:** Grow crops in strips parallel to one another. Alternate "erosion-permitting" crops (like maize or cotton) with "erosion-resistant" legumes or grasses (like cowpea or soybean).
- **Benefit:** Because strips are harvested at different times, the entire field is never bare or exposed at once.

Mulching and Cover Crops

- **When to Apply:** During fallow periods or between widely spaced crops to protect the soil from "splash erosion".
- **How to Apply:**
- **Mulching** spread a layer of organic material like straw, grass, or crop residues over the soil surface.

1. **Cover Crops:** Plant fast-growing species like legumes to act as "living mulch".
 - **Function:** These act as a cushion against raindrop impact, reduce evaporation, and add organic matter to the soil.

6.3. Natural and Biological Practices

Agroforestry

- **When to Apply:** Recommended for steep slopes or integrated farming systems to provide multi-year protection.
- **How to Apply:** Integrate trees or shrubs with traditional agricultural crops.
- **Benefit:** The tree canopy intercepts rain, while deep root systems bind the soil together more effectively than seasonal crops.

Grassed Waterways

- **When to Apply:** Used to manage concentrated runoff on natural drainage lines within a watershed.
- **How to Apply:** Plant hardy, soil-binding grasses along the routes where water naturally flows down a slope.
- **Benefit:** The grass moderates the flow and prevents the formation of rills and gullies by reducing the erosive velocity of the water.

6.4 Watershed and Policy Interventions

India has shifted toward a watershed management approach to synchronize soil and water conservation. Programs such as the Drought Prone Area Programme (DPAP) and the National Watershed Development Programme for Rainfed Areas (NWDPRAS) focus on sustainable resource utilization.

7. Conclusion

Soil erosion in India is a complex interplay of physical hydrology and anthropogenic pressures. While it is a geomorphic reality, its acceleration through reckless deforestation and unsustainable farming poses a grave threat to the nation's future. To achieve the goal of sustainable development, soil conservation must be treated as a prerequisite.

This requires not only engineering interventions but also a grassroots shift in land management practices, including a total ban on unscientific shifting cultivation and the widespread adoption of agroforestry and minimum tillage. Only by protecting our most precious asset—the soil—can we ensure long-term food security and environmental stability for future generations.

References

- Ahmad, N. S. B. N., Mustafa, F. B., & Didams, G. (2020). A systematic review of soil erosion control practices on the agricultural land in Asia. *International Soil and Water Conservation Research*, 8(2), 103-115.
- Ahirwal, A., Sharma, P., Sharma, A., & Singh, V. (2023). Soil Erosion – A Threatening for Agriculture. *Agrospheres: e-Newsletter*, 4(11), 58-60.
- Balasubramanian, A. (2017). Soil erosion-causes and effects. University of Mysore.
- Bansil, P. C. (1990). *Agricultural Statistical Compendium*. Techno-economic Research Institute.
- Bonthagorla, U., Reddy, T. S. K., Akash, S., Srikanth, H., & Ahmed, M. (2022). Effects of soil erosion and control: a review. *The Pharma Innovation Journal*, 11(6), 2925-2933.
- Dhir, R. P. (1989). Wind erosion in relation to land use and management in Indian Arid Zone. *International Symposium "Managing Sandy Soils"*, Jodhpur.
- Fernández-Raga, M., Palencia, C., Keesstra, S., Jordán, A., Fraile, R., Angulo-Martínez, M., & Cerdà, A. (2017). Splash erosion: A review with unanswered questions. *Earth-Science Reviews*, 171, 463-477.
- Kuldeep, Sahdev, Tomeshwar, Choubey, S., Induria, S. K., Sahu, K., Tandan, A., & Shriwas, D. (2023). A Review on Soil Erosion: Causes, Prevention, and Control. In *Rising to the Challenge: Sustainable Development in the Face of Climate*

Change (pp. 62-75).

- Maitra, S., & Pramanick, B. (2020). Causes and Effect of Soil Erosion and its Preventive Measures. In *Advances in Agriculture* (pp. 376-387). New Delhi Publishers.
- Narayana, V. V. D., & Ram Babu. (1983). Estimation of soil erosion in India. *Journal of Irrigation and Drainage Engineering*, 109(4), 419-434.
- Sahu, A. K., Kumar, A., Singh, V., & Singh, Y. (2023). Soil Erosion Control Techniques. In *Guardians of the Earth* (pp. 52-76).
- Saroha, J. (2017). Soil Erosion: Causes, Extent and Management in India. *International Journal of Creative Research Thoughts (IJCRT)*, 5(4), 1321-1330.
- Sehgal, J., & Abrol, I. P. (1994). *Soil degradation in India: status and impact*. Oxford and IBH.
- Singh, G., Ram Babu, Narain, P., Bhusan, L. S., & Abrol, I. P. (1990). Soil erosion rates in India. *Journal of Soil and Water Conservation*, 47(1), 97-99.
- Wischmeier, W. H., & Smith, D. D. (1978). *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning*. U.S. Department of Agriculture.

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POULTRY MANURE MANAGEMENT

INTRODUCTION

The poultry industry is one of the largest and fastest growing livestock production systems in the world. In India, there are about 851 million population of poultry with a waste generation of >3.30 million tons per year. The localized nature of poultry production also means that it can represent a significant percentage of the agricultural economy in many states or regions. Although economical and successful, the poultry industry is facing many highly complex and challenging environmental problems, many of which are related to its size and geographically concentrated nature. From an agricultural perspective, poultry wastes play a significant role in the contamination of ground water through nitrogen. Also, the eutrophication of surface water due to phosphorus, pesticides, heavy metals, and pathogens present in the poultry wastes applied to soils are the central environmental issues at the present time.

Composition of litter

Among animal manures, poultry droppings have higher nutrient contents. It has nitrogen (4.55 to 5.46 %), phosphorus (2.46 to 2.82 %), potassium (2.02 to 2.32 %), calcium (4.52 to 8.15 %), magnesium (0.52 to 0.73 %), and appreciable quantities of micronutrients like Cu, Zn, Fe, Mn etc. In addition to this cellulose (2.26 to 3.62%), hemicellulose (1.89 to 2.77 %) and lignin (1.07 to 2.16 %) are also present in poultry waste. These components upon microbial action can be converted to value added compost with high nutrient status.



In poultry droppings, 60% of nitrogen which is present as uric acid and urea is lost through ammonia volatilization by hydrolysis. This loss of nitrogen reduces the agronomic value of the product, and it is also causing atmospheric pollution.

Reduction of pH and Soluble Salts in Poultry Manure

Poultry manure is a powerhouse of nutrients, but its high alkalinity (pH) and salt content (electrical conductivity) can be "too much of a good thing" for most soils and crops. Managing these two factors is essential to prevent root burn and soil degradation.

Background

- Fresh poultry manure pH: 7.5–8.5 (sometimes higher)
- High soluble salts due to:
 - Uric acid
 - Ammonium compounds
 - Sodium & potassium salts
 - Undigested feed minerals
- Problems:
 - Soil salinity buildup
 - Ammonia volatilization
 - Crop root damage
 - Odor issues

Reducing pH (Acidification)

High pH in poultry manure (often 7.5 to 8.5) leads to ammonia loss and nutrient Tie-up. Lowering the pH stabilizes nitrogen and makes the manure more "plant friendly."

- **Aluminum Sulfate (Alum):** This is the industry standard. Adding alum to litter creates a chemical reaction that produces sulfuric acid, which neutralizes alkalinity. It also binds phosphorus, reducing environmental runoff.



ALUM

- **Elemental Sulfur:** When added to manure, Thiobacillus bacteria convert sulfur into sulfuric acid (H_2SO_4). This is a slower, biological process but highly effective for long-term pH reduction.
- **Ferrous Sulfate:** Like alum, it lowers pH and helps in odor control, though it is used less frequently than alum due to cost.
- **Organic Acids:** Adding citric or acetic acid can provide a temporary pH drop, though these are often less stable than mineral additives.

Reducing Salt Content (Salinity)

Salts in poultry manure primarily come from the birds' diet (sodium and potassium). High salinity can interfere with a plant's ability to take up water.

- **Composting with High-Carbon Bulking Agents:** Dilution is the best solution here. Mixing manure with straw, wood chips, or sawdust increases the total volume and "spreads" the salt concentration, making it less toxic per square inch of soil.
- **Leaching (Controlled):** If manure is kept in a controlled environment, light irrigation can wash soluble salts out. **Caution:** This must be done on a concrete pad with a collection system to prevent groundwater contamination (leachate is high in nitrates).
- **Gypsum ($CaSO_4 \cdot 2H_2O$) Application:** While gypsum is salt, the calcium displaces sodium on soil particles. This improves soil structure and allows sodium

salts to leach away more easily when it rains.

A. Gypsum Treatment (For Salt Reduction)

Dose: 5–10 kg gypsum per 100 kg poultry manure

Mechanism:

- Calcium replaces sodium.
- Reduces exchangeable sodium percentage (ESP).
- Lowers salt toxicity.
- Helps reduce ammonia volatilization.

B. Acidification Method (Controlled Use)

Use only under supervision.

Options:

- Alum (Aluminum sulfate)
- Phosphoric acid (diluted)
- Ferrous sulfate

Example: Alum @ 50–100 g per kg manure (mix thoroughly)

Effect:

- Reduces pH to 6–7
- Controls ammonia release
- Reduces odor



C Composting

Composting is a simple and natural process. Composted poultry litter has an extremely low odor. It is a more stable and consistent material than fresh litter. Composting poultry waste is an environment friendly method and can be an important way to protect our ground and surface waters from the excessive loading of litter nutrients. Poultry litter undergoes. Composting

with amendment seems promising in conservation of nitrogen in poultry droppings. Nitrogen in poultry waste can be conserved by composting with suitable organic amendments. The technologies developed will be useful to poultry farmers.

Technology for composting of poultry wastes

Preparation of poultry waste compost using paddy straw

A known quantity of fresh poultry droppings is to be collected and mixed thoroughly with chopped paddy straw (< 2 cm size) @ 1:1.25 ratio to attain a C/N ratio of 25 to 30 which is optimum for composting. Microbial inoculum is inoculated @1250g per ton of substrate. The poultry waste and paddy straw mix should be heaped under shade. The moisture content of the heap should be maintained at 50 to 60%. Periodical watering should be done once in 15 days and turning should be given on the 21st, 35th and 42nd day of composting (avoid turning during the first 3 weeks of composting). Within a period of 50 days, materials are converted to matured compost with the following nutrient contents;

N:	1.89%
P:	1.83%
K:	1.34%
C/N:	12.20%

Method of composting poultry waste with coir pith

A known quantity of the poultry waste as collected above along with coir pith is inoculated with Microbial inoculum @ 500g per ton of waste to speed up the composting process. This mixer should be placed under shade as heap. The moisture content of the heap should be maintained at 50 to 60%. Periodical turning must be given on 25, 28 and 35 days of composting. Another 500 g of microbial inoculum is to be added during turning given on the 28th day of composting.

Superior quality compost will be attained after 45th day of composting. The nutrient contents of the composts of poultry litter collected from caged system and deep litter systems are as below;

Nutrient	Caged system manure	Deep litter system manure
Nitrogen (%)	2.08	2.13
Phosphorous (%)	2.61	2.40
Potassium (%)	2.94	2.03
C:N ratio	13:1	14:1

Points to be remembered

- Elevated shady places are highly suitable.
- Within a period of 10 to 15 days, the temperature of the heap will rise to a maximum. If the temperature drops below 50 °C, the heaps should be spread and moistened with water to bring the moisture content to 60%.
- The color of the compost will turn from brown to black.
- The matured compost will be odorless.
- The volume of the compost heap will be reduced to 1/3.
- The temperature of the heap will be the same as the ambient air temperature and stable.
- Matured compost will be light and fine textured.
- Moisture content of the heap can be measured using a moisture meter or by taking a handful of compost from the heap and squeezing it with the fingers. If excess water drips out from the compost, then it is considered to have >60% moisture. If a small quantity of water oozes out as drops, then moisture content is optimum, i.e., at 60%.
- Each compost heap should have a minimum of one ton to retain the heat for post decomposition.

Scientific Effect:

- Carbon binds ammonium.
- Microbial activity reduces pH toward neutrality.
- Leaching of soluble salts during composting.
- Final pH: **6.8–7.2**
- EC reduced significantly.

Applications

This technology is widely suitable and applied to poultry farmers to utilize solid waste in an effective manner. The poultry waste compost will be an incredibly good organic manure @ 6 ton / ha for all the crops.

Vermicomposting (Highly Recommended)



Use species like:

- *Eisenia fetida*

Procedure:

1. Pre-compost poultry manure for 15 days.
2. Mix with cow dung (1:1).
3. Introduce earthworms.
4. Maintain moisture at 60%.
5. Harvest after 45–60 days.

Results:

- pH stabilizes around neutral.
- EC reduces.
- Nutrient-rich compost is produced.

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GENERALIZED SYSTEMS IN INSECTS

GENERALIZED SYSTEMS IN INSECTS ARE

1. Digestive system
2. Nervous system
3. Circulatory system
4. Excretory system

DIGESTIVE SYSTEM OF INSECTS.

Digestive system of insect is divided in three parts

1. Foregut (Fore intestine or stomodaeum)
2. Midgut (mesenteron or stomach or ventriculus)
3. Hindgut (hind Intestine or proctodaeum)

1. Foregut: (Fore intestine or stomodaeum)

- **Mouth** - The intake of food takes place through mouth
- **Pharynx** - is a region between the mouth and the oesophagus and concerned with the ingestion and passage of food
- **Oesophagus** - it is a simple straight tube serving as a connection between pharynx and crop.
- **Crop** - crop is a storage organ and functions as a food reservoir.
- **Gizzard** - is situated behind the crop and is best developed in grasshoppers. The dominant feature in its structure is the great development of the cuticular lining into prominent denticles.

Function of Foregut:

To begin the breakdown of food, storage of food and transport to the next region.

Cardiac valve - Foregut opens into midgut through cardiac valve and its function is to regulate the food flow.

2. Midgut (mesenteron or stomach or ventriculus)

- Midgut is endodermal in origin and contains no cuticular lining.
- Midgut is made up of three types of epithelial cells secretory cells (Columnar cells), Goblet cells (aged secretory cells) and Regenerative cells which replaces secretory cells.

(i) **Gastric caecae:** (Enteric caecae or Hepatic caecae) Finger like outgrowths found in anterior or posterior ends of midgut. This structure increases the functional area of midgut and shelter symbiotic bacteria in some insects.

(ii) **Peritrophic membrane** - It is the internal lining of midgut, secreted by anterior or entire layer of midgut epithelial cells. Present in solid feeders and absent in sap feeders. This layer is semipermeable in nature to digestive juices and digestion products. Its functions are

- (a) Lubricate and facilitate food movement
- (b) Envelops the food and protects the midgut epithelial cells against harder food particles

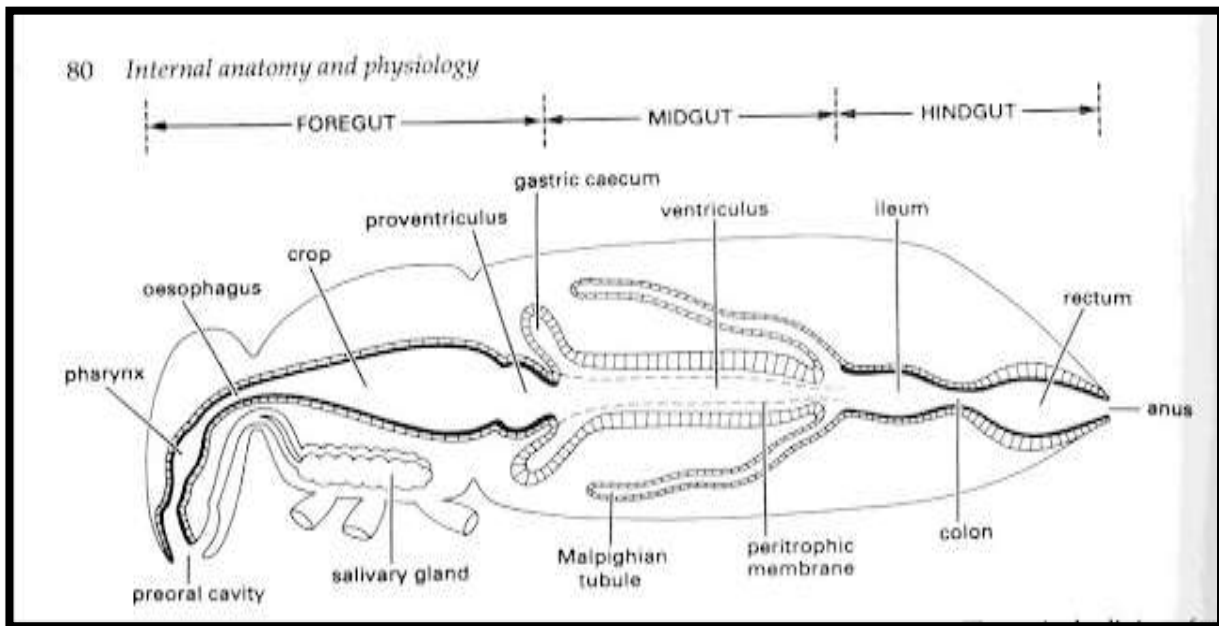


FIG. INSECT DIGESTIVE SYSTEM

Functions of Midgut: The cells of midgut are actively involved in enzyme production, secretion as well as absorption of nutrients

Pyloric valve: Midgut opens into hindgut through pyloric valve which regulate food flow.

3. Hindgut (Hind Intestine or proctodaeum)

- Anterior end of the hindgut can be marked by the presence of a set of Malpighian tubules which are excretory in function.
- The hindgut is usually differentiated in to three regions these are small intestine or ileum, the large intestine or colon and the rectum.
- The main functions of hindgut are the absorption of water, salt and other useful substances from the faeces and urine.
- In the larva of termites, ileum is pouch like for housing symbionts and acts as fermentation chamber.
- **Rectum** contains rectal pads helping in dehydration of faeces and it opens out through anus.

Functions of Hindgut: Reabsorption of water, salt and other useful substances from the faeces and urine.

INSECT CENTRAL NERVOUS SYSTEM

The basic component in the nervous system is the neuron

The group of neurons is called as ganglion

- The ganglia of adjoining segments are joined together by longitudinal fibers called as connectives.
- The ganglia of same segment unite by transverse fibers called as commissures.

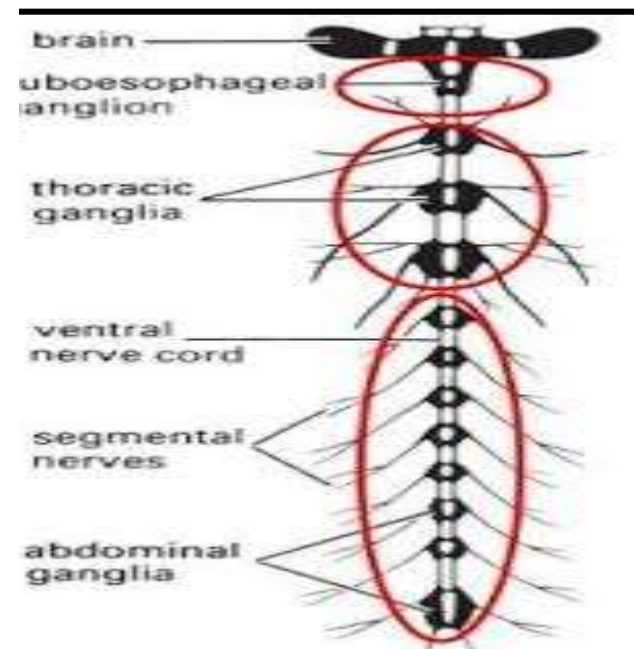


FIG. CENTRAL NERVOUS SYSTEM

Central nervous system includes the following organs –

1 Brain:

- Brain is the main sensory centre controlling insect behaviour
- It is divided into

(a) Protocerebrum:

- It is also known as **fore-brain**.
- It is formed by the union of the ganglia of preantennary segment and forms the greater part of the brain.
- It gives nerve connection to the **compound eyes and ocelli**.

(b) Deutocerebrum:

- It is also known as **mid-brain**.
- It is formed from the ganglia of antennary segment and it gives nerve connection to the **antenna**.
- Found beneath protocerebrum

(c) Tritocerebrum:

- It is also known as **hind brain**.
- It is formed by the union of ganglia of third/intercalary segment and is relatively small.
- It gives nerves connection to the **labrum**.

2. Ventral Nerve Cord (VNC):

- It is a median chain of segmental ganglia beneath oesophagus

3. Sub-oesophageal ganglion:

- It is present in the head below the oesophagus in the head.
- It is formed by the union of ganglia of the gnathocephalic segments.
- It gives nerves to **mandibular, maxillary, labial segment, salivary ducts, part of cervical muscles in the neck region and corpora allata**.

4. Thoracic ganglia:

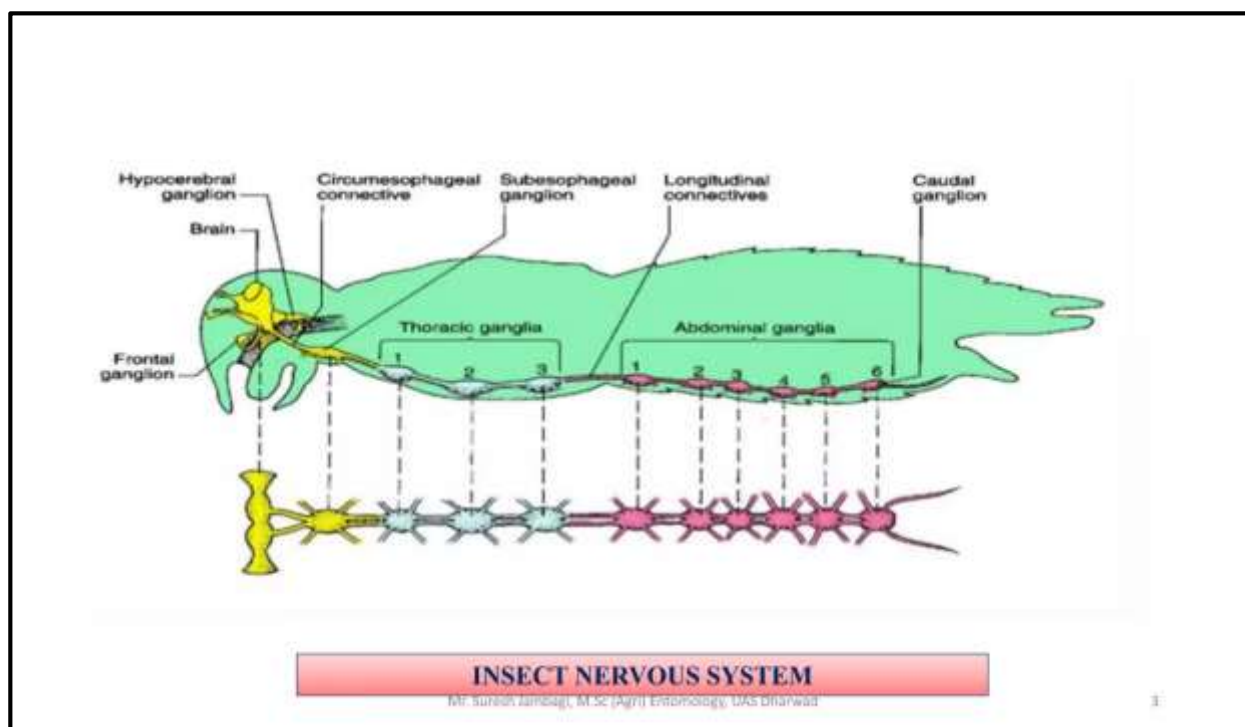
- Three pairs found in the respective thoracic segments
- It is largest ganglia and provides nerve connection to **legs and muscles**.

5. Abdominal ganglia:

- Maximum eight pairs are present and number may vary due to fusion of ganglia.
- It provides nerve connections to **spiracles**.

6. Thoraco abdominal ganglia:

- Thoracic and abdominal ganglia are fused to form a single compound ganglia.



- It provides **nerve connections to genital organs and cerci**.

EXCRETORY SYSTEM IN INSECTS

The removal of waste products of metabolism, especially nitrogenous compounds from the body of insects is known as **excretion** and the organs involved in removal of such waste products is termed as **excretory system**.

The various organs involved in excretion are –

1. Malpighian tubules

- This structure was discovered by **Marcello Malpighi**.
- It is thin, blind-ending tubules, originating near the junction of mid and hindgut.
- Predominantly involved in **regulation of salt, water and nitrogenous waste excretion**.

2. Nephrocytes:

- Cells that sieve the haemolymph for products that they metabolize
- Nephrocytes are cells **that take up foreign chemicals** of relatively high molecular weight which Malpighian tubules may be incapable of dealing with.

3. Fat bodies:

- It is a loose or compact aggregation of cells.
- It is mostly trophocytes that are suspended in the haemocoel
- Responsible **for storage and excretion**.

4. Oenocytes:

- These are specialised cells of haemocoel, epidermis or fat body with many functions. One of **the function is excretion**.

5. Integument:

- Through the process of moulting, insects remove the waste nitrogenous products, i.e. they are deposited in the form of exuviae.

6. Tracheal system:

- The respiratory tubes, the trachea which are distributed throughout the body, function in elimination of CO₂ through spiracles.

7. Rectum:

- The posterior part of hind gut.

8. Labial glands:

- These are seen in Collembola, Diplura, Thysanura
- They consist of sac-like structures called ampulla that leads to a long coiled tube that opens at the base of labium in the head.
- This gland helps to remove ammonia.

9. Chloride cells:

- These are the cells distributed on the body of aquatic insects such as larva of mayfly or stone fly.
- They absorb ions from salt water (body) and then excrete into surrounding medium to compensate the changes in the ionic concentration of haemolymph.

Storage Excretion

The excretory waste materials are retained within the body in different sites.

1. Urates

Uric acid is stored as urates in the cells of fat body
E.g., **American cockroach**.

2. Body wall

Uric acid is stored in the body wall, giving white colour, E.g., **Red cotton bug**.

3. Male accessory glands

Uric acid is stored in the male accessory glands to produce the outer coat of spermatophore, which is excreted during copulation.

4. Wing scales

Uric acid is stored in the wing scales giving white colour. E.g., **Pierid butterflies**.

5. Pupal metabolism

Waste products of pupal metabolism (meconium) is stored and released during adult emergence.

RESPIRATORY SYSTEM IN INSECTS.

- (1) Insects obtain oxygen from their environment and eliminate carbon dioxide respired by their cells.
- (2) This is gas exchange through series of gas-filled tubes providing surface area for gaseous exchange
- (3) Respiration refers to oxygen-consuming, cellular metabolic processes.

- (4) The trachea is the primary organ responsible for respiratory function.
 - (5) Gas exchange occurs by means of internal air-filled tracheae.
 - (6) These tubes branch and ramify through the body.
 - (7) The finest branches called **tracheole** contact all internal organs and tissues and are numerous in tissues with high oxygen requirements.
 - (8) Air usually enters the tracheae via spiracular openings positioned laterally on the body.
- Cuticulin layer is permeable to gases.
 - It is intracellular in nature, but enclosed only in the cytoplasm of tracheal and cell called **tracheoblast**.
 - In the trachea, thin walled-collapsible sac-like dilations are present, called as **airsacs** where **taenidia** is absent.

Functions of air sacs are

- Air sacs act as oxygen reservoir.
- It provides buoyancy to flying and aquatic insects.
- Provide space for growing organs.
- Acts as sound resonator and heat insulators.

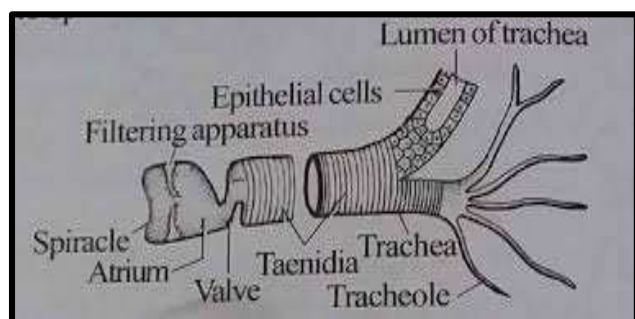


FIG. INSECT RESPIRATORY SYSTEM of insect

Organs of respiration are

Spiracles:

- Spiracles have a chamber or **atrium** with an opening and closing mechanism called **atrial valve**.
- This regulates air passage and minimizes water loss.
- Each spiracle is set in a sclerotized cuticular plate called a **peritreme**.
- Tracheae are invaginations of the epidermis and thus their lining is continuous with the body cuticle.
- The ringed appearance of the tracheae is due to the spiral ridges called **taenidia**.
- This allows the tracheae to be flexible but resist compression.
- The cuticular linings of the tracheae are shed during moulting.

Tracheoles

- Tracheoles are less than 1 µm in diameter and they end blindly and closely contact the respiring tissues.
- Taenidia and wax layer are absent.

CIRCULATORY SYSTEM IN INSECTS.

In insects, blood flows through the body cavity (i.e., haemocoel) irrigating various tissues and organs. It is known as an open type of circulatory system.

Haemocoel:

- Haemocoel of insects is divided into 3 sinuses (or) regions due to the presence of two fibro-muscular septa (or) diaphragms composed of connective tissues.

Dorsal or Pericardial Sinus:

- The area lying between the tergum and dorsal diaphragm. It contains the heart.

Ventral or Perineural Sinus:

- The area lying between the sternum and ventral diaphragm. It contains the nerve cord.

Visceral Sinus:

- The area between dorsal and ventral diaphragms. It harbours the visceral organs like alimentary canal and gonads.

Dorsal blood vessel:

- It is the principal blood-conducting organ in insects, which remains closed at the posterior end and opens anteriorly into the head.

Dorsal blood vessel is divided into an anterior aorta and posterior heart

1. Aorta:

- It is the anterior part of the dorsal blood vessel.
- Its functions as **principal artery**.
- It is present in the thoracic region and opens into the head near the brain.

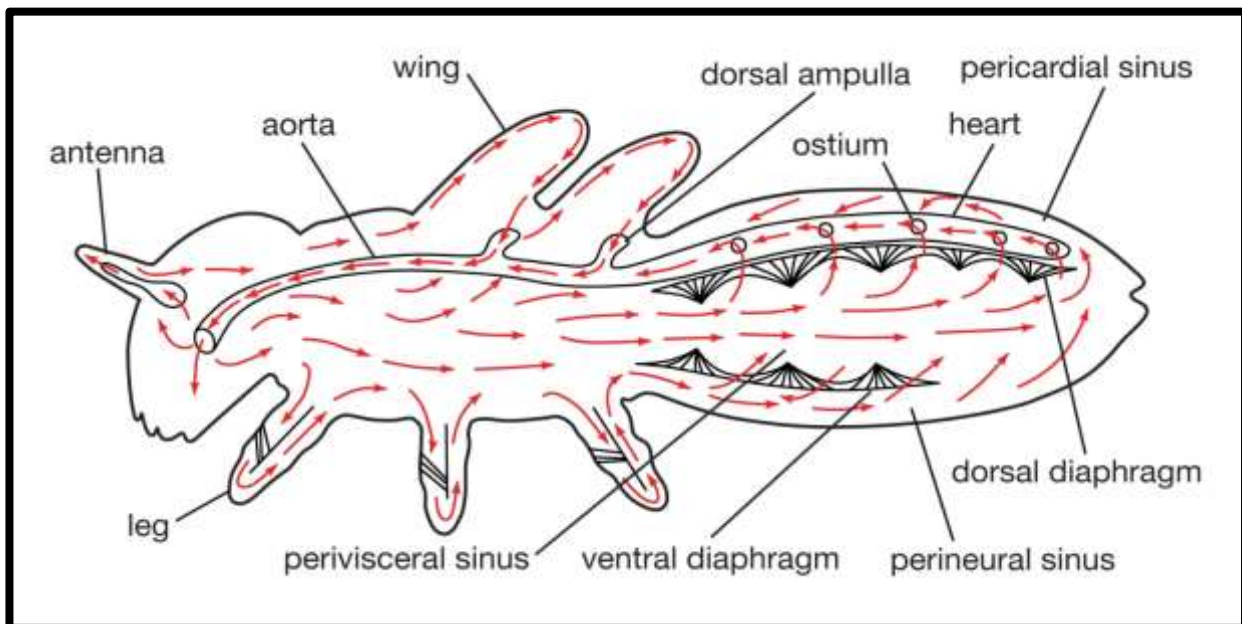


FIG. INSECT CIRCULATORY SYSTEM of insect

- Its attachment with the heart posteriorly is marked by an aortic valve.
 - Heart mainly functions as the **pumping organ in to the aorta.**
 - The flow of blood is mainly posterior anterior.
- 2. Heart:**
- It is the posterior part of dorsal blood vessel extending up to the terminal end of the abdomen.
 - Heart remains in position with the help of alary muscles.
 - These alary muscles appear to be distributed fan like over the heart in triangular shape
 - Heart consists of **13 chambers** marked by constrictions and the presence of the opening called 'ostia' which allow the entry of blood from pericardial sinus in to the heart and prevent back flow of blood from heart to sinus
- 3. Accessory pulsatile organs:**
- An insect consists of sac like structures called **accessory pulsatile organs**, which are present at the base of the appendages such as **wings, legs and antenna.**
 - They **pulsate independently** and **supply adequate blood to the appendages.**

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ARTICLE ID: 39

CLIMATE-SMART SERICULTURE: PATHWAYS TO LOW-CARBON SILK PRODUCTION

Introduction:

Historically, silk has been a metaphor for sophistication, culture, and refinement. But what lies beneath the glamour of silk is an agricultural system inextricably linked to the environment and natural resources. With the onset of climate change and the increasing importance of sustainability in global policies, the silk industry is unexpectedly turning out to be a climate-resilient sector. With less industrial input and greater rural employment, the silk industry, especially in countries such as India, has the potential to be a low-carbon, eco-friendly agricultural model.

India, the second-largest silk producer in the world, produces more than 34,000 metric tonnes of silk every year (Central Silk Board statistics, 2022-23). The industry sustains close to 9 million people, with the majority being small and marginal farmers, and a large number of them being women. Since the silk industry is agro-based and labor-intensive and not industry-based and fossil fuel-driven, it inherently has some environmental advantages over the production of synthetic fabrics.

Mulberry Cultivation as a Carbon Sink

Mulberry (*Morus spp.*) is the key component of sericulture. As a perennial crop, mulberry gardens serve as perennial carbon sinks. Perennial tree-based cropping systems, as estimated by agroforestry studies following the guidelines of the Food and Agriculture Organization, sequester much higher levels of carbon compared to seasonal crops because of their year-round biomass production.

Studies conducted in Indian sericulture areas have shown that properly maintained mulberry gardens can:

- Capture and store 10-15 tonnes of CO₂ equivalent per hectare per year through biomass and soil organic carbon.
- Increase soil organic carbon by 0.2-0.4% per year through organic farming practices.
- Protect the soil from erosion through year-round ground cover.

Mulberry gardens, unlike cotton, remain productive for 12-15 years with less soil disturbance and, consequently, lower emissions from land preparation.

Organic Nutrient Management and Soil Health

Conventional farming is a source of greenhouse gas emissions, especially due to nitrogen-based fertilizers, which emit nitrous oxide, a strong greenhouse gas ranked by the Intergovernmental Panel on Climate Change as having nearly 300 times the warming potential of CO₂.

Eco-friendly sericulture practices:

- Farm yard manure (FYM)
- Vermicompost
- Green manuring (sun hemp integration)
- Biofertilizers (Azotobacter, Azospirillum, PSB)

Field experiments carried out in Karnataka and Assam have demonstrated that integrated organic nutrient management practices can:

- Reduce the use of chemical nitrogen by 25-40%
- Increase leaf protein concentration
- Stabilize cocoon production

In addition, the use of silkworm litter (a combination of unused leaves and excreta) as compost helps to establish a closed-loop system, which is the essence of circular farming.

Integrated Pest and Disease Management (IPM)

Use of chemical pesticides raises the carbon footprint in terms of production and use, and affects soil biodiversity. Eco-friendly sericulture practices, on the other hand, use:

- Biological control agents (*Trichoderma*, *Beauveria bassiana*)
- Botanical pesticides (neem-based pesticides)
- Hygienic rearing methods
- Disease-resistant silkworm varieties

The Central Silk Board has encouraged IPM packages that have decreased pesticide use by almost 50% in pilot areas. These methods, in addition to lowering carbon emissions, also protect beneficial insects and preserve ecological balance in sericulture farming communities.

Water Conservation and Climate-Smart Irrigation

Textile crops such as cotton are among the most water-consuming crops globally. Mulberry, on the other hand, is a moderate and well-regulated irrigation crop. Use of Drip irrigation systems,

Mulching, Rainwater harvesting systems has decreased water consumption in mulberry farming by as much as 30-40% in semi-arid areas of South India.

Drip irrigation systems also conserve energy by reducing pumping time. When combined with solar-powered pumps, the carbon footprint is further reduced, making sericulture a suitable option for climate-smart agriculture initiatives.

Renewable Energy in Silk Processing

Energy consumption rises during cocoon drying, reeling, and twisting. Firewood and coal were conventionally employed for cocoon stifling. However, in contemporary eco-friendly processing units, the following renewable energy sources have been introduced:

- Solar cocoon dryers
- Advanced biomass gasifiers
- Energy-saving reeling machines

Pilot projects conducted under rural development programs in India have revealed that solar-powered cocoon drying can decrease the consumption of conventional fuel by 60-70%. This has resulted in a substantial decrease in CO₂ emissions, besides lowering the cost of processing for farmers.

Waste Minimization and Circular Economy

The biodegradable nature of sericulture waste makes it an excellent candidate for circular economy implementation.

The major recycling processes are as follows:

- Processing of silkworm pupae as poultry and fish food (protein-rich)
- Utilization of sericin (silk gum) in cosmetic and biomedical products
- Composting of mulberry pruning residues in fields

Silk is completely biodegradable, taking only a few years to decompose without the production of microplastics. This provides a major environmental advantage to silk over plastic

textile pollution in the current plastic age.

Ethical and Low-Impact Silk Variants

Eco-friendly innovations also apply to the processing philosophy. Eri silk also known as “Peace silk” or non-violent silk enables the moth to come out before reeling. Although the filament is shorter, this process corresponds to ethical consumerism and is often practiced in small-scale, low-energy production systems.

Moreover, natural dyeing with plant dyes (indigo, turmeric, madder) leads to lower chemical emissions compared to synthetic dyeing factories.

Socio-Environmental Sustainability

Low-carbon sericulture is more than just a carbon concern. It is a matter of sustainability and resilience. The Sericulture industry:

- Ensures year-round economic benefits for rural communities
- Offers women empowerment (over 60% in some sericulture clusters)
- Supports agroforestry diversification

Agroforestry diversification through mulberry-based farming systems (legume or vegetable intercropping) increases biodiversity and mitigates the risks of monocultures, ensuring long-term sustainability.

Comparative Carbon Perspective

Although specific lifecycle analysis is difficult to quantify, research on natural fibers shows that:

- Silk production is significantly less carbon-intensive than polyester production.

- Synthetic fibers rely heavily on fossil fuels, which are a major source of industrial CO₂ emissions.

- Silk production is a biological and renewable process.

As the global fashion industry sets its sights on net-zero emissions, eco-certified silk can be a promising substitute for high-carbon textiles.

Challenges Ahead

Although the eco-friendly sericulture has many benefits, it also has some challenges:

- Lack of knowledge about carbon accounting among farmers
- Cost of initial investment in drip and solar technology
- Development of certification processes for organic silk
- Climate change that affects the mulberry yield

Conclusion

Sericulture is at the crossroads of tradition and sustainability. With the mulberry plantations as carbon sinks, organic nutrient cycles, the adoption of renewable energy sources in processing, and biodegradable products, sericulture has the potential to be one of the most sustainable textile systems in the world.

In a world where fast fashion is pushing the Earth’s boundaries, sustainable sericulture is an attractive story: luxury fashion made not from fossil fuels but from leaves, livelihoods, and living systems.

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ARTICLE ID: 40

PUBLISH, PERFORM, PROGRESS: THE EXPANDING INFLUENCE OF SCOPUS ON ACADEMIC CAREERS

Abstract

From a bibliographic tool, Scopus became an important, central metric that is now utilized to shape academic careers thereby affecting hiring, promotions, funding, and university rankings. Through citation counts, h-index scores, and journal rankings, Scopus is seen as promoting international visibility and collaboration, as well as supporting the peer-review standard. While the use of these metrics increases transparency and levels of engagement (globally), it also creates pressure. Researchers may choose to focus on topics with high citation counts. Fields such as the humanities may represent a relatively small portion of the total citations; and inequities due to the structure of academia can negatively impact individuals in their career progression; and contributors in the areas of mentorship and teaching, as well as contributions made to the community through research, typically go unmeasured.

This article asserts that there must be balance between quantitative and qualitative methods of evaluation, with quantitative information being considered as an adjunct to qualitative assessment so that the values associated with an academic faculty member are reflective of both their measurable impact and the intellectual/societal benefits of their research.

Keywords: Scopus, Career advancement, Citation metrics, Research evaluation, Qualitative assessment

Introduction

In universities today, academic success is no longer defined only by good ideas or inspiring lectures. It is increasingly measured through visibility, citations, and journal rankings. Research must not only be conducted but also be counted. At the heart of this transformation is Scopus, a platform that has gradually reshaped how scholars build and sustain their careers.

Over the past two decades, Scopus has moved from being a background research tool to a central reference point in academic life. It influences the publishing choices of academics, the evaluation of their work, and the way they build their careers. It has become a source of stress as well as opportunity for many academics.

From Research Tool to Professional Standard

Elsevier launched Scopus in 2004 with the simple aim of indexing academic publications and tracking research citations. It enabled academics to know who was reading and building upon their work. Tracking citations, however, soon became more than a useful service. Universities began using data from Scopus to assess research output. Before awarding grants, funding organizations evaluated the impact on citations. Promotion committees reviewed publication records and h-index scores. What started as an information service became a powerful benchmark.

Today, in many institutions, a strong Scopus profile can influence hiring decisions, contract renewals, and academic promotions. The database does not merely organize scholarship but it helps determine academic futures.

Publishing with Purpose or Pressure?

Publishing has always been central to academic life. Yet the meaning of “publish or perish” has changed. Increasingly, it implies publishing in Scopus-indexed journals.

Many universities set clear publication targets for faculty members. Doctoral students may be required to publish at least one indexed article before completing their degrees. Journal rankings, particularly Q1 and Q2 quartiles, have become symbols of prestige.

There are definite advantages. The peer-review process is usually followed stringently by indexed journals. Indexed publications enhance the quality of research and help researchers connect with the international community. For researchers in a developing academic environment, being indexed in Scopus can be a long-awaited recognition.

However, the reality of the situation is not to be underestimated. Young researchers often view their first indexed publication as a relief. They become skilled at scrutinizing the statistics of journals, sometimes choosing topics that are more likely to be cited. Research that does not hold the promise of quantifiable outcomes may be harder to justify if it is long-term, high-risk, or locally focused.

Both productivity and anxiety can be sparked by the desire to publish. Behind every citation count is a researcher refreshing their profile, hoping their work has been noticed.

Living by the Numbers

One of Scopus’s defining features is its ability to translate scholarships into numbers. Citation numbers, h-index values, and rankings are now part of the parlance in faculty discussions and performance evaluations.

These metrics bring clarity and structure. They facilitate the fair evaluation of applicants and the comparison of research output between departments or nations. Numbers can provide clear benchmarks and lessen personal prejudice.

However, statistics seldom provide a complete picture. Both popularity and influence may be seen in an article with a high number of citations. A well-considered, community focused study may have a significant local

impact yet earn less citations. Scholars in the humanities, who frequently write books instead of journal articles, might not see as much of their work in citation databases.

Most significantly, mentorship, classroom creativity, and public involvement are not measured by metrics. The hours spent mentoring students or participating in policy discussions are not captured by them. When academic value is closely tied to measurable indicators, scholars may begin to equate personal worth with performance data. The satisfaction of intellectual discovery can be overshadowed by concern over impact factors and citation growth.

Career Progression in a Metric-Driven World

Professional advancement today often depends on publication records and citation impact. Promotion panels review indexed articles. Funding committees examine h-index scores. University rankings rely heavily on research output recorded in databases like Scopus.

This system has encouraged greater international collaboration. Researchers seek partnerships across borders, publish in global journals, and participate in worldwide conversations. Knowledge has diffused to a wider extent than ever before.

But the playing field is not always level. Research funding, light teaching loads, and editorial support are sometimes perks for academics in well-funded institutions. People in poor resource environments might struggle to juggle heavy workloads and publication pressures. Non-English speakers are at a disadvantage because English is so ubiquitous in many indexed articles. Career advancement is a significant factor in the impact of resources and access on outcomes when citation metrics are closely tied to career advancement.

Opportunities and Accountability

It would be unfair to view Scopus as a source of pressure alone. Scopus has contributed to raising global awareness, peer-review quality, and research integrity. Scopus provides valuable information that helps organizations make informed decisions.

The issue is not the existence of metrics but their prevalence.

Research is more than the number of publications. Curiosity, creativity, and engagement are all parts of research. It involves engaging with communities, mentoring the next generation, and addressing challenging societal questions. While the number of citations may not always capture these, they are vital to the mission of higher education.

Achieving a Balance

A positive academic environment requires balance. Assessment can be data-driven, but it should not be data-defined. Qualitative assessment, like peer assessment, educational effectiveness, social value, and lasting intellectual value, should be complementary to quantitative data.

Institutions can accommodate both measurable productivity and substantial scholarships when they recognize multiple types of brilliance.

Moving Past the Metrics

The increasing influence of Scopus is a symptom of broader changes in higher education, such as data-informed administration, accountability, and globalization. It has altered the way researchers publish, collaborate, and progress. It provides many researchers with the opportunity to be recognized on a global platform. It imposes new demands on others.

Ultimately, academic careers are founded on ideas that educate, interrogate, and motivate, not just impact. While they might point the way, metrics should not substitute for the destination.

The challenge universities face in today's metric-driven environment is clear: as we measure and evaluate research performance, we must not lose sight of the people and passions that inspire and sustain it.

Summary

The article explores how Scopus has reshaped higher education over the past two decades. Originally created in 2004 to track citations, it has become a major benchmark influencing hiring, funding, and promotions in universities.

Indexed journals improve global visibility, support collaboration, and maintain research quality through strict review standards. Metrics such as citation counts also offer more transparent ways to evaluate academic performance.

However, this system has downsides. The pressure to publish can push researchers toward trendy topics instead of meaningful or long-term work. Humanities fields often receive less recognition, while important contributions like mentoring, teaching innovation, and community service remain largely invisible. Additionally, non-English scholars and those in underfunded institutions face structural disadvantages in this metric-driven environment.

Conclusion

The central idea of the article is that research metrics can serve as a helpful guide to understanding impact, but they should never be treated as the ultimate goal. A strong academic culture depends on balancing numerical indicators with thoughtful qualitative evaluation.

Genuine scholarly worth lies in ideas that inform, challenge, and inspire people—not merely in those that accumulate citations. For universities to truly progress, they must adopt an approach where data supports decision-making without defining a researcher's full value, so that curiosity and innovation remain at the heart of academic work.

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ARTICLE ID: 41**Phyllosphere: A Habitat for Diverse Microflora****Introduction**

The word "Phyllosphere," invented by Dutch scientist Ruinen, refers to the interaction between plant leaves and the abundance of microorganisms present on leaf surfaces. He came up with the word "phyllosphere" to describe the link between the microorganisms on the surface of plants and their leaves. The quality and production of several essential medicinal plants and agricultural products, as well as the fitness of natural plant populations, may be impacted by the significant interactions of phyllosphere microbial residents. Antagonistic bacteria that can compete with the pathogen for resources and prevent pathogen growth by secreting poisons or antibiotics can thrive in phylloplane. The age of the plant, leaf area, morphology, and climatic conditions (temperature, humidity, etc.) all affect the quantity and quality of microorganisms on the leaf surface. Therefore, aerial plant surface is considered as a dynamic environment (Fokkema, 1976).

Microbiology of Phyllosphere

Fungi that live on the aerial parts of plants have been defined as endophytes if they live inside the plant tissues and as epiphytes if they live on the surface of their host (De Barry, 1866; Arnold, et al., 2000; Inacio et al., 2002; Lindow and Brandl, 2003). The aerial parts provide a suitable habitat for epiphytic micro-organisms, many of which also influence the growth of pathogens. Bacteria are generally the predominant initial inhabitants of newly expanded leaves, while yeasts and filamentous fungi dominate later in the growing season (Kinkel et al., 1987). The physical, chemical, and biological elements that make up the surrounding area make up the phyllosphere's habitat. The components of the microflora found on the leaf surface a- particular habitat known as the phylloplane—have received a lot of attention in recent years. Physiology of leaf includes exchange of gas, secretion of secondary metabolite, mobilization of water, and regulation of temperature, is determined by the arrangement of epidermal cells. According to Shiraishi et al. (2015), it explains the leaf microhabitat that permits the distribution and abundance of microbial communities on the foliar surface.

There is an uneven distribution of foliar microbial communities, with some areas being more strongly colonized than others. Leaf microbial hotspots are areas such as the bases of trichomes, above veins, epidermal cell grooves, stomata, and hydathodes that have a high permeation rate and are somewhat protected from environmental stressors (Hirano and Upper, 2000, Remus-Emsermann and Schlechter, 2018). Here, microbes congregate to take advantage of exudated sugars, inorganic nutrients, water (Van Der Wal and Leveau, 2011) and released volatile organic compounds like methanol (Knief et al., 2012).

Composition and diversity of phyllosphere microbiota

4.1. Bacterial community

With an average of 106–108 cells cm⁻² of leaf tissue (Andrews and Harris, 2000, Hirano and Upper, 2000), bacteria are thought to be the most prevalent species in the phyllosphere, making up roughly 1026 bacterial cells worldwide (Vorholt, 2012). These phyllospheric bacteria can be either pathogenic or non-pathogenic, endophytic or epiphytic (Newton et al., 2010; Mazinani et al., 2017). Proteobacteria (alpha (α)-, beta (β)-, and gamma (γ) proteobacteria), Bacteroides, Firmicutes, and Actinobacteria are the most prevalent groups of bacteria that typically live on the phyllosphere of various plant species, including model plants *Arabidopsis thaliana* and *Citrus* sp. (Kembel et al., 2014, Durand et al., 2018; Carvalho et al., 2020).

4.2. Fungal community

In addition to bacteria, the phyllosphere is home to a vast variety of filamentous fungus and yeasts, however they are less varied than their bacterial counterparts. Typically saprophytic, fungi can be either endophytically or epiphytically connected to the phyllosphere of plants. However, because some fungi that first colonize the leaf surface can actively reach the internal tissues via stomata or other epidermal regions, it has been unclear whether leaf fungi are endophytes or epiphytes (Jumpponen et al., 2006). *Aureobasidium pullulans*, a yeast-like fungus, typically predominates on fruit surfaces (Setati et al., 2012) and in the phyllosphere (Cordier et al., 2012a). It can be employed as a bio-control agent since it can outcompete plant pathogens (Cordier et al., 2012a, Setati et al., 2012). Filamentous fungus, in contrast to yeasts,

Table 1. Different fungal genera associated with phyllosphere of different plant species.

S.No.	Host Plants	Genera	References
1.	Palm (<i>Euterpe oleracea</i>) Tobacco (<i>Nicotiana tabacum</i>)	<i>Aspergillus</i>	(Rodrigues, 1994) (Wang et al., 2020)
2.	Lettuce (<i>Lactuca sativa</i>)	<i>Cladosporium</i>	(Hunter et al., 2015)
3.	Tobacco (<i>Nicotiana tabacum</i>)	<i>Cercospora</i>	(Wang et al., 2020)
4.	Lettuce (<i>Lactuca sativa</i>)	<i>Cladosporium</i>	(Hunter et al., 2015)
5.	European beech (<i>Fagus sylvatica</i>)	<i>Taphrina carpini</i>	(Cordier et al., 2012)
6.	European beech (<i>Fagus sylvatica</i>)	<i>Venturia hanliniana</i>	(Cordier et al., 2012)
7.	Rice (<i>Oryza sativa</i>)	<i>Curvularia lunata</i>	(Venkatachalam et al., 2016)
8.	Heldreich's Pine (<i>Pinus heldreichii</i>)	<i>Cyclaneusma niveum</i>	(Lazarević & Menkis, 2020)
9.	Grape wine (<i>Vitis vinifera</i>)	<i>Alternaria</i>	(Singh et al., 2019)
10.	Heldreich's Pine (<i>Pinus heldreichii</i>)	<i>Phaeosphaeria punctiformis</i>	(Lazarević & Menkis, 2020)
11.	Tobacco (<i>Nicotiana tabacum</i>)	<i>Phoma</i> , <i>Rhizopus</i>	(Wang et al., 2020)
12.	Lettuce (<i>Lactuca sativa</i>)	<i>Sporobolomyces</i>	(Hunter et al., 2015)
14.	Felty germander (<i>Teucrium poliu</i>)	<i>Penicillium chrysogenum</i>	(El-Din Hassan, 2017)
15.	Palm (<i>Euterpe oleracea</i>)	<i>Wardomyces</i>	(Rodrigues, 1994)
16.	Frost grape (<i>Vitis riparia</i>)	<i>Ramularia</i> spp.	(Kernaghan et al., 2017)
17.	Tobacco (<i>Nicotiana tabacum</i>)	<i>Rhizopus</i>	(Wang et al., 2020)
18.	Heldreich's Pine (<i>Pinus heldreichii</i>)	<i>Sydowia polyspora</i>	(Lazarević & Menkis, 2020)
19.	Tomato (<i>Lycopersicon esculentum</i>)	<i>Moesziomyces</i>	(Lynikienė et al., 2020)
20.	Rice (<i>Oryza sativa</i>)	<i>Bipolaris ravenelli</i>	(Venkatachalam et al., 2016)
21.	Tomato (<i>Lycopersicon esculentum</i>)	<i>Dioszegia</i>	(Toju et al., 2019)

are mostly endophytic and typically exist as latent spores, with the exception of older leaves, where they exhibit well-organized active mycelia (Andrews and Harris, 2000). Filamentous fungus typically belong to genera such as *Acremonium*, *Alternaria*, *Aspergillus*, *Cladosporium*, *Mucor*, and *Penicillium*, and their populations can vary from 102 to 108 CFU g⁻¹ of leaf tissue (Inácio et al., 2002). Table 1. Shows a list of some significant fungal genera that are present on the phyllosphere of various plant species.

The key elements of the leaf microbiome are fungi, which have a significant impact on the host. According to Yao et al. (2019), leaf fungal communities—both epiphytes and endophytes—have a rich species diversity and perform a variety of metabolic tasks, including early leaf litter decomposition and recycling of nutrients, especially carbon and nitrogen (Kannadan and Rudgers, 2008, Guerreiro et al., 2018), maintaining ecosystem productivity (Maherali and Klironomos, 2007, Van der Heijden et al., 2016), and tolerance to biotic stressors like salinity and drought (Arnold et al., 2007, Guerreiro et al., 2018). The phyllosphere is a peculiar microbial environment that is densely populated by several microbial communities that play a variety of roles in the ecology and growth of plants.

Our understanding is confined to only certain microorganisms and their interaction and dynamics of major groups of microbiota is still left to be unexplored.

References

- Durand, F. Maillard, V. Alvarez-Lopez, S. Guinchard, C. Bertheau, B. Valot, et al. (2018). Bacterial diversity associated with poplar trees grown on a Hg-contaminated site, Community characterization and isolation of Hg-resistant plant growth-promoting bacteria. *Sci. Total Environ.*, 622 pp. 1165-1177
- A. Jumpponen, K.L. Jones, J. Blair (2006). *Vertical distribution of fungal communities in tall grass prairie soil. Mycologia*, 102 pp. 1027-1041
- A. Van Der Wal, J.H.J. Leveau. Modelling sugar diffusion across plant leaf cuticles, the effect of free water on substrate availability to phyllosphere bacteria (2011). *Environ. Microbiol.*, 13 (3) pp. 792-797
- A.C. Newton, C. Gravouil, J.M. Fountaine. *Managing the ecology of foliar pathogens, ecological tolerance in crops.* Ann. Appl. Biol., 157 (2010), pp. 343-359
- A.E. Arnold, D.A. Henk, R.L. Eells, F. Lutzoni, R. Vilgalys. (2007), Diversity and phylogenetic affinities of foliar fungal endophytes in loblolly pine inferred by culturing and environmental PCR. *Mycologia.*, 99 (2) pp. 185-206
- Arnold, A.E., Maynard, Z., Gilbert, G.S., Coley, P.D. and Kursar, T.A. (2000). Are tropical fungal endophytes hyperdiverse? *Ecol Lett.*, 3:267-274.
- C. Knief, L. Frances, J.A. Vorholt (2010). Competitiveness of diverse *Methylobacterium* strains in the phyllosphere of *Arabidopsis thaliana* and identification of representative models, including *M. Extorquens* PA1. *Microb. Ecol.*, 60 pp. 440-452
- C.R. Carvalho, A.C. Dias, S.K. Homma, E.J. Cardoso (2020). Phyllosphere bacterial assembly in citrus crop under conventional and ecological management. *PeerJ*, 8 p. e9152
- De Barry, A. (1866). *Morphologie und Physiologie der Pilze, Flechten und Myxomyceten.* Engelmann, Leipzig. 316 p.
- Fokkema, N.J. and Heuvel, J.V. (1986). *Microbiology of the phyllosphere.* Cambridge University Press, Cambridge. 392 p. *Fungal Divers.*, 89 (1) pp. 237-251
- G. Kernaghan, M. Mayerhofer, A. Griffin. (2017). Fungal endophytes of wild and hybrid *Vitis* leaves and their potential for vineyard biocontrol. *Can. J. Microbiol.*, 63 pp. 583-595
- H. Maherali, J.N. Klironomos. (2007). Influence of phylogeny on fungal community assembly and ecosystem functioning. *Science.*, 316 pp. 1746-1748

- H. Toju, K. Okayasu, M. Notaguchi. (2019). Leaf-associated microbiomes of grafted tomato plants. *Sci. Rep.*, 9 (1) pp. 1-11
- H. Wang, Q. Chen, L. Cai, P. Goodwin, J. Ma, F. Wang, Z. Li. Fungal Composition and Diversity of the Tobacco Leaf Phyllosphere during Curing of Leaves (2020)
- H. Yao, X. Sun, C. He, P. Maitra, X.C. Li, L. D. Guo, et al. (2019). Phyllosphere epiphytic and endophytic fungal community and network structures differ in a tropical mangrove ecosystem. *Microbiome.*, 7 p. 57
- Inacio, J., Pereira, P., De Carvalho, M., Fonseca, A., Amaral-Collaco, M.T. and Spencer-Martins, I. (2002). Estimation and diversity of phylloplane mycobiota on selected plants in a Mediterranean-type ecosystem in Portugal. *Microbial Ecol.*, 44:344-353.
- J. Inácio, P. Pereira, D.M. Carvalho, A. Fonseca, M.T. Amaral-Collaco, I. Spencer-Martins, et al. (2002), Estimation and diversity of phylloplane mycobiota on selected plants in a mediterranean-type ecosystem in Portugal. *Microb. Ecol.*, 44 (4) pp. 344-353
- J. Lazarević, A. Menkis. (2020). Fungal Diversity in the Phyllosphere of *Pinus heldreichii* H. ChristéAn Endemic and High-Altitude Pine of the Mediterranean Region. *Divers*, 12 p. 172
- J. Lynikienė, D. Marčiulynienė, A. Marčiulynas, A. Gedminas, M. Vaičiukynė, A. Menkis. (2020). Managed and unmanaged *Pinus sylvestris* forest stands harbour similar diversity and composition of the phyllosphere and soil fungi. *Microorganisms*, 8 p. 259
- J.A. Vorholt. *Microbial life in the phyllosphere.* (2012). *Nat. Rev. Microbiol.*, 10 pp. 828-840.
- J.H. Andrews, R.F. Harris. (2000). The ecology and biogeography of microorganisms on plant surfaces. *Annu. Rev. Phytopathol.* 38 (1) pp. 145-180
- J.H. Andrews, R.F. Harris. (2000). *The ecology and biogeography of microorganisms on plant surfaces.* *Annu. Rev. Phytopathol.*, 38 (1) pp. 145-180
- K. Shiraishi, M. Oku, K. Kawaguchi, D. Uchida, H. Yurimoto, Y. Sakai, et al. (2015),
- K.F. Rodrigues (1994). The foliar fungal endophytes of the Amazonian palm *Euterpe oleracea*. *Mycologia*, 86 (3) pp. 376-385
- Kannadan and Rudgers, (2008) Endophyte symbiosis benefits a rare grass under low water availability. *Funct. Ecol.*, 22 pp. 706-713
- Kinkel, L.L., Andrews, J.H., Berbee, F.M. and Nordheim, E.V. (1987). Leaves as islands for microbes, *Oecologia.*, 71:405-408.
- Lindow, S.E. and Brandl, M.T. (2003). Microbiology of the phyllosphere. *Appl Environ. Microbiol.*, 69:1875-1883.
- M. Grube, F. Schmid, G. Berg (2011). Black fungi and associated bacterial communities in the phyllosphere of grapevine. *Fungal Biol.*, 115 (10) pp. 978-986
- M.A. Guerreiro, A. Brachmann, D. Begerow, D. Peršoh. (2018). Transient leaf endophytes are the most active fungi in 1-year-old beech leaf litter. *Fungal Divers.*, 89 (1) pp. 237-251
- M.A. Guerreiro, A. Brachmann, D. Begerow, D. Peršoh. (2018). Transient leaf endophytes are the most active fungi in 1-year-old beech leaf litter
- M.E. Setati, D. Jacobson, U.C. Andong, F. Bauer (2012). The vineyard yeast microbiome, a mixed model microbial map. *PLoS One*, 7 p. e5260
- M.G. Van der Heijden, S. de Bruin, L. Luckerhoff, R.S. van Logtestijn, K.A. Schlaeppi. (2016). Widespread plant-fungal-bacterial symbiosis promotes plant biodiversity, plant nutrition and seedling recruitment. *ISME J.*, 10 pp. 389-399
- M.N. Remus-Emsermann, R.O. Schlechter. (2018) Phyllosphere microbiology, at the interface between microbial individuals and the plant host. *New Phytol.*, 218 pp. 1327-1333. *Microbiol. Mol. Biol. Rev.*, 64 (3) pp. 624-653
- P. Singh, S. Santoni, A. Weber, P. This, J.P. Péros (2019). Understanding the phyllosphere microbiome assemblage in grape species (Vitaceae) with amplicon sequence data structures. *Sci. Rep.*, 9 (1) pp. 1-11
- P.J. Hunter, D.A. Pink, G.D. Bending (2015). Cultivar-level genotype differences influence diversity and composition of lettuce (*Lactuca*

- sp.) phyllosphere fungal communities. *Fungal Ecol.*, 17 pp. 183-186
- S. El-Din Hassan. (2017). Plant growth-promoting activities for bacterial and fungal endophytes isolated from medicinal plant of *Teucrium polium*. *L. J. Adv. Res.*, 8 (6) pp. 687-695
 - S. Kannadan, J.A. Rudgers. (2008). Endophyte symbiosis benefits a rare grass under low water availability. *Funct. Ecol.*, 22 pp. 706-713
 - S. Venkatachalam, K. Ranjan, R. Prasanna, B. Ramakrishnan, S. Thapa, A. Kanchan, et al. (2016). Diversity and functional traits of culturable microbiome members, including cyanobacteria in the rice phyllosphere. *Plant Biol.*, 18 pp. 627-637
 - S.S. Hirano, C.D. Upper. (2000). Bacteria in the leaf ecosystem with emphasis on *Pseudomonas syringae*—a pathogen, ice nucleus, and epiphyte. *Microbiol. Mol. Biol. Rev.*, 64 (3) pp. 624-653
 - S.W. Kembel, T.K. O'Connor, H.K. Arnold, S.P. Hubbell, S.J. Wright, J.L. Green, et al. (2014). Relationships between phyllosphere bacterial communities and plant functional traits in a neotropical forest. *Proc. Natl. Acad. Sci. U.S.A.*, 111, pp. 13715-13720
 - T. Cordier, C. Robin, X. Capdevielle, O. Fabreguettes, M.L. Desprez-Loustau, C. Vacher, et al. (2012). The composition of phyllosphere fungal assemblages of European beech (*Fagus sylvatica*) varies significantly along an elevation gradient. *New Phytol.*, 196 (2) pp. 510-519.
 - Z. Mazinani, M. Zamani, S. Sardari. (2017). Isolation and identification of phyllospheric bacteria possessing antimicrobial activity from *Astragalus obtusifolius*, *Prosopis juliflora*, *Xanthium strumarium* and *Hippocrepis unisiliqiosa*. *AJMB.*, 9 pp. 31-37.

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TELANGANA FARMERS TOWARDS DIGITALISATION OF AGRICULTURE

Introduction

Agriculture has always been the backbone of Telangana's economy, with over 60% of the state's population depending on farming for their livelihood. The state is home to millions of farmers who cultivate cotton, paddy, maize, chilli, and soybean across its fertile lands. For decades, these farmers have faced persistent challenges-erratic weather, fertiliser shortages, exploitative middlemen, and lack of market access.

But today, a digital revolution is quietly reshaping the fields of Telangana. Smartphones, internet connectivity, and government-backed digital platforms are bridging the gap between the farmer and the system. From booking urea fertiliser online to selling cotton directly to government procurement centres, technology is empowering Telangana's farming community like never before. This article traces that journey-from the basics of agricultural digitalisation to the new gen apps that are leading the change.

Why Digitalisation in Agriculture? The Need of the Hour

Why digitalisation became necessary in the first place.

Telangana farmers traditionally had to stand in long queues for fertilisers, often travelling to distant dealers only to find stocks exhausted. Cotton farmers were at the mercy of middlemen who bought their produce at prices far below the Minimum Support Price (MSP).

The Government, recognising these ground realities, began integrating digital tools into its agriculture policy. The vision was clear: use technology to bring transparency, efficiency, and better income to the farming community.

Key Digital Agriculture Apps.

1. Kapas Kisan App -A Game Changer for Cotton Farmers

Cotton is one of Telangana's most important cash crops, and its farmers have historically suffered from price exploitation by traders and middlemen. The **Kapas Kisan app** was introduced to directly address this problem.

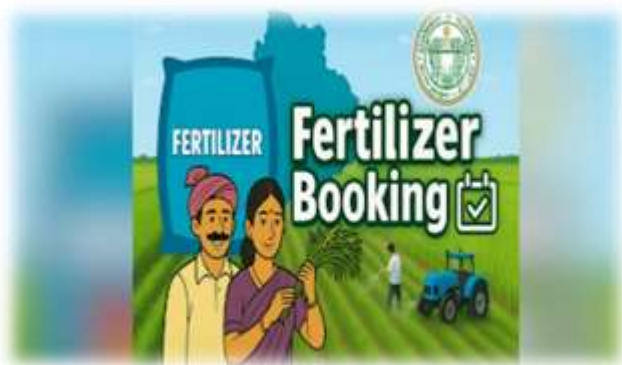
By registering on the Kapas Kisan app and booking a slot, farmers can directly market their cotton to the Central Cotton Inventory with support from both the central and state governments. The MSP for cotton is currently ₹8,110 per quintal. The government has set up procurement centres across Telangana, and farmers can book slots through the Kapas Kisan app to sell their cotton at these centres. The most significant benefit of this app is the elimination of middlemen. Selling directly to the Central Cotton Inventory allows farmers to avoid middlemen, potentially increasing their income by 20–25%.

How it works: the registered cotton farmer books a slot at the nearest procurement centre. On the scheduled day, they arrive with their produce, which is weighed and purchased directly at the MSP rate, with payment deposited straight into their bank account. No haggling, no manipulation, no loss. With the awareness of the Mandal Agriculture officers and Agriculture extension officers on the slot booking the work has been flowing without any hurdles.

2. Fertiliser Booking App (Urea Booking App)- Ending Fertiliser Queue Culture

Every *Kharif* and *Rabi* season, fertiliser distribution in Telangana used to descend into chaos. Farmers would gather in hundreds outside dealer shops from the early hours of the morning, unsure whether they would get their share of urea. The Kharif 2025 season witnessed particularly intense crowds due to panic buying, prompting the government to act decisively.

The Telangana Agriculture Department introduced a mobile phone app-based system that allows farmers to book fertiliser online, aiming to streamline distribution and prevent shortages. The Fertiliser Booking App, developed for Android phones, was piloted in select districts. App was trial run in over 5 districts for nearly 2 months and after successful bookings and distribution with transparency of the urea bags the government to implement in all the districts of Telangana.



Key Features of the Fertiliser Booking App:

Urea can be booked from home using a mobile number and Pattadar Passbook. Live position of the stock status is visible at the state, district, mandal and dealer

levels. The booking process is made as simple as online ticket booking, with crop-wise urea supply covering paddy, cotton, maize, chilli, and other crops. Farmers can check stock availability at the district, mandal and village levels. Dealers are required to update truckload receipts on the app, ensuring real-time transparency of stock availability. Tenant farmers are also eligible through an OTP-based landowner consent system. The booking ID generated is valid for 24 hours.

How to Use the App:

Farmers open the Google Play Store, search for "Fertilizer Booking App," install it, enter their registered mobile number, receive and enter an OTP to log in, then choose their district and farming season such as Rabi or Kharif to proceed with their booking.

The Road Ahead: What Digitalisation Promises Telangana Farmers

The digital agriculture movement in Telangana is not just about apps — it is about building a smarter, fairer, and more resilient farming ecosystem. When integrated effectively, these platforms together offer a comprehensive support system:

Transparency: With fertiliser booking digitised and stock levels visible at village level, black-market diversion and hoarding become nearly impossible.

Fair Income: The Kapas Kisan app ensures that cotton farmers get the full MSP directly into their bank accounts, cutting out exploitative intermediaries and boosting their real income.

Empowerment of Tenant Farmers: Digital systems that include OTP-based consent mechanisms officially recognise and serve tenant farmers, who were often left out of formal agriculture support systems.

Data-Driven Policy: Real-time data from these platforms helps the state government understand demand patterns, identify supply gaps, and make better agricultural policy decisions.

Conclusion

India stands at a fascinating crossroads -the ancient

tradition of farming meeting the modern power of digital technology. The Kapas Kisan app, the Fertiliser Booking App represent the government's commitment to bringing the benefits of the digital age directly to the doorstep of the farmer. Will technology alone solve the problems of agriculture? No. Infrastructure, fair pricing, water availability and climate resilience remain equally important. But as a tool that brings transparency, speed and equity to the farming process, digitalisation is proving to be a powerful ally. The farmer who once stood for hours in a queue or sold cotton at a loss to a trader can today make transactions from a mobile phone under a tree in their own field. That shift- small as it may seem -is nothing short of revolutionary. With continued government support, better digital literacy programmes and wider smartphone access, Telangana's farmers are well on their way to turning technology into their strongest harvest.

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INNOVATIONS IN CROP PRODUCTION, PROTECTION AND MANAGEMENT: ADVANCES AND FUTURE PROSPECTS

1. Abstract: The way we grow food is changing fast. We are moving away from methods that hurt the environment and use a lot of resources. Now we are using technology to make farming better. This is because the world is facing problems like too many people, climate change and soil that is getting worse. We need to change the way we farm to make sure everyone has food and the Earth is protected. This paper looks at ideas in three areas: growing crops, protecting crops and managing farms. With Crop Production we are using computers and machines to make farming more precise. This helps us grow food and use resources better. We are also using biology to make crops stronger and more resistant to stress. In Crop Protection we are moving away from using chemicals and towards using methods. This includes using sprays that can stop pests and diseases without hurting the environment. We are also using computers to look at plants from above and find diseases before they become a problem. In Crop Management we are trying to make farming more sustainable. We are using methods like conservation agriculture and special fertilizers that are better for the Earth. We are also using computers to help farmers make decisions. Even with all these new ideas many farmers are not using them. This is because they do not have the money or the support they need. We also need to make sure that these new methods are fair and do not hurt the environment.

Keywords: Digital Farming, CRISPR-Cas9, RNA Interference (RNAi), Biopesticides, Agroforestry, Carbon Sequestration, Soil Health, Artificial Intelligence.

2. Introduction: Agriculture is the foundation of food security, economic stability and human survival around the world.. The way we produce food today is facing big problems that threaten its future. Recently we have seen that hunger is not a temporary issue but a long-term problem. In the last few years over 295 million people have suffered from acute hunger worldwide. This is a situation caused by wars, economic problems and climate change. At that time the world population is expected to reach almost 10 billion by 2050. This means we need to produce a lot of food to feed everyone. However we cannot just use land for agriculture because it is already responsible for most of the deforestation in the world. This destroys the environment. Makes climate change worse. The big challenge for agriculture today is that the natural resources it relies on are being severely damaged. Climate change is the long-term threat to food security. Rising temperatures, changing weather patterns and extreme weather events are disrupting food production and safety.

These changes are happening at the time of environmental degradation. Bad farming practices have damaged a portion of the earth's land affecting the well-being of over 3.2 billion people and causing big economic losses. Soil pollution from pesticides and other pollutants is also harming the soil and its ability to support life. Agriculture has made progress in the past especially with the Green Revolution, which increased food production significantly. However this progress came at a cost, including the degradation of ecosystems and the depletion of water resources. Today farming is expensive and not very profitable for small-scale farmers. The use of pesticides and fertilizers is also polluting our water and air. Contributing to climate change. So we need to find ways to produce food that are better for the environment and more sustainable. This is called Sustainable Intensification. It means producing food while reducing the damage to the environment and restoring natural resources. We need to change the way we produce, protect and manage food. By using technologies and managing resources more efficiently we can make agriculture more sustainable. The rest of this review will explore the technologies and methods that are being developed to make this happen.

3. Innovations in Crop Production: To make crop production better we need to use different approaches. This means using tools and advanced plant biology as well as automated systems. New innovations have changed how we grow crops, how we make them stronger and how we predict how much we will get. This is helping the farming industry to become more controlled and efficient.

3.1 Precision Agriculture: IoT, Sensors, Drones and GIS: Precision agriculture is a change from the way we used to do farming. We used to manage fields all the same way. Now we can look at each part of the field and do what is best for that specific area. We use the Internet of Things, geographic information systems and

drones to make farming better. This way of farming can increase the amount of crops we grow by 20 to 30 percent. It also helps us not waste water, seeds and fertilizers. We can reduce waste by 40 to 60 percent. The way we use the Internet of Things in farming is pretty complicated. We have layers of sensors in the soil and on the crops. These sensors are all. They check things like how much water is in the soil, how hot or cold it is and how many nutrients the plants have. When we use these sensors with drones that can fly over the fields farmers can see exactly what is going on in each part of the field. The drones have cameras that can see things that we cannot see with our eyes. They can take pictures of the plants. Tell us exactly how healthy they are. This information helps us put the amount of water, seeds and fertilizers in the right places. We call this Variable Rate Technology. It helps us grow crops and not hurt the environment. Precision agriculture is about using the right tools, like IoT, sensors, drones and GIS to make farming better. Precision agriculture and the use of precision agriculture techniques are very important.

3.2 Smart Irrigation Systems and Climate-Smart Agriculture: Water is very scarce. This is a big problem for farming all around the world. This problem is getting worse because of climate change. To deal with this issue smart irrigation systems have become an important part of climate-smart agriculture. These systems use sensors to check the moisture in the soil and they also use weather forecasts to decide when to water the crops. This helps to save a lot of water 40 to 60 percent. These systems are very advanced. They can automatically give water to the crops when they need it. This way the crops get the right amount of water and this helps to prevent water from being wasted. In the past people used to water their crops using methods like flooding the fields or using sprinklers but these methods wasted a lot of water. Climate-smart agriculture is not about water, it is about many other things too. For example there is a method called the System of Crop Intensification. This method helps crops to grow by changing the way they are planted and by using natural fertilizers to make the soil

healthier. This method also helps to control weeds, which can harm the crops. When farmers use this method they can get up to 25 percent of their crops and they can also reduce the bad things that farming can do to the environment.

3.3 Hydroponics and Vertical Farming: There is another way of farming called Controlled Environment Agriculture. This includes hydroponics, aeroponics and vertical farming. These methods are very different from farming because they do not use soil. Instead they use systems to give nutrients to the crops. These systems are very good because they can produce up to 20 times crops per square meter than traditional farming. They also use less water and land around 95 percent less. This is very important because traditional farming is often affected by weather and it can also harm the environment.. Vertical farming is not affected by these things so it is a very reliable way to produce food. This is especially important for cities, where people need a supply of food.

3.4 Gene Editing Technologies: CRISPR and Biochemical Enhancements: Biotechnology has been used in farming for a time but now there is a new tool called CRISPR. This tool is like a pair of scissors that can cut and edit the genes of plants. This means that scientists can make plants that're stronger and more resistant to disease. They can also make plants that can survive in conditions, like drought. This is very important because climate change is making it harder for plants to grow.. With CRISPR scientists can make plants that can thrive in these conditions. They can also make plants that're better quality like avocados that do not turn brown. There are also ways to improve crops like using special biochemicals. For example scientists have found that a special spray can help wheat to grow. This spray helps the plant to make food and it also helps it to grow stronger. This is an important discovery because it can help to feed more people without harming the environment.

3.4 Artificial Intelligence in Yield Prediction: The huge amount of data from farming. Like how

electricity moves through soil, local weather and how plants reflect light. Needs special tools to turn it into useful information for farming. Artificial Intelligence and machine learning are necessary for this. Old ways of predicting crop yields involved taking samples and using statistics, which took a long time and were often wrong. Now Artificial Intelligence is used to predict crop yields. It uses tools like deep neural networks and special models to forecast yields by looking at what is happening in the environment and comparing it to past data. Companies like CropSafe, Descartes_Labs and OneSoil use pictures from satellites, drones and weather forecasts to predict what crops will be like at the end of the season. They can even find problems with plants with over 90% accuracy. By using these Artificial Intelligence models the people in charge of farms can make sure they are using their resources in the way. They can change things like how nitrogen they use based on the weather and how the plants are doing. Artificial Intelligence helps them make these decisions throughout the growing season so they can get the results from their crops.

4. Innovations in Crop Protection: Crop protection methods are changing a lot. This is because we need to reduce the harm that synthetic pesticides cause to the environment. We also need to deal with pests that are becoming resistant to chemicals and handle the changes in where pathogens are found due to global warming. The new approach focuses on being specific and using data to prevent problems.

4.1 Integrated Pest Management (IPM) and Biological Control Agents: The market for products like biofertilizers, biostimulants and biopesticides is growing fast. It is expected to grow at 12% every year and reach \$115 billion by the 2040s. These products are key to IPM strategies. IPM aims to reduce the use of pesticides. This helps keep the ecosystem balanced and resilient. It uses a mix of cultural and mechanical controls. Microbial biopesticides are a good alternative to synthetic chemicals. They come from bacteria, fungi, viruses and

nematodes. They work in ways to control pests. For example they produce toxins. Make pests sick. This slows down the development of pest resistance. Trichoderma filamentous fungi are widely used in agriculture. They protect plant roots from pathogens. Help roots grow strong. Bacterial agents like *Pseudomonas fluorescens* and *Agrobacterium radiobacter* strain K1026 are effective. K1026 produces an antibiotic that stops pathogens from causing disease. Biocontrols like the *Cydia pomonella* granulovirus control pest populations in a specific and environmentally friendly way.

4.2 RNA Interference (RNAi)-Based Pest Control

A breakthrough in crop protection is the use of RNA interference (RNAi). RNAi is a process that regulates gene expression. In agriculture it is used through Spray-Induced Gene Silencing (SIGS). This approach involves spraying stranded RNA (dsRNA) on plants. The dsRNA targets genes in pests or pathogens. The RNAi mechanism works through -kingdom RNAi. When a pest ingests or absorbs the dsRNA it is processed into interfering RNAs (siRNAs). These siRNAs help. Degrade messenger RNA (mRNA) sequences in the pest. This shuts down protein synthesis and neutralizes the threat. Because dsRNA sequences are designed to match only the target species genome SIGS offers high specificity. It virtually eliminates off-target effects on insects, soil microbiota and human consumers. In 2023 the US Environmental Protection Agency (EPA) approved Ledprona. It is the sprayable dsRNA biopesticide. This validates the viability of this technology.

4.3 Nanotechnology in Pesticide Delivery: The idea of using RNAi and other biological compounds to control pests is really good in theory. However these compounds break down quickly when they are exposed to the elements. When RNA molecules are not protected they degrade rapidly in sunlight, rain and when they come into contact with enzymes. Some insects have alkaline gut environments that can break down these molecules. To get around these

problems scientists have started using nanotechnology to deliver biopesticides. They have created nanocarriers that can carry the active RNA molecules and protect them from the environment. This makes it easier for the target organisms to take in the RNA. A lot of nanomaterials have been shown to work well in recent studies. This is especially important for controlling pests that have gut environments. The nanoparticles help protect the RNA from breaking down and make it last longer.

Table 1: Efficacy of various nanocarriers in the delivery of RNAi-based crop protection.

Nanocarrier Material	Target Pathogen / Pest	Documented Efficacy / Impact
Cationic Chitosan Nanoparticles	Fungal Pathogens / <i>A. gossypii</i>	Prolonged protection up to 20 days; 19.95% improved reduction in pests
Layered Double Hydroxide (LDH) Clay	General Foliar Pathogens	Protects dsRNA from UV degradation; extends functional longevity on leaf surface
Star Polycations (SPc)	White-backed planthopper (<i>S. furcifera</i>)	Achieved more than 60% mortality of the target pest; efficient systemic delivery
Mesoporous Silica Nanoparticles	Tomato leaf curl New Delhi virus	Resulted in a threefold reduction of viral load; highly stable delivery matrix

4.4 Remote Sensing for Preemptive Disease

Detection: To protect crops we need to find diseases. Sensing technology and machine learning are helping us do this. We can use drones with sensors and information from the fields to see when plants are stressed before we see any signs of disease. Special computer programs like YOLOv11 can look at pictures taken from the air to see what is going on with the plants. These programs can tell which plants are sick by looking at things like how food they are making the shape of their leaves and how hot they are. This means farmers can treat the plants that need it instead of using a lot of chemicals everywhere. This way we can stop the disease from spreading, use insecticides and fungicides and save farmers money.

5. Innovations in Crop Management: The way we take care of crops is changing. We want to get the most out of our crops and also take care of the earth. This is called crop management. New ideas in this area are based on being careful with what we have. We try to reduce waste and reuse things as much as possible. We also want to make the soil and the environment healthy again.

5.1 Conservation Agriculture and Carbon Sequestration Practices: There is a way of farming called Conservation Agriculture. It is very good for the soil. This type of farming has three rules: do not dig up the soil too much, keep the soil covered with plants or mulch and change the crops. By following these rules we can keep the soil healthy. Stop carbon from going into the air. The soil can hold a lot of carbon. If we use Conservation Agriculture. By adding organic matter to the soil we can increase the amount of carbon it holds. This is good for the environment. Also makes the soil better. For example in areas where grapes are grown we can add the leftover branches from pruning. This reduces the amount of digging. Can hold a lot of carbon. Conservation Agriculture also helps the soil hold water and makes it stronger. It can even help crops grow more.

5.2 Agroforestry Systems: Agroforestry systems. Which means growing trees and crops on

the same land. Are really good for food security and dealing with climate change. They help farmers grow food and keep the environment healthy at the time. Trees provide shade, which can lower the temperature by 2 to 5 degrees Celsius. This shade helps crops and animals stay cool during hot weather. Trees also have roots that hold the soil in place. This prevents soil erosion. Which happens when soil gets washed or blown away. In fact trees can reduce soil erosion by 50 to 70 percent. This helps keep the soil fertile and healthy and also helps to retain water in the soil. Agroforestry systems are also good for people's health and economy. When farmers grow fruit and nut trees along with their crops they have a variety of food to eat. This leads to health outcomes like a reduction in vitamin A deficiency. In fact studies have shown that it can be reduced by 18 percent. These systems also help to store carbon, which's important for reducing climate change. They can store 0.5 to 2 tons of carbon per hectare every year. Because of these benefits agroforestry systems are being considered for inclusion in projects that aim to reduce deforestation and promote sustainable land use. These projects are known as REDD+ or Reducing Emissions from Deforestation and Forest Degradation. They provide incentives for farmers to adopt sustainable land use practices. As a result agroforestry systems are becoming increasingly popular among farmers and policymakers.

5.3 Soil Health Monitoring Technologies: The success of agriculture depends on how well we can measure and keep an eye on soil health over time. These days we do not just check the nutrients in the soil. We look at the picture, including how the soil works physically, chemically and biologically. We can now keep track of things like how dense the soil's how much water it can hold and how well it can keep that water. We also check the quality of the compounds in the soil and how much carbon is in the soil. When it comes to biology we want to know how many different kinds of microbes are in the soil and how active they are. One big improvement in this area is the use of -invasive geophysical techniques. Ground-penetrating

radar is a way to look at the soil without digging it up. It helps us see what is going on under the surface. If the soil is getting damaged or compacted. This method is fast. Does not hurt the soil, which is a big change from the old way of taking samples. The old way was slow, hurt the soil and did not cover the area.

Table 2: Efficiency parameters of various advanced nano-fertilizer formulations based on recent field data.

Nano-Fertilizer Type	Delivery / Matrix Mechanism	Documented Efficiency & Yield Impact
Nano-polymer fertilizers	Biodegradable polymers with NPK	25% increase in NUE; improved overall nutrient uptake
Nano-composite carriers	Nano-clay composites with slow-release NPK	30% reduction in environmental nutrient leaching
Nano-encapsulated micronutrients	Nano-polymers encapsulating specific micronutrients	20% average increase in overall plant growth
Nano-biochar composites	Biochar matrix combined with nano-fertilizers	15% increase in NUE; significant improvement in soil fertility

5.4 Sustainable Nutrient Management: Nano-fertilizers: The old way of using fertilizers is not very good for the environment. It causes a lot of pollution and wastes a lot of nutrients. To make things better we are using kinds of fertilizers called nano-fertilizers. These fertilizers are made up of particles that have nutrients inside them.

They are so small that they can go into the plant through tiny openings. This means the plant gets the right amount of nutrients and we do not waste as much. We have been testing these nano-fertilizers in fields from 2015 to 2024. They work really well. They help the plant use the nutrients efficiently so we do not waste as much. In fact they can increase the yield of crops like wheat by a lot. For example, using nano-zinc on wheat made the yield go up by 31.2 percent. It also made the wheat healthier by putting zinc in it. We have also used nano-silicon on cotton in places that are very dry, like Uzbekistan. It helped the cotton grow better and used chemicals, which is good for the environment and saves money.

Nano-fertilizers consist of essential plant nutrients strictly encapsulated within engineered nanomaterials ranging from 1 to 100 nm in size, such as biodegradable polymer matrices or advanced nano-clays. Because of their exceptionally high surface-area-to-volume ratio and specific delivery mechanisms entering plants directly through natural openings like stomata and lenticels, nano-fertilizers facilitate a slow, highly targeted release of nutrients. This mechanism aligns nutrient availability perfectly with the plant's biological uptake curve, drastically reducing leaching and volatilization.

5.5 Digital Farm Management Platforms (FMIS): The coordination of precision agriculture tools, variable rate applications and biological inputs requires centralized oversight. Farm Management Information Systems serve as the system of modern agricultural operations. These platforms combine -layered datasets including satellite imagery, soil sensor data, financial metrics, labor allocation and weather forecasts into user-friendly dashboards. These digital platforms automate data. Simplify operational planning, regulatory reporting and inventory management. In 2025 over 70% of leading Farm Management Information Systems feature AI analytics integration. For example AI advisory systems like Jeevn AI can analyze up to 1.5 million data points per farm annually offering guidance on irrigation scheduling, crop management and disease intervention. To address

internet connectivity in rural areas emerging platforms utilize on-farm edge computing enabling real-time analytics and machinery adjustments on-site.

6. Challenges and Limitations: The future of farming looks bright. There are big challenges to overcome. With all the new technology we still have a long way to go to make farming better and kinder to the environment. Some of the problems are money, policies and making sure we do things right.

6.1 Economic Barriers and Smallholder Adoption Issues: Farmers with farms, who grow a lot of the world's food face big hurdles in using new farming tech. The main problem is they don't have money to invest in new equipment, software and special seeds. They also don't have roads, which makes it hard to sell their products and get the things they need. In places like South Africa bad roads make it tough for farmers to get their products to market. Small farmers also don't have the tools to sell directly to consumers, which leaves them open to competition from big farms. In countries like the United States small farmers have to follow rules about food safety, which can be expensive. They also don't have access to education and training which makes it hard for

them to use new technology.

6.2 Policy Constraints and Misaligned Global Support: The way governments support farming is often not very helpful. A recent report showed that between 2021 and 2023 the global agricultural sector got an average of \$842 billion in support each year. Most of that money goes to big farms and not enough to small farmers or sustainable farming practices. This can lead to problems like much of certain crops being grown and too much pollution. We need to change the way governments support farming so that it encourages practices and helps small farmers.

6.3 Environmental and Ethical Concerns: The fast change to technology in farming has brought up many difficult questions about what is right and wrong and about the law. These questions are mainly about keeping information private, making sure computer programs are fair and deciding who owns digital information. The special equipment used in farming called precision farming equipment collects a lot of detailed information about the health of the soil, the special characteristics of seeds, the chemicals used and how much food was produced in the past. The problem is that there is no set of rules that says who owns all this information about farming. This creates a lot of confusion between the farmers who produce the information and the

Table 3: Comparison of leading Digital Farm Management Information Systems in 2025.

Top FMIS / Digital Tool	Core Functionality	AI & Integration Focus	Unique Selling Point
Farmonaut	Satellite Monitoring & FMIS	High (API/App); Jeevn AI	Affordable, scalable, blockchain-enabled traceability
Granular	Comprehensive FMIS Software	High; Data/Finance analytics	Extensive operations dashboard for large-scale farms
Taranis	AI/Analytics Platform	High; AI stress detection	Analyzes multi-layered AI datasets for 93% accuracy
CropX	IoT Soil Sensors	Medium; Irrigation analytics	Provides precise, field-scale soil moisture recommendations
AgriWebb	Livestock & Mixed FMIS	Medium; Intuitive mobile interface	Specifically tailored for livestock grazing and mixed farming

big companies that provide technology for farming called Agricultural Technology Providers, which store this information on their online platforms. This situation is not fair because the companies have a lot of power and the farmers do not. The companies could use all the information they collect to help themselves make money, set prices or decide how much land is worth which would hurt the farmers. Also the computer programs used in farming can be wrong sometimes. These programs are trained using a lot of information from farms that grow only one type of crop. So when they make predictions they often do not work well for farms that grow many different types of crops or for farms that use natural methods. If the people who make the rules do not do something about this, these computer programs could make all farms around the world grow crops in this way, which would be bad for the environment because we need many different types of plants and animals to keep the earth healthy. The new technologies that can change the genes of plants and animals are also being closely watched because of concerns about the environment. A technology called CRISPR can change genes precisely but we are still worried about what might happen if we use it. We are concerned that it could have effects, create new things that people are allergic to or cause problems when these changed plants breed with plants that grow wild. We need to be very careful and watchful when we use these technologies and the people who make the rules need to make sure everyone is being transparent and honest about what they're doing.

7. Future Prospects: As we look to the future it's clear that farming will be very different by 2030. New technologies like automation data analysis and eco-friendly practices will change the way we grow food.

7.1 AI-Driven Autonomous Farming and Robotics: The number of people working on farms is going down so we need to find ways to automate farming. The market for robots is growing fast and is expected to be worth \$62.75 billion by 2032. These robots will be able to do

things like plant crops, weed and fertilize all on their own. This will help farmers work efficiently and reduce their labor costs. Companies are already testing tractors and robotic weeders and we can expect to see more of these technologies in the future. To make these tools more accessible to farmers the industry is moving towards a "Robot-, as-a-Service" model, where farmers can lease or subscribe to use robots.

7.2 Blockchain in the Agricultural Supply Chain: Achieving sustainability and restoring public trust requires transparent records from the point of origin to the end consumer. By 2025 blockchain technology has started to work as a ledger for the global agricultural supply chain. It provides records of every transaction and physical change.

When combined with IoT sensors monitoring transport modules for temperature and humidity blockchain networks ensure the food chain's integrity. In case of illness or contamination blockchain enables quick recalls isolating affected batches without disrupting the entire supply network. The BeefLedger network, built on the Ethereum platform shows how combining verification with machine intelligence can establish trust, eliminate food fraud and provide consumers with the exact origin and environmental impact of their purchases. Export markets require traceability proof for regulatory compliance and tariff benefits making blockchain necessary for international market access.

7.3 Sustainable Intensification and the Food-Water-Energy Nexus: The future of agriculture depends on Sustainable Intensification requiring a reconfiguration of the Food-Water-Energy (FWE) nexus. The energy dimension is a challenge due to agriculture's high energy demands. Future agricultural models must balance energy demands and water use efficiently. Research methods vary by region: North America focuses on scenario analysis, East Asia uses optimization models while developing regions in South Asia and Africa prioritize stakeholder-centered approaches.

7.4 Agricultural Carbon Markets: Agriculture can transition from being an emitter of greenhouse gases to a global carbon sink. The voluntary agricultural carbon market is expected to grow, generating up to \$13.7 billion in carbon credits annually by 2050. The market's future relies on high-quality carbon removal credits generated through verified soil carbon sequestration practices. Driven by net-zero targets and compliance schemes like CORSIA demand for high-integrity carbon credits is increasing. The carbon market provides a revenue stream that subsidizes the global transition to regenerative agriculture providing social and environmental benefits. By directing capital to farmers who implement conservation tillage cover cropping and agroforestry the carbon market supports a lucrative secondary revenue stream.

8. Conclusion: Many big problems are happening in the world like bad climate changes, soil getting ruined, too many people and not enough water. We need to change how we do agriculture worldwide and fast. This review shows that we have the tools to make this change. Precision farming, which uses AI, IoT and robots can help us use resources better and grow food. New biology tools, like gene editing and special biopesticides can help us grow food without hurting the environment. We also need to take care of the soil and water. Practices like conservation farming, rotating crops and planting things together can help.. Just having these tools is not enough. The main problems are not technical; they are about money and society. We need policies that help green technology and give money to farmers who take care of the environment. We need to help farmers make sure AI is fair and keep data private. The future of farming needs to mix technology with taking care of nature. We need to help farmers use methods to make it profitable to take care of the environment and make sure supply chains are transparent. If we do this farming can change from hurting the environment to helping it. This is the way we can make sure everyone has food and the planet is safe, for future generations.

9. References:

- Innovations in Crop Production (Precision Agriculture, AI, IoT, and CRISPR)
- Mohan, R. N. V. J., Rayanoothala, P. S., & Sree, R. P. (2025). Next-gen agriculture: integrating AI and XAI for precision crop yield predictions. *Frontiers in Plant Science*, 15:1451607 ``.
- Syam, K. K. S., Manju, G., Thomas, S., & Binson, V. A. (2024). Precision Crop Prediction Using IoT-Enabled Soil Sensors and Machine Learning. *ITEGAM J. Eng. Technol. Ind. Appl.*, 10:65–70 [1].
- Issa, A. A., Majed, S., Abdul Ameer, S., & Al-Jawahry, H. M. (2024). Farming in the Digital Age: Smart Agriculture with AI and IoT. *E3S Web Conf.*, 477:00081 [1].
- Karunathilake, E. M. B. M., et al. (2023). The path to smart farming: innovations and opportunities in precision agriculture. *Agriculture*, 13(8):1593 [2].
- Sun, et al. (2024) and Zhan, et al. (2023). Applications of novel CRISPR-associated proteins (Cas12/Cas13) for multiplex editing and crop improvement ``.
- Salami, P., & Ahmadi, H. (2010). Review of Farm Management Information Systems (FMIS). *New York Science Journal*, 3(5) [3].
- Innovations in Crop Protection (RNAi, Biopesticides, and Remote Sensing)
- *Frontiers in Plant Science* (2025). The RNA-based spray-induced gene silencing (SIGS) technology and recent advances in crop protection, including the EPA approval of Ledprona [4].
- Singh, A., Bhardwaj, R., & Singh, I. K. (2019/2024). Biocontrol Agents: Potential of Biopesticides for Integrated Pest

- Management. Biofertilizers for Sustainable Agriculture and Environment [5].
- Pan, W., et al. (2023). Karst vegetation coverage detection using UAV multispectral vegetation indices and machine learning algorithm. *Plant Methods*, 19:7 ``.
 - Innovations in Crop Management (Circular Economy, Nano-fertilizers, and Soil Health)
 - Boincean, B., Pacurariu, R. L., Rhazzali, A. L., & Cebanu, D. (2025). Circular Economy and Sustainable Practices in Regenerative Agricultural Productivity. *Economics Ecology Socium*, 9(4):1 [6].
 - Supriadi, E., et al. (2025). Circular Economy in Agriculture: Integrating Technology for Sustainable Waste Management. *International Journal of Science and Society*, 7(4):135-148 [7].
 - Setyardi, P. M., et al. (2025). Review of the Circular Economy Implementation in the Agriculture Sector: A Regional Development Approach. *Circular Economy and Sustainability*, 5(2):1509-1533 [8].
 - Demeke, E. D., et al. (2025). A comprehensive review on nano-fertilizers: preparation, development, utilization, and prospects for sustainable agriculture in Ethiopia ``.
 - Seelam, J., et al. (2025). Variable Rate Technologies for Nutrient Management Efficiency. *International Journal of Research in Agronomy* [9].
 - Kumar, A. (2025). Sustainable Intensification of Agriculture Balancing Productivity and Environmental Impact – A Review [10].
 - Garg, D., et al. (2023). Nano-biofertilizer formulations for agriculture: a systematic review on recent advances and prospective applications. *Bioengineering*, 10:1010 ``.
 - Challenges, Policy, and Future Prospects (Blockchain, Carbon Markets, and Ethics)
 - Blockchain technology in agriculture: Enhancing supply chain transparency and traceability (2025) [11].
 - OECD (2025). Agricultural Policy Monitoring and Evaluation: Innovation for Sustainable Productivity Growth [12].
 - Global Report on Food Crises 2025. Evaluation of hunger, climate chaos, and environmental vulnerabilities [13].
 - Carbon Markets 2025 Review and Outlook. Analysis of carbon credit markets, soil carbon sequestration, and high-quality removal credits [14].
 - Ethical and Secure AI Applications in Agricultural Research (2025). Analysis of data ownership, algorithmic bias, and ecological implications [15].
 - Global Autonomous Robots for Agriculture Market Report (2025-2032). Investigating swarm robotics, autonomous phenotyping, and the shift to intelligent farming ecosystems [16].

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ROOTED IN SUSTAINABILITY: THE RISE OF BIO-PLASTICS

Introduction:

In recent decades, the use of plastic has increased tremendously. Because it is inexpensive, lightweight, durable, and easily available, plastic has gained a significant place in our daily lives. However, since traditional plastic is petroleum-based, it takes hundreds of years to decompose in the soil. This has resulted in serious issues such as ocean and land pollution, adverse effects on marine and animal life, and the entry of micro-plastics into the food chain.

As a solution to this global crisis, the world is now turning toward **plant-based bio-plastic** as an eco-friendly alternative.

What is Bio-Plastic?

Bio-plastic is a substance created entirely or partially from natural sources that can easily decompose in the environment. There are two primary types:

- **Plant-based Plastic:** Derived from sources like corn, sugarcane bagasse, potato, cassava, wheat, rice bran, sorghum, millet, coconut coir, and sugarcane fiber.
- **Biodegradable Plastic:** This type decomposes completely within a few weeks or months through the influence of natural microorganisms, temperature, and humidity.

The Importance of Plant Sources

Various agricultural products and wastes serve as essential raw materials for this technology:

- **Sugarcane Bagasse:** A major waste product of the sugar industry that is highly useful for bio-plastic production.
- **Corn:** Its high sugar and starch content makes it a primary raw material for natural plastics.
- **Potato & Cassava:** Their high starch content is ideal for creating thin films and bags.
- **Agricultural Waste:** Items like coconut coir, grain husks, and straw are cost-effective and useful for manufacturing non-food items.

The Production Process

The manufacturing of bio-plastic involves several key stages:

1. **Extraction:** Starch, sugar, or fibers are separated from plants to collect raw materials.
2. **Fermentation:** Natural bacteria convert the plant sugars into useful substances like lactic acid.
3. **Polymerization:** These substances are combined to create strong, flexible molecular chains.
4. **Molding:** The material is transformed into granules, thin sheets, molded containers, fibers, or bags.
5. **Testing:** The final product undergoes rigorous testing for temperature resistance, durability, and tensile strength before entering the market.

Benefits

- **Low Carbon:** Significantly reduces emissions.
- **Farmer Income:** Provides a market for waste.
- **Energy Efficient:** Uses less power to produce
- **Non-Toxic:** No harmful smoke if burned

Applications

- **Food Service:** Plates, cups, bowls, and cutlery.
- **Medicine:** Capsules and hospital disposables.
- **Agriculture:** Seed strips and mulching films.
- **Retail:** Shopping bags and fruit/vegetable wraps.
- Children's toys and pharmaceutical coatings.

The Future of Green Economy

The ban on single-use plastics has provided a significant boost to the bio-plastic industry in India, particularly in states like Maharashtra, Karnataka, Gujarat, and Tamil Nadu. This shift is creating opportunities for small-scale industries in rural areas, generating employment for women and fostering entrepreneurship among the youth.

Future research is currently focused on developing bio-plastics that are water-soluble, safe for marine decomposition, and even more durable. Ultimately, plant-based bio-plastic is not just a replacement for traditional plastic—it is the foundation of a robust **green economy** that ensures a cleaner, healthier environment for future generations.

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ARTICLE ID: 45

Integrated Multi- Storey Cropping Systems for Sustainable and Efficient Land Use

Abstract

Multi-storey cropping system is an innovative and sustainable land use strategy designed to maximize productivity per unit area, especially under small and marginal landholdings. By integrating crops of different heights, canopy structures and rooting depths within the same field, the system ensures efficient utilization of sunlight, soil nutrients, moisture and vertical space. Widely practiced in tropical regions of India, multi-storey systems such as coconut-, arecanut-, cashew-, cocoa-, coffee- and black pepper-based models provide diversified production and year-round income. These systems mimic natural forest stratification, improve soil organic matter, enhance biodiversity and reduce the risk of total crop failure. Proper crop selection based on ecological compatibility, shade tolerance and rooting pattern is essential for successful implementation. Performance of such systems is evaluated using tools like Land Equivalent Ratio (LER) and Relative Yield Total (RYT), which measure biological efficiency and resource complementary. Values greater than unity indicate yield advantage and positive inter specific interactions. Thus, multi-storey cropping represents a viable approach to ensure food security, income stability and ecological sustainability under shrinking land resources and changing climatic conditions.

Keywords: Cropping systems, Coconut, Arecanut, coffee, Cocoa

Introduction

India is one of the leading agricultural nations of the world and ranks as the second largest producer of fruits and vegetables globally. According to the Indian Horticulture Database (2017), horticulture plays a crucial role in ensuring nutritional security and livelihood generation. However, with the population projected to reach nearly 1.5 billion by 2030, the demand for fruits, vegetables and plantation products is increasing rapidly. Although productivity levels have improved in recent decades, the available arable land is either stagnant or shrinking due to rapid urbanization, industrialization, infrastructure development (roads, dams, hydroelectric projects) and land degradation caused by soil erosion, salinity and water logging. A major structural challenge in Indian agriculture is the predominance of small and marginal holdings. More than 85% of farmers fall under this category, and estimates suggest that by 2050, over 95% of landholdings will be small or marginal in size.

The average operational holding in many states is less than one hectare, with a large proportion below 0.5 ha. Under such circumstances, horizontal expansion of cultivated land is nearly impossible. Therefore, increasing productivity per unit area through scientific intensification becomes essential.

In this context, the multi-storied cropping system emerges as a viable and sustainable solution. Multi-storied cropping is an advanced form of multiple cropping in which crops of different heights, canopy structures and rooting depths are grown simultaneously on the same piece of land. The system is designed to maximize vertical space utilization, improve light interception, enhance nutrient recycling and optimize water use efficiency. By integrating perennial fruit trees, plantation crops and short-duration annuals, farmers can harvest multiple products from the same land throughout the year.

This system is particularly suitable for perennial fruit crops such as Mango, Sapota Banana, and plantation crops like Coconut, Arecanut, Coffee and Cocoa, which are tall, widely spaced and have long per-bearing periods. In such orchards and plantations, a significant portion of sunlight and soil space remains underutilized during early growth stages. Multi-storied cropping effectively fills this gap by introducing compatible inter crops such as vegetables, spices, legumes and root crops.

Ecologically, the system mimics natural forest stratification, consisting of an upper canopy (tall trees), middle layer (shrubs or medium crops), lower layer (herbs and vegetables) and ground layer (tubers and creepers). Because of this resemblance to forest ecosystems, it is sometimes referred to as “forest farming.” The approach promotes biodiversity, improves soil organic matter through biomass recycling and enhances carbon sequestration.

Multi-storied cropping systems are widely practiced in the Western Ghats, North-East India and other tropical humid regions where space constraints and ecological sensitivity demand sustainable land use approaches. Research findings from various agricultural institutions highlight that such diversified cropping systems improve system productivity, stabilize income, reduce risk of crop failure and maintain long-term soil fertility.

Thus, in the face of demographic pressure, shrinking land resources and climate variability, multi-storied cropping represents a sustainable land use strategy capable of ensuring food, nutritional and income security for small and marginal farmers while maintaining ecological balance.

Advantages of multi-storied cropping system

Multi-storied cropping system offers numerous agronomic, ecological and economic advantages, particularly under small and marginal landholdings. By integrating crops of varying heights, canopy structures and rooting depths within the same field, this system maximizes resource use efficiency and enhances overall farm sustainability.

1. Higher income per unit area

One of the most significant advantages of multi-storied cropping is the substantial increase in income per unit area. A mixture of compatible crop species often produces a higher combined yield compared to mono cropping systems grown in the same proportion. Since farmers harvest multiple crops—fruits, vegetables, spices, plantation products and sometimes fodder—from the same land, total farm returns increase considerably. Diversification also ensures year-round income flow, reducing dependency on a single seasonal crop.

2. Reduced risk and yield stability

Multi-storied systems reduce the risk of total crop

failure. If one component crop performs poorly due to market fluctuation or climatic stress, other crops compensate economically. The presence of trees and cover crops enhances carbon sequestration and improves soil organic carbon, which strengthens resilience to climate variability. Because the system creates a semi-closed ecosystem, it buffers crops against temperature extremes, heavy rainfall and drought.

3. Efficient utilization of natural resources

This system ensures optimal use of sunlight, soil nutrients, moisture and vertical space. Tall trees capture upper canopy sunlight, while medium and lower crops utilize filtered light. Root systems of different crops exploit nutrients and water from different soil layers, reducing direct competition. As a result, productivity per unit area and per unit time increases significantly.

4. Improvement of soil health and fertility

Multi-storied cropping improves soil structure, fertility and biological activity. Leaf litter, pruned biomass and crop residues are recycled within the system, increasing soil organic matter. Leguminous inter crops enhance nitrogen availability through biological nitrogen fixation. Continuous soil cover reduces erosion caused by wind and rain, thereby conserving topsoil and nutrients. The integration of perennial crops also promotes greater microbial diversity and earthworm activity, leading to long-term soil health improvement.

5. Reduced weed, pest and disease incidence

Crop diversification disrupts pest and disease cycles. Since plants of the same species are spaced apart within mixed systems, the spread of species-specific pests and pathogens is reduced. The diversity of plant types lowers insect population buildup. Ground cover crops suppress weeds through shading and sometimes through allelopathic effects. Overall, the need for chemical pesticides and herbicides may decrease

compared to mono cropping.

6. Climate moderation and hazard reduction

Multi-layer canopy structures protect crops from high light intensity, heavy rainfall, soil erosion, floods and even landslides in hilly regions. Trees act as windbreaks and reduce the impact of raindrops on soil surface, preventing erosion. Shaded environments help conserve soil moisture and reduce evapo transpiration losses. In tropical humid regions, this system provides a favorable microclimate that enhances crop growth even during peak summer.

7. Biodiversity enrichment and ecological balance

The presence of multiple plant species in different layers enriches biodiversity. It creates habitats for beneficial insects, birds and soil organisms, thereby maintaining ecological balance. Such systems mimic natural forest ecosystems and support sustainable land use practices.

8. Employment generation and cost reduction

Multi-storied cropping generates continuous employment due to staggered planting and harvesting schedules. It provides labor opportunities throughout the year rather than seasonally. In some cases, the natural canopy reduces the need for artificial shade structures, lowering investment costs. Inputs such as fertilizers are utilized more efficiently because nutrients are shared among multiple crops within the system.

9. Enhanced national and nutritional benefits

At a broader level, multiple cropping increases total agricultural output, potentially boosting exports and foreign exchange earnings. It contributes to diversified food production, helping families achieve a balanced diet by producing fruits, vegetables, legumes and plantation crops simultaneously.

10. Optimum land use efficiency

In areas where agricultural land expansion is not

feasible, multi-storied cropping maximizes productivity from small landholdings. It increases harvest per unit of land without requiring additional cultivated area. This makes it especially suitable for densely populated countries like India where land resources are limited.

Components of multie storied cropping systems

1. Base crop

The base crop forms the structural and economic foundation of the multi-storey cropping system. It is usually a tall-growing, perennial, and widely spaced crop that occupies the uppermost canopy layer. Because of its height and long duration, it remains in the field for several years and determines the overall layout of the system. Examples commonly include coconut, arecanut, mango, sapota, oil palm, and other perennial plantation crops.

The base crop should ideally have a deep root system, allowing it to draw nutrients and moisture from deeper soil layers. This reduces direct competition with inter crops that generally utilize nutrients from the upper soil layers. Wide spacing between base crop plants creates sufficient interspace for cultivating additional crops at different vertical levels. For example, coconut planted at wider spacing allows enough sunlight penetration to support under-story crops.

Another important consideration is canopy architecture. The canopy of the base crop should allow filtered sunlight to reach the lower layers rather than creating complete shade. Crops with feathery or moderately dense canopies are more suitable than those with extremely dense foliage. Since the base crop is perennial, long-term soil fertility planning, organic matter addition, and integrated nutrient management are critical to maintain sustained productivity.

2. Other crops (inter crops or component crops)

The additional crops grown in the inter-space are selected based on ecological compatibility and economic value. These crops occupy the middle and lower canopy layers. Proper selection ensures complementary use of resources rather than competition.

One of the most important factors is root system differentiation. Crops with varying rooting depths should be chosen so that they extract nutrients and water from different soil horizons. For example, shallow-rooted vegetables or spices can be grown along with moderately deep-rooted crops like banana, while the base crop extracts nutrients from deeper layers. This vertical stratification of roots minimizes nutrient competition and enhances overall resource use efficiency.

Height variation is another essential principle. Crops of different heights are arranged in layers — tall (base crop), medium (such as banana, papaya, or guava), and short or ground-level crops (vegetables, spices, medicinal plants, fodder crops). This layered structure ensures maximum interception of sunlight at different vertical levels. Efficient light distribution improves photosynthetic efficiency and total biomass production.

Canopy structure also plays a vital role. Crops with different leaf shapes, canopy spreads, and growth habits allow better air circulation and light penetration. Proper airflow reduces humidity buildup, thereby minimizing pest and disease incidence. In addition, crops in the lower tier must be capable of tolerating partial shade, as they receive filtered sunlight due to shading by upper layers. Shade-tolerant crops such as ginger, turmeric, colocasia, leafy vegetables, medicinal plants, and certain spices perform well under such conditions.

Local adaptability is another key criterion. The

inter crops selected should be well suited to the local climate, soil type, and rainfall pattern. Using locally adapted varieties ensures better survival, reduced input requirement, and higher economic returns. Seasonal crops can also be included to ensure continuous income throughout the year.

Integrated management considerations

For successful multi-storey cropping, proper nutrient management is essential. Since multiple crops coexist, nutrient demand is higher than mono cropping systems. Integrated nutrient management combining organic manures, compost, green manuring, bio-fertilizers, and balanced chemical fertilizers ensures sustained soil fertility. Irrigation scheduling should be adjusted according to the water requirement of

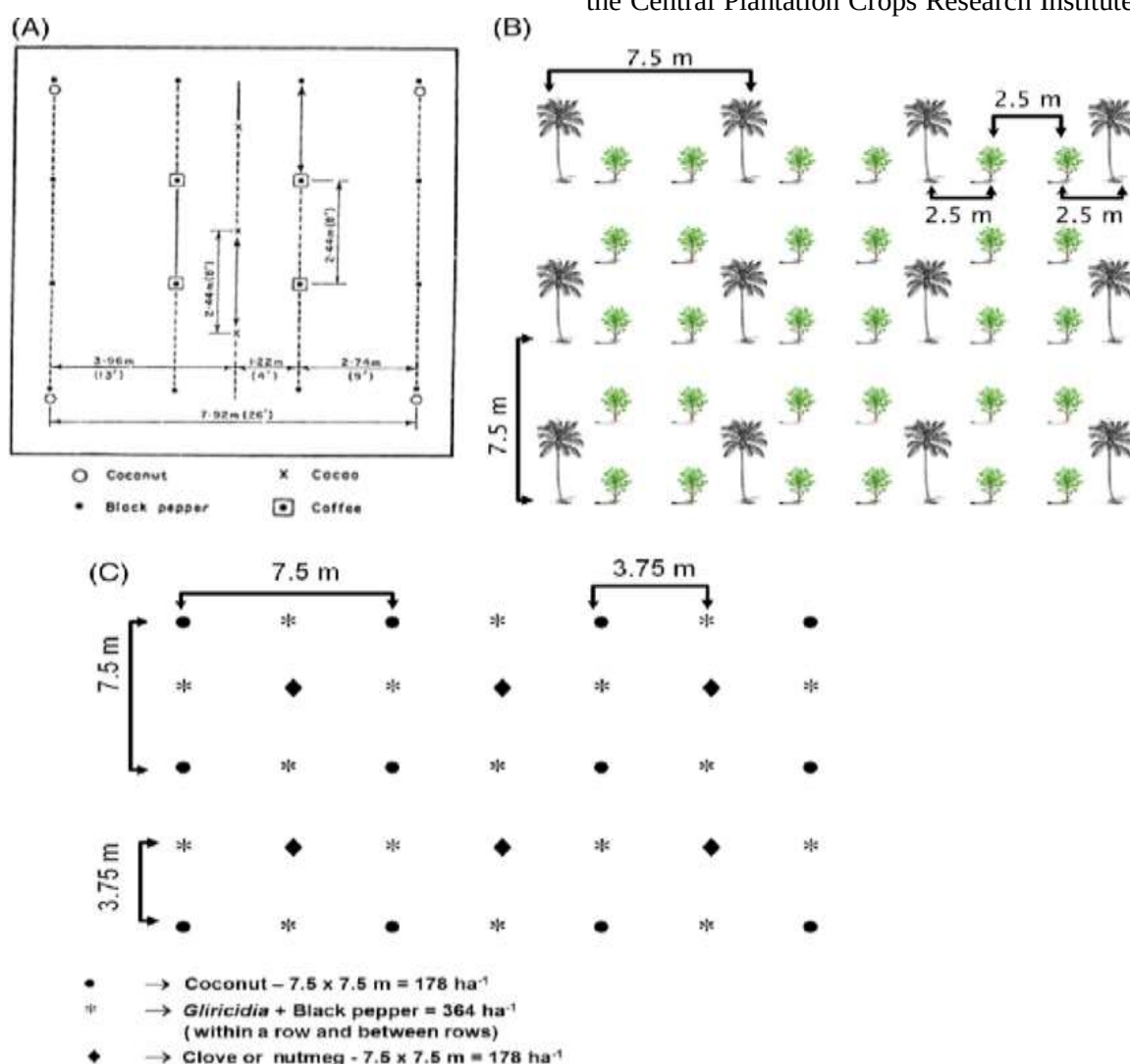
different crops, preferably using micro-irrigation systems like drip irrigation to optimize water use efficiency.

Regular pruning and canopy management of the base crop and intermediate crops help regulate light distribution. Weed management, pest monitoring, and disease control should follow an integrated approach to prevent cross-infestation among crops.

Planting methods in multie storey cropping system

1.coconut -based multi-storey cropping systems:

Coconut-based multi-storey cropping systems are among the most extensively researched and successful models in tropical horticulture. Studies conducted at the Central Plantation Crops Research Institute under





the Indian Council of Agricultural Research have clearly demonstrated the vast potential for inter cropping in coconut plantations. When coconut palms are spaced at $7.5 \text{ m} \times 7.5 \text{ m}$, each palm occupies 56.25 square meters of land. However, research findings indicate that the major concentration of feeder roots is confined to only about 12.57 square meters, which accounts for approximately 22 percent of the allotted area. This implies that nearly 78 percent of the land remains available for cultivating additional crops. Moreover, canopy studies have shown that about 45 to 50 percent of sunlight penetrates through the coconut canopy to reach the ground surface, providing an opportunity to utilize otherwise unused solar energy for growing compatible inter crops.

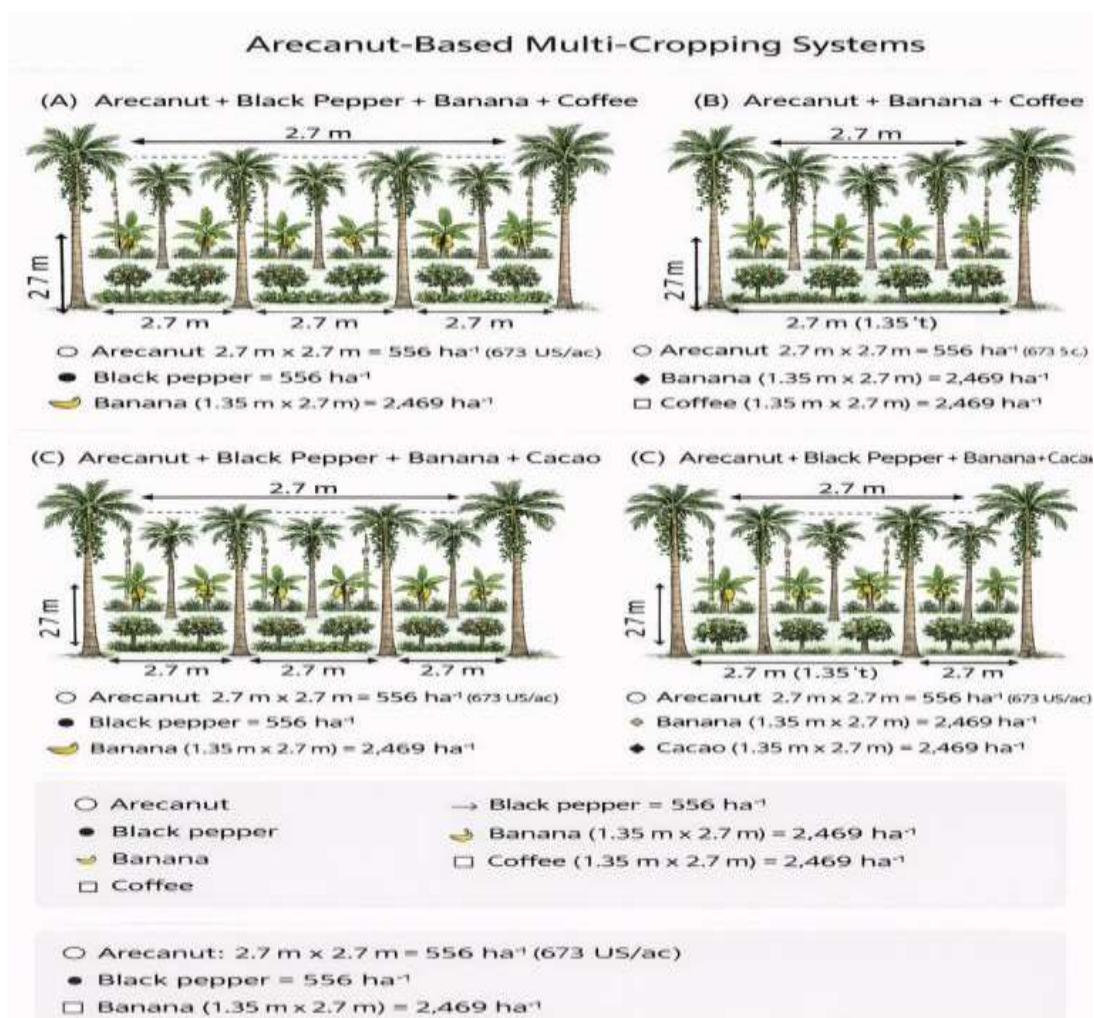
During the initial five years of coconut plantation establishment, when canopy spread is limited and light availability is higher, short- and medium-duration crops can be profitably cultivated. Crops such as banana, turmeric, ginger, pineapple, papaya, vegetables, sorghum, legumes, sunflower, tapioca, elephant foot yam, sweet potato, and guava are commonly recommended. Crop rotation during this phase further enhances soil fertility and biological activity. Research reports suggest that integrating inter crops during the early growth period can even improve coconut productivity by improving soil health and micro climatic conditions. As the plantation matures after 20 to 25 years, filtered light of around 40 percent still reaches the inter-row spaces, making it suitable for shade-tolerant crops. At this stage, multi-tier

combinations such as coconut with black pepper, cocoa, pineapple, turmeric, or ginger are widely adopted. In this arrangement, coconut forms the upper canopy, black pepper climbs on the coconut trunk, cocoa occupies the intermediate layer, and pineapple or spices form the ground layer, thereby achieving efficient vertical space utilization and enhanced income.

2. arecanut- based multi-storey cropping systems:

Arecanut-based multi-storey cropping systems are equally promising, particularly in coastal Karnataka and parts of eastern India. Research conducted in humid tropical regions has demonstrated that inter cropping in arecanut plantations significantly increases yield and economic returns compared to sole cropping. Inter crops such as amorphophallus, Chinese potato, colocasia, ginger, sweet potato, tapioca, and turmeric have been successfully grown in the inter spaces. Studies have indicated that combinations like arecanut with ginger recorded higher land equivalent ratios and better benefit–cost ratios compared to mono cropping. Mixed cropping models incorporating banana and turmeric have shown improvements in palm growth, leaf production, and nut yield. These findings confirm that arecanut- based multi-storey systems enhance both biological efficiency and farm profitability. Spacing maintained in this cropping system Arecanut ($2.7 \times 2.7 \text{ m}$), Banana ($1.35 \times 2.7 \text{ m}$), Black pepper (1vine/palm), Coffe ($1.35 \times 2.7 \text{ m}$), Cocoa ($1.35 \times 2.7 \text{ m}$).

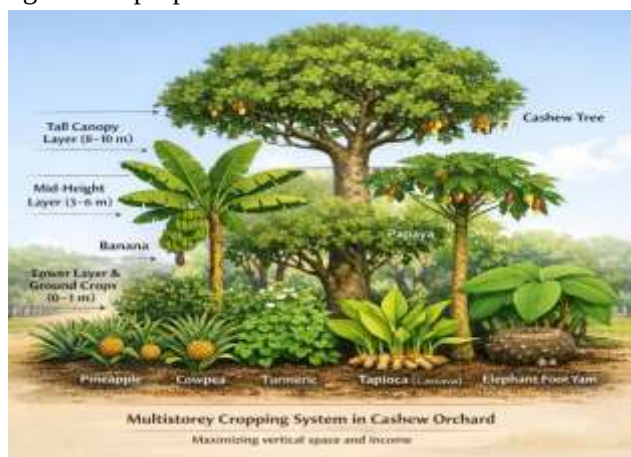




3. Cashew-based multi-storey cropping systems:

Cashew-based cropping systems also offer considerable scope for inter cropping, particularly during the early years of orchard establishment. Since cashew trees expand their canopy gradually, a significant proportion of land remains underutilized in

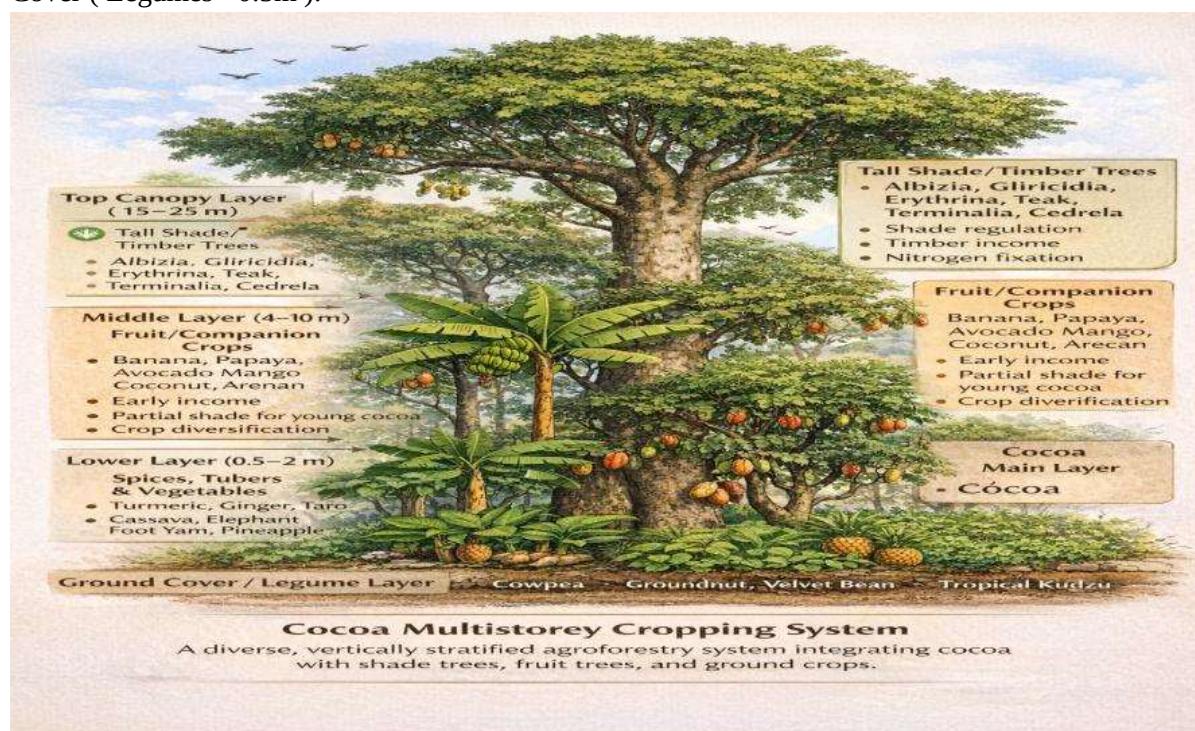
the first three years. When planted at wider spacing, canopy coverage is minimal during the early growth stages, allowing farmers to cultivate inter crops such as pineapple, banana, papaya, cowpea, tapioca, turmeric, and elephant foot yam. Inter cropping in cashew not only provides additional income but also suppresses weed growth and improves soil organic matter content, especially when legumes are include . Spacing maintained here in between the crops are Top Layer with main crop i.e Cashew (3-5m) which acts as a main crop here in this system, which initially slow - growing ,providing light shade and structural support. Middle Layer (Banana/papaya - 2-3m) Fast growing perennials that utilize the middle vertical space ,providing income in years of duration 2-3 . Low Layers (Annuals/tubers - 0-1m) Shade tolerant crops like turmeric,ginger,elephant foot yam,or ground cover like cowpea that utilizes ground - level space,suppress weeds,and improve soil fertility.



4.cocoa-based multi-storey system: Cocoa-based multi-storey systems are naturally suited to shaded environments because *Theobroma cacao* is inherently a shade-loving crop. Cocoa is widely cultivated beneath coconut plantations and fits well into multi-tier systems. It is generally planted at a safe distance from the coconut trunk to avoid root competition, with appropriate spacing between cocoa plants to ensure proper growth. In regions where coconut palms are spaced widely, several rows of cocoa can be accommodated in the inter spaces.

This allows optimal utilization of soil moisture, nutrients, and filtered sunlight, leading to diversified income sources for farmers. Different layers in this method Top canopy (Timber & Shade Trees 15 - 25 m), Middle Layer (Banana, papaya, Coconut, 4-10 m), Main layer (cocoa 2 -5 m), Lower layer (Turmeric, Cassava, Pine apple 0.5 - 2 m), Ground Cover (Legumes <0.5m).

diversified structure conserves soil moisture, enhances biodiversity, and stabilizes farm income. Spacing maintained here is Upper storey (Shade trees 10 - 20m), Middle storey (Coffee 1.5 - 2.5m), Climber Layer, (Black pepper 8 - 10 m), Lower Storey, (Cardamom 0.5 - 1m), Filler crop (Banana 2-3m).



5. coffee - based multi-storey system:

Coffee plantations, particularly in the Western Ghats region of South India, traditionally follow a multi-storey structure. Coffee is cultivated under shade trees, and additional crops such as black pepper, cardamom, and banana are integrated within the system. This

6. Black pepper - based multi- storey systems

Black pepper-based systems also widely practiced in plantation ecosystems. Pepper vines utilize vertical support from coconut, arecanut, or shade trees, making them ideal components of multi-storey cropping. Inter cropping pepper with ginger, turmeric, colocasia, and

elephant foot yam has shown positive economic outcomes. However, prolonged cultivation of banana in mature pepper gardens may reduce pepper yield due to competition for nutrients and light. Diversified mixed cropping systems have also been associated with reduced disease incidence and improved ecological balance. Spacing maintained in Black Pepper based multi storey cropping systems Upper Storey (Coconut/Arecanut/ Shade trees 10 - 20m), Climber Layer (Black pepper 8-10m), Middle/Lower Storey (Ginger, turmeric 0.5 - 1m), Ground Layer (Colocasia 0.5-1m), Tuber Layer(



Elephant foot yam 0.6 - 1m).

Cropping system performance evaluation

tools: The sustainability and long-term success of any cropping system—particularly a multi-storey cropping system—depend on how efficiently the different crop components utilize available resources such as light, water, nutrients, and space. In multi-storey systems, crops are arranged vertically and horizontally to maximize resource use efficiency while minimizing competition. Therefore, evaluating system performance requires quantitative indices that measure productivity advantage, biological efficiency, and inter specific interactions. Among the most widely used tools are the Land Equivalent Ratio (LER) and Relative Yield Total (RYT). These indices help determine whether inter cropping provides a yield benefit compared to mono-cropping and assess the degree of complementary

or competition among component crops. Land Equivalent Ratio (LER) is one of the most important and widely accepted indices for evaluating inter cropping systems. It measures the relative land area required under sole cropping to achieve the same yield as obtained from an inter cropping system. LER is calculated using the formula:

$$LER = \sum (Y_{pi} / Y_{mi})$$

where Y_{pi} represents the yield of each crop in the poly culture (inter-crop system), and Y_{mi} represents the yield of each crop when grown as a sole crop (monoculture). The summation is taken for all component crops in the system. According to the classical work of R. Wiley (1979), LER provides a direct measure of biological efficiency in inter cropping systems.

An LER value equal to 1.0 indicates that there is no difference in yield between inter-cropping and mono-cropping; the crops are simply sharing resources without any net advantage or disadvantage. A value greater than 1.0 indicates a yield advantage of inter cropping, meaning that more land would be required under sole cropping to produce the same yield. For example, an LER of 1.25 implies that 25% more land would be needed in monoculture to match the inter-crop yield. Conversely, an LER less than 1.0 indicates a yield disadvantage or negative interaction among crops. In multi-storey cropping systems, LER values greater than 1 generally reflect positive complementary interactions, such as differential rooting depth, varied canopy architecture, and staggered nutrient uptake patterns. These positive inter specific interactions are stronger than the intraspecific competition observed in monoculture, thereby enhancing overall productivity and resource use efficiency. Relative Yield Total (RYT) is another significant biological index used particularly in replacement series experiments. It quantifies the extent to

which two species share or compete for the same limiting resources. The formula for RYT when two species are inter cropped is:

$$\text{RYT} = (\text{X}_{\text{mix}} / \text{X}_{\text{sole}}) + (\text{Y}_{\text{mix}} / \text{Y}_{\text{sole}})$$

where X_{mix} and Y_{mix} are the yields of species X and Y in the mixture, and X_{sole} and Y_{sole} are their respective yields in monoculture. The concept and interpretation of RYT were elaborated by R. Mead (1986), who emphasized its importance in understanding resource partitioning and competition dynamics.

An RYT value greater than 1 indicates that the species utilize different ecological niches or avoid direct competition for limiting resources, suggesting complementarity in resource use. In multi-storey cropping systems, this often occurs due to differences in canopy height, root distribution, and temporal growth patterns.

An RYT value equal to 1 indicates complete sharing of the same limiting resource without antagonism, meaning the crops compete equally but do not negatively affect each other beyond expected competition. An RYT value less than 1 indicates mutual antagonism, where competition between species reduces overall system productivity.

Conclusion:

Multi-storey cropping systems offer a practical solution to the challenges of limited land availability, increasing population pressure and climate variability. By efficiently utilizing vertical and horizontal space, these systems enhance productivity, diversify farm income and improve ecological balance. Integration of perennial base crops with compatible inter crops strengthens soil health, reduces pest incidence and promotes long-term sustainability. Evaluation indices such as LER and RYT confirm the biological and economic advantages of diversified cropping over monoculture. When properly managed through integrated nutrient, water and canopy management practices, multi-storey cropping not only increases land use efficiency but also ensures environmental resilience. Therefore, it stands as a promising strategy for sustainable agricultural development and livelihood security in tropical and subtropical regions.

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OUAT, Bhubaneswar***ARTICLE ID: 46****RICE FORTIFICATION AS A STRATEGY FOR ADDRESSING
MICRONUTRIENT DEFICIENCY AND ENHANCING FOOD
SECURITY****ABSTRACT**

Micronutrient deficiency, commonly referred to as 'hidden hunger,' remains a pervasive global public health challenge, disproportionately affecting populations in low- and middle-income countries (LMICs) that are heavily dependent on rice as a staple food. Rice, consumed daily by over half of the world's population, is inherently low in essential micronutrients such as iron, zinc, vitamin A, vitamin B12, and folic acid. Rice fortification—the deliberate addition of these critical nutrients to milled rice—has emerged as a cost-effective, scalable, and sustainable food-based intervention to address micronutrient deficiencies and improve food security outcomes. This review critically examines the scientific basis, technological approaches, nutritional efficacy, food safety considerations, consumer acceptance, and policy frameworks governing rice fortification programs globally. Evidence from clinical trials, observational studies, and large-scale program evaluations demonstrates that fortified rice significantly improves micronutrient status, reduces anemia prevalence, and enhances dietary quality among vulnerable population groups including women of reproductive age, children under five, and school-age children. Despite promising outcomes, challenges including supply chain constraints, regulatory harmonization, consumer acceptability, and program sustainability remain. This article concludes with recommendations for strengthening rice fortification programs as a complementary strategy to achieve the United Nations Sustainable Development Goal 2 (Zero Hunger) and SDG 3 (Good Health and Well-being).

Keywords: rice fortification, micronutrient deficiency, food security, hidden hunger, ultra rice, iron, vitamin A, zinc

1. INTRODUCTION

Food security, as defined by the food and agriculture organization(fao), exists when all people, at all times, have physical, social, and profitable access to sufficient, safe, and nutritional food that meets their salutary requirements and food preferences for an active and healthy life(fao, 2009). Among the four pillars of food security — vacuity, access, application, and stability — salutary quality and nutrient application are decreasingly honored as central to achieving meaningful nutritive issues. Hidden hunger, characterized by habitual insufficiency in essential vitamins and minerals despite acceptable sweet input, affects roughly two billion people encyclopedically(who, 2022). Iron insufficiency anemia, vitamin a insufficiency, and zinc insufficiency remain among the most current and consequential nutritive diseases worldwide.

Rice (*oryza sativa*) is the primary chief food for further than 3.5 billion people, particularly across asia,sub-saharan africa, and corridor of latin america(fao, 2021). In numerous of these regions, rice constitutes 50 – 80 of total diurnal sweet input, making it an ideal vehicle for the delivery of essential micronutrients to large, nutritionally vulnerable populations. Still, the milling process that produces the white polished rice preferred by consumers removes the bran and origin layers, significantly depleting the grain's naturally being micronutrient content. Accordingly, populations that calculate generally on mulled white rice are at elevated threat of micronutrient scarcities.

rice bastion offers a compelling result to this nutritive gap. Unlike salutary diversification strategies that bear sustained behavioral change, or supplementation programs that depend on healthcare delivery systems, rice bastion leverages being food force chains and consumption habits to deliver micronutrients at scale, with minimum dislocation to consumers. The fashion involves perfecting reused rice with one or further micronutrients through colorful technological approaches, including hot extrusion, warm extrusion, dusting, and coating styles.

this review synthesizes current scientific substantiation on the efficacy, safety, technology, adequacy, and policy geography of rice bastion programs, with particular attention to their part in perfecting food security issues among vulnerable populations in low- and middle- income countries. By furnishing a comprehensive overview of the field, this composition aims to inform unborn exploration precedences and companion policy opinions related to large- scale rice bastion perpetration.

2. MICRONUTRIENT DEFICIENCIES AND THE NUTRITIONAL COMPOSITION OF RICE

2.1 Global Burden of Micronutrient Deficiency

Micronutrient deficiencies constitute one of the most serious yet under recognized public health burdens of the twenty-first century. The World Health Organization estimates that iron deficiency anemia affects approximately 1.62 billion people globally, representing 24.8% of the world's population (WHO, 2022). Children under five and women of reproductive age bear the greatest disease burden, with anemia contributing to increased maternal mortality, impaired cognitive development, reduced work productivity, and diminished immune function. Vitamin A deficiency (VAD) affects an estimated 190 million preschool-age children in developing countries and is the leading preventable cause of childhood blindness and increased susceptibility to infectious diseases (UNICEF, 2019). Zinc deficiency, present in approximately 17% of the global population, impairs growth, immune function, and reproductive outcomes (Wessells & Brown, 2012).

The economic consequences of micronutrient deficiencies are equally significant. The World Bank has estimated that malnutrition, including hidden hunger, costs the global economy up to 2–3% of GDP annually through reduced productivity, increased healthcare expenditure, and diminished human capital development (World Bank, 2016). In rice-dependent economies of South and Southeast Asia, where stunting and anemia remain highly prevalent, the impact is particularly acute.

2.2 Nutritional Profile of Milled White Rice

Whole grain brown rice contains meaningful concentrations of B vitamins (thiamine, riboflavin, niacin, B6, folate), minerals (iron,

zinc, magnesium, phosphorus), and dietary fiber. However, the commercial milling and polishing processes remove the outer bran and germ layers to produce the white rice preferred by the majority of consumers for its taste, texture, and extended shelf life. This processing removes up to 90% of thiamine, 70% of riboflavin, 50% of niacin, 60% of iron, and significant proportions of other nutrients (Dipti et al., 2012). The resulting polished white rice, while providing readily digestible carbohydrate energy, is a nutritionally poor food when consumed as the predominant dietary staple without adequate dietary diversification.

Furthermore, rice contains phytic acid and other anti-nutritional factors that reduce the bioavailability of minerals such as iron and zinc, compounding the problem of nutrient inadequacy in predominantly rice-based diets. These factors underscore the importance of fortification as an intervention that not only adds micronutrients but, in some formulations, also incorporates bioavailability enhancers to maximize absorption.

3. RICE FORTIFICATION TECHNOLOGIES AND APPROACHES

3.1 Overview of Fortification Methods

Several technological approaches have been developed and validated for adding micronutrients to milled rice. Each method differs in terms of nutrient retention, cost, scalability, and consumer acceptability. The most widely used methods include: (1) hot extrusion (ultra rice technology), (2) warm extrusion, (3) coating, and (4) dusting. Selection of an appropriate method depends on the target nutrients, local infrastructure, regulatory standards, and program objectives.

3.2 Hot Extrusion (Ultra Rice Technology)

Hot extrusion, also known as the ultra rice or

reconstituted rice grain (RRG) method, is the most extensively studied and widely implemented fortification technology. In this process, rice flour is blended with a premix containing the desired micronutrients, water, and other food-grade ingredients. The mixture is then extruded under high temperature and pressure through a die shaped to mimic normal rice grains. The resulting fortified rice kernels (FRKs) are nearly indistinguishable from natural rice grains in size, shape, and color, and can be blended with unfortified rice at a standard ratio of 1:100 or 1:200 (one fortified kernel per 100 or 200 regular grains) before reaching the consumer (Aaron & Bhagwat, 2014).

The hot extrusion process provides excellent nutrient retention and allows for the incorporation of a wide range of water-soluble and fat-soluble vitamins and minerals, including iron, zinc, folic acid, vitamin B12, vitamin A, niacin, and thiamine. Retention studies demonstrate that iron and zinc retention in extruded FRKs after normal cooking is high, ranging from 75–95%, depending on the specific nutrient formulation and cooking method. A critical advantage of ultra rice technology is that the fortified kernels are processed through the existing rice supply chain without requiring significant modifications to milling, distribution, or retail infrastructure.

3.3 Coating and Dusting Methods

Coating methods involve applying a layer of micronutrients dissolved or suspended in a food-grade edible coating material directly onto polished rice grains. Multiple layers may be applied to improve retention and protect labile nutrients from degradation. While coating is less expensive than extrusion for certain nutrient combinations, water-soluble nutrients such as B vitamins are susceptible to significant losses during washing and cooking, which are standard

practices in many rice-consuming cultures. Dusting, the simplest and least expensive method, involves directly applying dry micronutrient premixes to polished rice. However, this method results in high variability in nutrient distribution, poor consumer acceptance due to altered grain appearance, and substantial nutrient losses during washing. As a result, dusting is generally not recommended for population-level fortification programs.

3.4 Nutrient Stability and Bioavailability Considerations

The stability of added micronutrients throughout the supply chain—from fortification to consumption—is a critical determinant of program efficacy. Iron compounds used in rice fortification include ferrous sulfate, ferric pyrophosphate, electrolytic iron, and NaFeEDTA, each differing in bioavailability, stability, and organoleptic impact. Ferrous sulfate, while highly bioavailable, can cause undesirable color changes and rancidity in rice. Micronized ferric pyrophosphate and NaFeEDTA offer improved stability and acceptable sensory properties while maintaining adequate bioavailability (Hurrell et al., 2010). Vitamin A in the form of retinyl palmitate is commonly used due to its stability under normal storage conditions, while folic acid and vitamin B12 require encapsulation or coating to minimize degradation during high-temperature extrusion processing.

4. NUTRITIONAL EFFICACY AND HEALTH OUTCOMES OF RICE FORTIFICATION

4.1 Evidence from Randomized Controlled Trials

The nutritional efficacy of fortified rice has been evaluated in numerous randomized controlled trials (RCTs) conducted across diverse settings. A

landmark RCT conducted in the Philippines among school-age children demonstrated that consumption of iron-fortified rice for six months significantly increased serum ferritin concentrations and reduced the prevalence of iron deficiency anemia compared to unfortified rice (Gera et al., 2012). Similarly, a study in Cambodia among women of reproductive age found that daily consumption of multi-micronutrient fortified rice over six months significantly improved iron status, reduced anemia prevalence from 44% to 28%, and improved folate and vitamin B12 concentrations (Laillou et al., 2012).

Studies conducted in India, Bangladesh, Indonesia, and Brazil have consistently reported significant improvements in hemoglobin concentration, serum ferritin, serum retinol, and zinc status among populations consuming fortified rice compared to control groups receiving unfortified rice. A systematic review and meta-analysis by Garg et al. (2014) of ten RCTs concluded that iron-fortified rice consumption was associated with a significant increase in hemoglobin concentration (weighted mean difference: 3.04 g/L, 95% CI: 1.77–4.31) and a significant reduction in iron deficiency anemia prevalence. The evidence base for zinc and vitamin A fortification of rice is smaller but similarly promising.

4.2 Impact on Vulnerable Population Groups

Children under five and women of reproductive age represent the most nutritionally vulnerable populations and have been the primary focus of rice fortification efficacy research. In young children, iron deficiency impairs neurodevelopment, cognitive function, and behavioral development, with potentially irreversible consequences if deficiency occurs during critical windows of brain development. RCTs among preschool and school-age children

in Southeast Asia have demonstrated that consumption of iron-fortified rice significantly improves cognitive performance, attention, and school attendance in addition to improving iron status biomarkers (Beard et al., 2007).

For women of reproductive age, iron and folate status are particularly critical for preventing maternal anemia, neural tube defects in offspring, and adverse pregnancy outcomes. Multi-micronutrient fortified rice incorporating iron, folic acid, and vitamin B12 has demonstrated significant efficacy in improving maternal nutritional status in studies conducted in Cambodia and India. School feeding programs utilizing fortified rice in Brazil, India, and the Philippines have shown reductions in student absenteeism and improvements in nutritional status attributable to regular fortified rice consumption.

4.3 Large-Scale Program Evaluations

Beyond controlled trial settings, real-world evaluations of national and regional rice fortification programs provide important evidence of program effectiveness. The World Food Programme's rice fortification programs in refugee settings in Thailand, Nepal, and Uganda have demonstrated improvements in iron and micronutrient status among beneficiary populations consuming fortified rice over extended periods (WFP, 2020). Brazil's mandatory fortification of wheat and corn flour, combined with voluntary rice fortification programs, has contributed to significant declines in iron deficiency anemia prevalence over the past two decades, demonstrating the potential population-level impact of food fortification strategies.

India's large-scale pilot programs under the Centrally Sponsored Scheme for rice fortification

have reached millions of beneficiaries through the public distribution system and midday meal program, with monitoring data indicating high program reach and preliminary improvements in nutritional indicators in program districts (FSSAI, 2022).

5. FOOD SAFETY AND QUALITY ASSURANCE IN RICE FORTIFICATION

5.1 Regulatory Standards and Nutrient Specifications

Food safety and quality assurance are fundamental prerequisites for any large-scale rice fortification program. The Codex Alimentarius Commission, through its guidelines on food fortification with micronutrients (CAC/GL 9-1987, revised 2015), provides an international framework for establishing nutrient levels, safety considerations, and labeling requirements for fortified foods. National regulatory bodies, including the Food Safety and Standards Authority of India (FSSAI), the Bureau of Philippine Standards, and equivalent agencies in other rice-consuming nations, have established specific standards for fortified rice kernels, including minimum and maximum nutrient levels, quality specifications for fortified kernels, and quality control protocols for manufacturers.

Micronutrient levels in fortified rice are carefully calibrated to provide a meaningful contribution to daily nutrient requirements without approaching tolerable upper intake levels (ULs). For iron, typical fortification levels deliver approximately 30–50% of the recommended daily intake per standard serving, while vitamin A fortification is designed to provide 20–30% of the recommended daily allowance per serving, ensuring safety even among population groups with diverse dietary intakes.

5.2 Quality Control and Monitoring Frameworks

Effective quality control throughout the fortification value chain—from premix production and fortification at the mill level to distribution and retail—is essential for program integrity. Internal quality control involves regular testing of fortified kernels and blended rice for nutrient content, blend ratio verification, and physical quality parameters including kernel size, color, and integrity. External quality assurance involves independent third-party laboratory testing and government regulatory inspections. The Global Alliance for Improved Nutrition (GAIN) and the WFP have developed standardized quality assurance protocols and monitoring tools that have been adopted in national rice fortification programs across multiple countries.

6. CONSUMER ACCEPTABILITY AND BEHAVIORAL CONSIDERATIONS

6.1 Sensory Characteristics and Consumer Perceptions

Consumer acceptability is a critical determinant of the real-world effectiveness of rice fortification programs. Unlike fortification of highly processed foods, where the carrier food itself may mask sensory changes, rice fortification presents unique challenges because rice is consumed with minimal processing and consumers are highly attentive to changes in the appearance, texture, and taste of rice grains. Studies of consumer acceptance of fortified rice have generally found high levels of acceptability when fortified kernels are well-matched to local rice grain characteristics in terms of size, shape, and color, and when the blend ratio of fortified to regular rice kernels is appropriately low (1:100 or 1:200).

However, consumer acceptance varies substantially across different cultural and

socioeconomic contexts. In some populations, particularly among educated urban consumers, concerns about the artificial nature of fortification or misconceptions that fortified rice is of inferior quality present barriers to acceptance. Effective communication and social marketing campaigns that transparently convey the nutritional benefits of fortified rice and address common misconceptions are therefore essential components of successful rice fortification programs.

6.2 Washing and Cooking Practices

A particularly important behavioral consideration in the context of rice fortification is the widespread practice of washing rice prior to cooking, which is common across many Asian and African rice-consuming cultures. Washing rice can result in significant losses of water-soluble nutrients, including B vitamins, from both naturally occurring and fortified sources. Studies have demonstrated that a single washing cycle can remove 20–40% of water-soluble vitamins from fortified rice kernels, with losses increasing with multiple washing cycles and extended soaking. Technological innovations, including the use of encapsulation and coating technologies that protect water-soluble nutrients during washing, have been developed to address this challenge. Consumer education initiatives encouraging minimal or no washing of fortified rice are also an important complementary strategy.

7. POLICY FRAMEWORKS AND GLOBAL PROGRAMS

7.1 International Policy Landscape

The global momentum for rice fortification has accelerated significantly over the past decade, driven by growing evidence of efficacy, declining technology costs, and increased political commitment to addressing malnutrition as a development priority. The United Nations Decade

of Action on Nutrition (2016–2025) and the Scaling Up Nutrition (SUN) Movement have provided important policy frameworks that have catalyzed national commitments to food fortification, including rice fortification, as part of comprehensive nutrition strategies. The World Health Organization has endorsed rice fortification as one of several recommended strategies for improving iron status and reducing anemia in populations consuming rice as a staple food (WHO, 2018).

At the national level, several governments have enacted mandatory rice fortification legislation or established large-scale voluntary fortification programs. The Philippines enacted Executive Order No. 382 in 1989 mandating the fortification of rice with iron, representing one of the world's first national mandatory rice fortification policies. India has committed to scaling up rice fortification through its public distribution system to reach the entire eligible population by 2024, representing the world's largest rice fortification program by scale and reach (Government of India, 2021). Costa Rica, Nicaragua, and Panama have implemented mandatory rice fortification with iron and B vitamins, contributing to documented declines in iron deficiency anemia prevalence in these populations.

7.2 Role of International Organizations

International organizations including the World Food Programme, UNICEF, the Global Alliance for Improved Nutrition (GAIN), PATH, and the Micronutrient Forum have been instrumental in providing technical assistance, funding, and advocacy support for national rice fortification programs. The WFP alone has procured and distributed fortified rice to vulnerable populations in more than 40 countries through its food assistance operations, representing a significant global reach (WFP, 2020). GAIN's fortification programs have supported the establishment of

premix manufacturing capacity, regulatory frameworks, and quality assurance systems in numerous countries, contributing to the sustainability of national fortification efforts.

7.3 Integration with Food Security Programs

Rice fortification achieves its greatest impact when integrated within broader food security and nutrition programs rather than implemented as a standalone intervention. Social protection programs including food distribution schemes, school feeding programs, and conditional cash transfer programs represent particularly effective delivery platforms for fortified rice, as they reach nutritionally vulnerable populations with a high degree of coverage and regularity. The integration of rice fortification into India's Integrated Child Development Services (ICDS) scheme, midday meal program, and public distribution system exemplifies this approach, leveraging existing government infrastructure to deliver fortified rice to women, children, and low-income households at scale.

8. CHALLENGES AND LIMITATIONS

8.1 Supply Chain and Infrastructure Constraints

Despite the significant progress achieved in rice fortification over the past two decades, important challenges remain that limit the scale and sustainability of existing programs. Supply chain complexity represents one of the most significant operational challenges. The introduction of fortified rice kernels into existing milling and distribution systems requires careful management of blending ratios, storage conditions, and distribution logistics to maintain nutrient content and prevent segregation of fortified kernels from unfortified rice. In countries with fragmented rice milling sectors dominated by large numbers of small-scale mills, achieving consistent

fortification quality and coverage presents substantial logistical and regulatory challenges.

8.2 Economic and Financing Considerations

The incremental cost of rice fortification is generally modest—estimated at USD 0.07–0.12 per kilogram of fortified rice, or approximately USD 10–20 per person per year at the population level—and cost-effectiveness analyses consistently demonstrate favorable returns on investment through reductions in healthcare costs and improvements in productivity (Horton & Ross, 2003). However, in low-income country contexts, even modest incremental costs may present barriers to program sustainability, particularly when public financing is constrained. Public-private partnerships, leveraging private sector investment in premix production and fortification technology, alongside government commitment to regulatory frameworks and procurement, offer a potentially sustainable financing model.

8.3 Knowledge Gaps and Research Priorities

Several important knowledge gaps remain in the evidence base for rice fortification. Long-term impact studies examining the sustainability of nutritional improvements beyond the intervention period are limited. The interaction between rice fortification and other dietary factors, including phytate content, cooking methods, and overall dietary diversity, requires further investigation to optimize program design. Research on the optimal nutrient combinations and levels for multi-micronutrient fortified rice, particularly with respect to interactions between iron and zinc, and the impact of fortification on vitamin A status in settings with high VAD prevalence, is an important priority for future research.

9. RECOMMENDATIONS AND FUTURE DIRECTIONS

Based on the evidence reviewed in this article, the following recommendations are proposed to strengthen rice fortification as a strategy for addressing micronutrient deficiency and enhancing food security:

First, governments in rice-dependent low- and middle-income countries should prioritize the development and implementation of evidence-based rice fortification policies, incorporating rice fortification into national nutrition action plans and food systems strategies. Regulatory frameworks should establish clear standards for fortified rice kernels, blending ratios, quality control requirements, and labeling, drawing on international guidelines from the Codex Alimentarius Commission and WHO.

Second, rice fortification programs should be designed with explicit attention to equity, ensuring that nutritionally vulnerable populations—including women of reproductive age, children under five, and low-income households—have consistent access to fortified rice through social protection delivery platforms. Integration with existing food assistance, school feeding, and public distribution programs maximizes reach and cost-effectiveness.

Third, robust quality assurance systems encompassing internal mill-level quality control, external third-party verification, and government regulatory oversight are essential to ensuring that fortified rice reaching consumers consistently delivers the intended nutrient content. Investment in laboratory capacity and regulatory enforcement infrastructure is a critical enabler of program success.

Fourth, consumer communication and social marketing campaigns should be integral components of rice fortification programs, providing clear and transparent information about the nutritional benefits of fortified rice, addressing common misconceptions, and

promoting appropriate handling and cooking practices to minimize nutrient losses.

Fifth, the research community should prioritize long-term impact evaluations of rice fortification programs, studies of optimal nutrient formulations and levels, and investigations of the interactions between fortification and broader dietary patterns and food system factors. Investment in implementation research is needed to generate evidence on effective strategies for scaling and sustaining rice fortification programs across diverse contexts.

10. CONCLUSION

Rice fortification represents one of the most promising and evidence-based strategies for addressing the pervasive challenge of micronutrient deficiency in populations dependent on rice as a staple food. The scientific evidence demonstrates that well-designed and effectively implemented rice fortification programs can deliver meaningful improvements in iron, zinc, vitamin A, and B vitamin status among vulnerable population groups, contributing to reductions in anemia prevalence, improvements in cognitive development and productivity, and advancement toward global food security and nutrition goals. Technological advances in fortification methods, declining premix costs, and growing political commitment to nutrition as a development priority have created favorable conditions for scaling rice fortification programs globally.

At the same time, the limitations of rice fortification as a standalone intervention must be acknowledged. Fortification addresses micronutrient inadequacy but does not resolve the underlying structural determinants of food insecurity, including poverty, inadequate dietary diversity, inequitable food systems, and lack of access to health services. Consequently, rice fortification is most effectively deployed as one

component within a comprehensive and integrated approach to food and nutrition security that includes dietary diversification, supplementation for high-risk groups, nutrition education, and structural improvements in food systems and social protection.

As the global community works toward achieving the 2030 Sustainable Development Goals, rice fortification offers a practical, scalable, and cost-effective means of improving nutritional outcomes for billions of people. By strengthening the evidence base, building regulatory and technical capacity, and integrating rice fortification within broader food security strategies, it is possible to leverage this intervention to make meaningful progress toward a world free from hidden hunger.

REFERENCES

1. Aaron, G. J., & Bhagwat, S. (2014). Rice fortification: A review of its technical and programmatic context. *International Journal of Food Sciences and Nutrition*, 65(4), 391–399. <https://doi.org/10.3109/09637486.2014.886176>
2. Beard, J. L., Murray-Kolb, L. E., Rosales, F. J., Solomons, N. W., & Angelilli, M. L. (2007). Interpretation of serum ferritin concentrations as indicators of total-body iron stores in survey populations: The role of biomarkers for the acute phase response. *American Journal of Clinical Nutrition*, 86(6), 1502–1509. <https://doi.org/10.1093/ajcn/86.6.1502>
3. Dipti, S. S., Bergman, C., Indrasari, S. D., Herath, T., Hall, R., Lee, H., & Habibi, F. (2012). The potential of rice to offer solutions for malnutrition and chronic conditions. *Rice*, 5(1), 16. <https://doi.org/10.1186/1939-8433-5-16>

4. Food and Agriculture Organization of the United Nations. (2009). *The state of food insecurity in the world*. FAO.
5. Food and Agriculture Organization of the United Nations. (2021). *Rice market monitor*. FAO.
6. Food Safety and Standards Authority of India. (2022). *Guidelines for rice fortification in government food programs*. FSSAI.
7. Garg, M., Sharma, N., Sharma, S., Kapoor, P., Kumar, A., Chunduri, V., & Arora, P. (2018). Biofortified crops generated by breeding, agronomy, and transgenic approaches are improving lives of millions of people around the world. *Frontiers in Nutrition*, 5, 12. <https://doi.org/10.3389/fnut.2018.00012>
8. Gera, T., Sachdev, H. S., & Boy, E. (2012). Effect of iron-fortified foods on hematologic and biological outcomes: Systematic review of randomized controlled trials. *American Journal of Clinical Nutrition*, 96(2), 309–324. <https://doi.org/10.3945/ajcn.111.031500>
9. Global Alliance for Improved Nutrition. (2020). *Rice fortification: Addressing hidden hunger through staple food fortification* (GAIN Working Paper Series No. 12). GAIN.
10. Government of India. (2021). *Vision, strategy and action plan for rice fortification in India*. Ministry of Consumer Affairs, Food and Public Distribution.
11. Horton, S., & Ross, J. (2003). The economics of iron deficiency. *Food Policy*, 28(1), 51–75. [https://doi.org/10.1016/S0306-9192\(02\)00070-2](https://doi.org/10.1016/S0306-9192(02)00070-2)
12. Hurrell, R., Ranum, P., de Pee, S., Biebinger, R., Davidsson, L., & Zimmermann, M. B. (2010). Revised recommendations for iron fortification of wheat flour and an evaluation of the expected impact of these new guidelines. *Food and Nutrition Bulletin*, 31(1_suppl), S7–S21. <https://doi.org/10.1177/15648265100311S102>
13. Laillou, A., Thierry, K., Tung, D. V., Jimenez-Miquel, T., Jagger, P., Wieringa, F. T., & Moench-Pfanner, R. (2012). Micronutrient fortification of fish sauce does not affect acceptance or sensory attributes of cooked foods. *Food and Nutrition Bulletin*, 33(4), 282–291.
14. UNICEF. (2019). *Vitamin A supplementation: A statistical snapshot*. UNICEF.
15. Wessells, K. R., & Brown, K. H. (2012). Estimating the global prevalence of zinc deficiency: Results based on zinc availability in national food supplies and the prevalence of stunting. *PLoS ONE*, 7(11), e50568. <https://doi.org/10.1371/journal.pone.0050568>
16. World Bank. (2016). *Investing in nutrition: The foundation for development*. World Bank Group.
17. World Food Programme. (2020). *Fortified rice: Addressing malnutrition and supporting food security* (Technical brief). WFP.
18. World Health Organization. (2018). *Guideline: Fortification of rice with vitamins and minerals as a public health strategy*. WHO.
19. World Health Organization. (2022). *Global anaemia estimates, edition 2021*. WHO Global Health Observatory.

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MY PYRAMID AND MY PLATE

Introduction:

In the modern era, where lifestyle-related diseases are steadily increasing across the world, a growing awareness reminds us that what we eat is deeply connected to our health outcomes. Diet therapy — using food both as prevention and as treatment — has emerged as a scientifically supported and sustainable approach to restoring wellness and reducing the risk of chronic diseases.

Lifestyle diseases primarily arise from unhealthy habits, especially poor diet, physical inactivity, and prolonged stress. These include:

- Type 2 Diabetes
- Obesity
- Hypertension
- Heart Disease
- Certain Cancers (Colon, Breast)
- Fatty Liver Disease
- Metabolic Syndrome

According to global health estimates, nearly 71% of deaths worldwide are caused by non-communicable diseases, with unhealthy diet being a major contributing factor.



My Pyramid and My Plate: A Science-Guided Approach

Diet therapy is much more than simply eliminating junk food. It involves personalizing nutrition based on scientific understanding of disease processes, nutrient requirements, and even genetic background.

Objectives:

- Prevent disease onset by modifying risk factors before illness develops.
- Manage existing conditions and sometimes reverse disease progression.
- Restore optimal health by improving energy, mood, and resilience.

Core Principles:

1. Prioritize Nutrient-Dense Foods

Choose foods rich in vitamins, minerals, and beneficial plant compounds such as leafy greens, berries, citrus fruits, whole grains, nuts, legumes, and fatty fish.

2. Reduce Harmful Foods

Limit processed meats, refined sugar, fried snacks, trans fats, excess salt, sugary beverages, and ultra-processed foods.

3. Promote Fiber and Probiotics

Increase dietary fiber to support gut health, regulate blood sugar, and manage cholesterol. Fermented foods such as yogurt and kefir promote a healthy microbiome.

4. Balance Macronutrients

Adjust carbohydrates, proteins, and fats according to individual needs. Lower carbohydrates may help in diabetes, while higher protein supports muscle health in aging.

5. Personalization and Monitoring

Customize diets based on age, medical condition, culture, and preferences. Regular monitoring ensures safety and effectiveness.

Success Stories:

Case 1: Reversing Diabetes: A 45-year-old individual adopted a low-glycemic, high-fiber Mediterranean-style diet under medical supervision. Within six months, blood sugar levels normalized without medication, along with healthy weight loss.

Case 2: Managing Hypertension: A middle-aged woman followed the DASH diet rich in fruits, vegetables, low-fat dairy, and nuts while reducing salt intake. Within eight weeks, her blood pressure normalized and sleep improved.

Practical Plate Model:

- Half the plate: Non-starchy vegetables and fruits
- One quarter: Whole grains or starchy vegetables
- One quarter: Lean protein (beans, fish, chicken)

Conclusion:

Healing begins on our plate. By making mindful and informed food choices, we can transform our health, prevent disease, and promote longevity — one meal at a time. Healing from the plate is a philosophy and strategy rooted in ancient wisdom and now strongly supported by modern science. By making mindful and conscious choices about what we eat, we can transform our health, prevent disease, and promote longevity — one meal at a time.

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Rainfed Agriculture: The Silent Backbone of Global Food Security

Abstract

Rainfed agriculture constitutes the dominant production system across the world's cultivated land, supporting the livelihoods of billions while contributing substantially to global food security. Despite its importance, it remains constrained by climatic variability, resource limitations, and technological gaps. This manuscript synthesizes the structural importance of rainfed systems, their productivity gaps, and modern scientific interventions required to transform them into resilient, high-efficiency production ecosystems. By integrating advances in plant breeding, climate-smart agronomy, soil–water management, and digital agriculture, rainfed farming can evolve from a vulnerable system into a sustainable and profitable enterprise. Policy and institutional convergence will be crucial in unlocking this transformation.

Keywords: Rainfed agriculture; Climate resilience; Dryland farming; Crop improvement; Water-use efficiency; Sustainable intensification

1. Introduction

Rainfed agriculture occupies approximately 80% of the global cultivated area and contributes nearly 60–70% of the world's staple food production. In countries like India, rainfed regions support a large proportion of smallholder farmers and account for a major share of pulses, oilseeds, millets, and coarse cereals production.

However, rainfed agriculture is highly sensitive to climatic variability, particularly rainfall uncertainty, temperature stress, and soil degradation. The yield gap between rainfed and irrigated systems often ranges from 30–60%, highlighting both the vulnerability and the untapped potential of these systems.

2. Characteristics of Rainfed Agro-Ecosystems

Rainfed agricultural systems are characterized by:

Dependence on precipitation: No assured irrigation supply

High rainfall variability: Temporal and spatial fluctuations

Low soil fertility and organic carbon levels

High risk of droughts and crop failures

Dominance of marginal and smallholder farmers

These factors collectively contribute to unstable yields and income insecurity.

3. Productivity Constraints

3.1 Climatic Variability

Erratic monsoon patterns, delayed onset, early withdrawal, and extreme events (droughts, floods) severely impact crop growth stages, particularly germination and grain filling.

3.2 Soil Degradation

Rainfed soils often suffer from:

Low organic matter

Poor water-holding capacity

Nutrient deficiencies (N, P, S, Zn)

3.3 Limited Access to Technology

Farmers in rainfed areas frequently lack access to:

Improved seed varieties

Precision agronomy

Mechanization

Market linkages

3.4 Socio-economic Constraints

Fragmented landholdings, credit limitations, and price volatility further limit investment capacity in improved practices.

4. Scientific Strategies for Rainfed Transformation

4.1 Climate-Resilient Crop Breeding

Modern plant breeding offers solutions through:

Drought-tolerant genotypes

Early-maturing varieties

Heat-resilient hybrids

Root architecture optimization

Integration of genomic selection, marker-assisted breeding, and doubled haploid technology can accelerate genetic gains under stress environments.

4.2 Water Management Innovations

In-situ moisture conservation (mulching, contour bunding)

Rainwater harvesting (farm ponds, check dams)

Micro-irrigation (drip and sprinkler)

Deficit irrigation strategies

These approaches enhance water productivity (kg

grain per mm water).

4.3 Soil Health Restoration

Integrated nutrient management (INM)

Use of biofertilizers and compost

Conservation agriculture (minimum tillage, residue retention)

Cover cropping and crop rotation

4.4 Climate-Smart Agronomy

Altered sowing windows based on monsoon prediction

Intercropping systems (e.g., maize + pigeonpea, sorghum + cowpea)

Agroforestry integration

Stress-adaptive cropping sequences

4.5 Digital and Decision Support Systems

Remote sensing for drought monitoring

AI-based yield prediction

Mobile-based agro-advisories

Weather-indexed insurance

5. Case of India: Rainfed Potential and Challenges

India has nearly 52–55% of its net sown area under rainfed conditions. These regions contribute significantly to:

80% of pulses

90% of millets

70% of oilseeds

Despite lower productivity compared to irrigated areas, rainfed regions possess immense untapped potential due to large yield gaps and adaptability to climate-resilient crops.

6. Policy and Institutional Interventions

For sustainable transformation, the following policy measures are essential:

Investment in watershed development programmes

Strengthening seed systems for stress-tolerant varieties

Expansion of climate-smart extension services

Crop insurance and risk-buffer mechanisms
Market reforms ensuring MSP and procurement
for dry land crops

7. Future Outlook

Rainfed agriculture will play a decisive role in ensuring food and nutritional security under climate change. Future research must focus on:

Systems biology for drought tolerance
Root phenomics and soil–plant interactions
Carbon-neutral rainfed farming
Integration of AI and breeding pipelines

8. Conclusion

Rainfed agriculture is not merely a subsistence system but a strategic pillar of global food security. With targeted scientific innovations, improved governance, and farmer-centric policies, rainfed ecosystems can transition into resilient, productive, and sustainable agricultural landscapes.

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Conflict of Interest

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References:

- Rockström, J., et al. (2010). Managing water in rainfed agriculture. *Agricultural Water Management*, 97, 543–550.
- FAO (2019). *The State of Food and Agriculture*. FAO, Rome.
- ICAR (2021). *Vision 2050 for Dryland Agriculture*. Indian Council of Agricultural Research.
- Passioura, J. (2007). The drought environment. *Functional Plant Biology*, 34, 101–112.
- Ceccarelli, S. (2015). Efficiency of plant breeding. *Agronomy for Sustainable Development*, 35, 1–14.

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**GREEN CRIMINOLOGY: SHINING A CRITICAL LENS ON
SOIL CONTAMINATION AND ITS SUSTAINABLE
REMEDiation**

INTRODUCTION

Green criminology provides for inter-disciplinary and multi-disciplinary engagement with environmental crimes and wider environmental harms. Green criminology applies a broad “green” perspective to environmental harms, ecological justice, and the study of environmental laws and criminality, which includes crimes affecting the environment and non-human nature. Within the ecological justice and species justice perspectives of green criminology there is a contention that justice systems need to do more than just consider anthropocentric notions of criminal justice, they should also consider how justice systems can provide protection and redress for the environment and other species. Green criminological scholarship has, thus, paid direct attention to theoretical questions of whether and how justice systems deal with crimes against animals and the environment; it has begun to conceptualize policy perspectives that can provide contemporary ecological justice alongside mainstream criminal justice. Moving beyond mainstream criminology’s focus on individual offenders, green criminology also explores state failure in environmental protection and corporate offending and environmentally harmful business practices. A central discussion within green criminology is that of whether environmental harm rather than environmental crime should be its focus, and whether green “crimes” should be seen as the focus of mainstream criminal justice and dealt with by core criminal justice agencies such as the police, or whether they should be considered as being beyond the mainstream. This article provides an introductory overview that complements a multi- and inter-disciplinary article collection dedicated to green criminological thinking and research.

GREEN CRIMINOLOGY: A CALL TO ARMS

Green criminology is not easily categorized given that it draws together a number of different perspectives as well as theoretical and ideological conceptions. Thus, rather than there being one distinct green criminology, it is rather an umbrella term for a criminology concerned with the general neglect of ecological issues within criminology. Indeed as Lynch and Stretesky (2014) succinctly state:

“As criminologists we are not simply concerned that our discipline continues to neglect green issues, we are disturbed by the fact that, as a discipline, criminology is unable to perceive the wisdom of taking green harms more seriously, and the need to reorient itself in ways that make it part of the solution to the large global environmental problems we now face as the species that produces those problems”

Given green criminology's nature as a broad field encompassing discourse on a range of issues relating to environmental harm, this thematic article collection offers discussion of a range of issues that help to advance green criminological discussion. Green Criminology also examines mechanisms for disrupting and preventing environmental crime and reducing harms to non-human animals and the environment.

Green criminology conceptualizes environmental harms, including the effects of soil pollution, by highlighting the need to address it not only as ecological failures or technical and ethical problems, but also as forms of environmental victimization involving actors, structures, and processes that may be linked to crimes, regulatory omissions, a lack of socio-environmental justice, or poor decision-making. Therefore, the use of phyto-remediation with tree species, integrated within green criminology, critically justifies this technique as a sustainable, low-impact, and economical tool that, in turn, improves the environmental quality of certain rural or urban communities exposed to contaminated soils that have less access to legal or remedial mechanisms.

Contaminated soils represent a socio-environmental challenge that affects human health, biodiversity, and ecosystem functionality. Furthermore, from the perspective of Green Criminology, soil contamination is analyzed as a form of environmental harm that, although not always classified as a crime, implies responsibility on the part of economic and governmental actors. This approach makes visible environmental injustice, the lack of effective regulation, and the need to ensure transparent and participatory remediation processes. Integrating tree technologies and Green Criminology offers a comprehensive framework for the restoration and prevention of environmental harm.

Soil contamination poses a socio-environmental and public health challenge due to industrial activities, mining, oil spills, and the persistent presence of heavy metals and toxic compounds in agricultural and urban areas. For example, states with significant mining activity have soils contaminated by metals such as mercury (Hg), chromium (Cr), cadmium (Cd), lead (Pb), arsenic (As), nickel (Ni), zinc (Zn), and other potentially toxic elements, resulting from historical and contemporary extractive practices. Likewise, there are hundreds of sites with soil affected by oil spills, especially in oil-producing regions, where a high proportion of the contaminated areas have not yet been fully and effectively remediated.

Integrating phyto-remediation with Green Criminology opens a holistic perspective for addressing soil contamination with plant species and helps improve corporate and institutional decision-making. On the one hand, it leverages the ecological potential of plants that can extract or degrade contaminants; on the other hand, it incorporates a critical evaluation of the social causes and consequences of contamination, the assessment of public policies, the responsibility of public and private actors, and socio-environmental justice for affected communities. This integrated approach not only strengthens the science of remediation but also drives a transformation toward responsible, legally sound, and socially equitable practices that promote soil regeneration and the well-being.

In this context, the remediation of contaminated is analyzed through the use of native tree species as a phyto-remediation strategy, integrating the approach of Green Criminology to identify the socio-environmental impacts, the responsibilities of the actors involved and the implications in terms of socio-environmental justice, in order to propose a comprehensive framework that contributes to the

restoration of ecosystems, the protection of human health and the strengthening of public policies aimed at the prevention and care of environmental harms.

SUSTAINABLE SOIL REMEDIATION : A PERSPECTIVE FROM GREEN CRIMINOLOGY

From this perspective, the lack of timely remediation, the negligence of authorities, or non-compliance with environmental regulations can exacerbate forms of structural violence and gradual ecocide. In this sense, remediation using tree species can be understood as a preventive and restorative response to environmental crimes and harms analyzed by Green Criminology. Furthermore, by prioritizing nature-based solutions, a model of socio-environmental justice is promoted that seeks to repair ecological and social harms, rather than simply punishing infractions after the harm has occurred. However, for these strategies to be effective, they must be accompanied by monitoring, transparency and accountability mechanisms that prevent the recurrence of practices that generate pollutants.

ECOLOGICAL-BIOLOGICAL USE AND GREEN CRIMINOLOGY IN SOIL REMEDIATION

The persistence of heavy metals in the environment causes toxicity, which in turn impacts environmental and human health. These metals, such as Pb, Cd, Zn, As, and Ni, do not degrade easily and tend to bio-accumulate in food chains, affecting the quality of food, water, soil, and ecosystem services. In response to these challenges, ecological-biological remediation strategies have been developed, which utilize natural processes or those assisted by living organisms to reduce metal concentrations or their mobility in the soil.

At the same time, Green Criminology is emerging as a trans-disciplinary approach to

addressing environmental crimes and harms from an ecological justice perspective, analyzing the social, economic, and regulatory causes of environmental degradation and proposing more integrated responses that go beyond technical management. To understand the relationship and complexity of the issue, it is necessary to combine physicochemical data from the contaminated soil with an assessment of the socio-ecological impact, which integrates remediation approaches, strategies, and processes. This is linked to studies that have used plant species capable of bio-accumulating or phyto-stabilizing these contaminants, as well as their association with microorganisms and arbuscular mycorrhizal fungi.

Based on these assessments, Green Criminology focuses its analysis on the broad and persistent socio-environmental crimes and harms in the area, including pollution, exploitation of natural resources, and other negative impacts of human and non-human development. It encompasses both illegal conduct and legal practices that generate significant environmental harm, examining their structural causes, socio-environmental effects, and regulatory frameworks. From this perspective, soil degradation due to heavy metals is not only a technical pollution problem, but also a socio-legal and ethical phenomenon that calls into question the effectiveness of environmental policies, corporate and institutional co-responsibility, and justice for affected communities.

Remediation from an ecological-biological approach constitutes an efficient and sustainable alternative for the recovery of soils contaminated with heavy metals, since methods such as phyto-remediation and microbial bioremediation have demonstrated significant technical-biological potential, while Green criminology broadens the understanding of

environmental pollution from a Criminological perspective by analyzing the structural, regulatory, and social crimes and harms that perpetuate the degradation of soils and ecosystems. In this context, a trans-disciplinary and interdisciplinary methodological framework that integrates soil biology, ecology, environmental law, and Green Criminology can generate comprehensive solutions and promote socio-environmental justice in regions affected by heavy metal pollution.

On the other hand, there may be a barrier to implementing environmental legislation and integrating biological solutions into formal remediation requirements. However, integration with green criminology can lead to alternative regulatory and institutional adjustments and alternatives to facilitate the integration of biological solutions as viable, verifiable, and socially just options within remediation processes.

SOCIAL-ANTHROPOLOGICAL USE AND GREEN CRIMINOLOGY IN SOIL REMEDIATION

The problem of soil contaminated with heavy metals not only affects the ecological and biological environment but also harms human health and generates social impacts on the population surrounding the contaminated area. Finding alternatives for site remediation requires not only technical and scientific solutions, but also social, anthropological, and legal approaches that allow for a comprehensive understanding of the causes, consequences, and mitigation strategies. To begin, a review of the contaminated areas and the damage they have caused must be conducted. In this regard, it has been documented that many of the countries have heavy metal levels exceeding the limits established by international standard.

This problem is intensified in areas with a

history of mining or industrial activities, where the mobilization of heavy metals translates into significant socio-environmental and socio-economic risks. However, these approaches, in addition to supporting the physical recovery of the soil, must also evaluate the role of economic viability, social acceptability, and long-term sustainability. In this sense, social anthropology provides conceptual tools to analyze how communities perceive and respond to soil contamination, how discourses on socio-environmental risk are shaped, and how cultural and structural factors influence the management of environmental problems.

This approach allows us to unravel local narratives about soil degradation, the everyday practices of social actors, and the symmetrical power relations that shape the distribution of environmental risks and benefits. Social intervention involves participatory processes where affected communities are actively involved in identifying remediation priorities, designing projects, and developing environmental monitoring and remediation strategies. Similarly, Green Criminology delves into remediation and decision-making processes, examining violations of environmental regulations, environmental crimes and harms (beyond the strictly penal), addressing ethical, social and institutional issues, as mentioned above, related to ecological degradation.

ECONOMIC-ADMINISTRATIVE USE AND GREEN CRIMINOLOGY IN SOIL REMEDIATION

Socioeconomic and administrative strategies must be integrated into remediation processes, as they are key to sustainability and, together with Green Criminology, become complementary tools for recovering affected areas. Thus, in economic terms, soil

contamination generates negative externalities, that is, environmental, health, and production costs that are not directly borne by the responsible parties. Environmental economics proposes instruments such as remediation fees, environmental subsidies, pollution rights markets, and payment for environmental services (PES) mechanisms to internalize these costs and, thereby, promote sustainable practices within an economic and administrative framework.

From the perspective of Green Criminology, an epistemological framework is provided for understanding how certain economic and political practices can contribute to environmental degradation and lack accountability mechanisms. This discipline is a contemporary perspective within criminology that studies crimes and harms to biodiversity and ecosystems. Therefore, it is beginning to consolidate itself as a trans-disciplinary and interdisciplinary field that seeks to explain structural environmental harm that is not always efficiently addressed by the traditional justice system.

Furthermore, to assess economic viability, administrative capacity, socioeconomic impact, and legal responsibility, a mixed methodological framework is necessary. Green Criminology acts as a cross-cutting axis by studying and highlighting environmental crimes and harms, institutional failures, and economic practices that externalize ecological costs, thus promoting fairer, more equitable, sustainable, and effective remediation policies.

The remediation of soils contaminated with heavy metals requires a balanced synergy between technical methods of environmental remediation, robust economic strategies, and a solid theoretical and methodological framework of Green Criminology. This comprehensive approach will help us to understand and

implement sustainable management of contaminated soils through public policies that internalize environmental costs, economic incentives that promote green technologies, and criminological action that documents, interprets, and contributes to the remediation of environmental harm under criteria of socio-ecological justice. Furthermore, it is necessary to continue working on the recovery of contaminated soil and to make this issue a national priority. Therefore, biotechnology must be integrated with Green Criminology as part of the research frameworks for the remediation, restoration, and prevention of environmental crimes and harms.

BIOTECHNOLOGICAL INTEGRATION WITH TREE SPECIES AND GREEN CRIMINOLOGY

The crisis of soil contamination and the degradation of forest systems demands trans-disciplinary and interdisciplinary strategies that go beyond traditional management. Therefore, biotechnology applied to timber tree species, together with Green Criminology, forms a framework for detecting, preventing, and guiding decision-making and the application of the law to environmental crimes. In this sense, environmental biotechnology, using tree species, the development and regulation of biological systems for the remediation of contaminated environments, and environmentally friendly processes, utilizes restoration ecology and ecological restoration after remediation.

The plant species used for these processes, and within the field of biotechnology, employ genetic improvement, increase the resilience of forest species and accelerate the regeneration of degraded areas. Additionally, restoration and reforestation efforts have been incorporating biotechnology as a tool that can increase the

effectiveness of assisted planting and regeneration in contaminated soils. While biotechnology offers means to remediate, restore, and rehabilitate affected ecosystems, Green Criminology provides a preventive approach to addressing the social, economic, and legal causes of environmental harm.

Furthermore, there is a need to strengthen the legal framework by increasing the capacity for environmental forensic investigation, specialized expert reports, and sanctions proportionate to the harm caused, to create synergistic axes. Environmental governance can also be strengthened, fostering evidence-based public policy and promoting a culture of nature conservation. This comprehensive model, which unites science, technology, law and society, can be a route to face the socio-environmental challenges in the world, due to soil contamination by heavy metals, transforming the way in which the relationship between development, socio-environmental justice and socio-ecology is conceived.

EPILOGUE

The sustainable remediation of heavy metals using tree species represents a strategic alternative, integrating environmental, social, and economic benefits. Its connection with Green Criminology allows for the visibility of pollution as a form of social and ecological harm that requires more robust preventive, restorative, and regulatory responses. Strengthening the legal framework, promoting nature-based solutions, and guaranteeing environmental justice are essential steps to advance towards comprehensive and ethical management of contaminated soils in the country.

Evidence from case studies conducted revealed that the native tree species and woody vegetation have real potential for the phyto-

remediation of soils contaminated with heavy metals. Therefore, it is shown that it is possible to apply this process effectively, even in soils degraded by mining. However, these cases underscore the importance of continuing applied research that integrates ecological, microbiological, and environmental management aspects, to consolidate sustainable environmental remediation protocols for any country with similar environmental challenges. Furthermore, the application of tree species for the remediation and restoration of soils contaminated with heavy metals represents a comprehensive and sustainable strategy when integrated with ecological-biological, socio-anthropological, and economic-administrative approaches, strengthened by Green Criminology as a critical tool for evaluation and monitoring. From an ecological-biological perspective, trees contribute to phyto-stabilization and phyto-remediation, restoring soil functions and biodiversity; from a socio-anthropological perspective, they promote community participation, socio-environmental justice, and the recovery of affected territories. Meanwhile, from an economic-administrative perspective, they allow for cost optimization, the promotion of local economies, and support for evidence-based public decision-making.

Green Criminology provides an analytical framework for identifying responsibilities, preventing environmental crimes and harms, and monitoring illegal practices and negligence associated with pollution, ensuring transparency and regulatory compliance. Taken together, this trans-disciplinary and interdisciplinary vision not only improves the effectiveness of remediation processes but also consolidates socio-environmental management models oriented towards sustainability, social equity and the protection of the environment in the medium and long term, as well as the communities.

REFERENCES

- Lynch MJ, Stretesky PB (2014) Exploring green criminology: Toward a green criminological revolution. Ashgate, Farnham.
- Lynch MJ. (2019) Green criminology and environmental crime: criminology that matters in the age of global ecological collapse. *Journal of White Collar and Corporate Crime*. 2019; 1(1): 1-12. DOI: 10.1177/2631309X19876930.
- Nurse A. (2017) Green criminology: shining a critical lens on environmental harm. Palgrave Communications. ; 3: 10. DOI: 10.1057/s41599-017-0007-2.
- South N (2010) The ecocidal tendencies of Late Modernity: Transnational crime, social exclusions, victims and rights. In White R (ed) *Global environmental harm: Criminological perspective*. Willan, Devon, p 228–247.
- Weston B, Bollier D (2013) *Green governance: Ecological survival, human rights and the law of the commons*. Cambridge University Press, New York, NY.

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“ROLE OF HORTICULTURE IN DOUBLING FARMER’S INCOME”

Introduction:

In the present agricultural scenario, increasing farmers' income has become a national priority. Rising input costs, climate variability, fragmented landholdings, and unstable market prices have reduced the profitability of traditional cereal-based farming. In this context, horticulture has emerged as a high-potential sector capable of significantly enhancing farm income through diversification, higher productivity, and market-oriented production.

Horticulture plays a vital role in enhancing farmer's income and contributing to agricultural growth. By focusing on high-value crops like fruits, vegetables, and flowers, farmers can increase their earnings and improve their livelihoods.

Key roles of Horticulture in Income Generation:

1. **Higher Returns:** Horticulture crops often fetch higher prices in the market compared to traditional crops, leading to increased income for farmers.
2. **Diversification:** Growing a mix of horticulture crops can help farmers reduce dependence on a single crop, mitigating risks and ensuring stable income.
3. **Employment Opportunities:** Horticulture provides employment opportunities for rural laborers, contributing to the local economy.
4. **Nutritional Security:** Horticulture crops provide essential nutrients, improving food security and health.
5. **Export Potential:** Many horticulture crops have export potential, generating foreign exchange earnings.
6. **Increased Productivity:** Improved varieties, modern farming techniques (like hi-tech polyhouses), and better management boost yields significantly, as seen with high returns from capsicum, cucumber, etc.

Horticulture as a High-Value Farming System

Horticultural crops such as fruits and vegetables provide much higher returns per unit area compared to conventional field crops. Short crop duration, multiple harvesting, and continuous market demand ensure regular cash flow for farmers. In recent years, there has been a noticeable shift from subsistence farming to commercial vegetable and fruit production, particularly among small and marginal farmers seeking better income stability. The growing demand for fresh, nutritious, and quality produce due to urbanization and changing food habits has further strengthened the economic importance of horticulture. Vegetables like tomato, capsicum, cucumber, onion, and leafy greens are increasingly cultivated as commercial crops due to their strong market demand and quick returns.



➤ **Diversification and Income Stability**

Crop diversification through horticulture reduces farmers' dependence on a single crop and minimizes risks associated with climate stress and price fluctuations. Integrating fruits and vegetables into existing farming systems allows better utilization of land, water, and labor resources. Diversified farming systems have proven to be more resilient and profitable under present climatic and economic challenges.

➤ **Technology-Led Growth and Protected Cultivation**

The adoption of improved varieties, precision irrigation, fertigation, and protected cultivation has transformed horticultural production. Polyhouses, net houses, and low tunnels enable farmers to produce vegetables during off-season periods, when market prices are high. This technology-driven approach has helped farmers increase yield, improve quality, and enhance net income despite limited land resources.

➤ **Value Addition and Market Orientation**

Post-harvest losses continue to be a major concern in horticulture. However, recent emphasis on

value addition, processing, and better market linkage has opened new income avenues for farmers. Processing fruits and vegetables into products such as juices, pickles, dehydrated items, and ready-to-cook vegetables increases shelf life and profitability. Direct marketing, farmer-producer organizations (FPOs), and export-oriented production further strengthen farmers' income.

➤ **Employment Generation and Rural Entrepreneurship**

Horticulture supports income growth not only through crop production but also by generating employment in allied activities such as nursery raising, seedling production, floriculture, and food processing. Increasing participation of youth and women in horticulture-based enterprises reflects the sector's growing role in rural economic development.

➤ **The Diverse World of Horticulture: Exploring its Branches and Income Opportunities**



Horticulture is a vast and dynamic field that encompasses various branches, each with its

unique importance and income-generating potential. From pomology to floriculture, the different branches of horticulture offer a wide range of opportunities for farmers, entrepreneurs, and professionals.

1. Pomology: The Science of Fruit Production.

Pomology is the branch of horticulture that deals with the cultivation of fruits. With the increasing demand for fresh and healthy produce, pomology has become a lucrative venture for many farmers. Fruits like apples, bananas, mangoes, and citrus fruits are in high demand, generating significant income through fresh sales, juice production, and processing.

2. Olericulture: The Art of Vegetable Production.

Olericulture is another vital branch of horticulture that focuses on growing a wide range of vegetables. From leafy greens to root vegetables, olericulture provides ample opportunities for farmers to generate income through fresh sales, pickling, canning, and frozen vegetable production.

3. Floriculture: The Beauty of Flower Production.

Floriculture is a high-value branch of horticulture that deals with the cultivation of flowers. With the increasing demand for flowers in the wedding and event industry, floriculture has become a profitable venture for many farmers. Fresh flower sales, bouquet production, and floral arrangements are just a few examples of the income-generating opportunities in floriculture.

4. Landscape Horticulture: Designing and Maintaining Outdoor Spaces.

Landscape horticulture is a branch that involves designing, building, and maintaining outdoor spaces like gardens, parks, and green roofs. This branch requires a combination of horticultural knowledge and design skills, offering opportunities for landscape designers,

contractors, and maintenance professionals.

5. Nursery Production: Growing Plants for the Future.

Nursery production is a vital branch of horticulture that involves producing plants, trees, and shrubs for landscaping, gardening, and reforestation. Nurseries provide a wide range of plants, from ornamental plants to fruit trees, generating income through plant sales and tree planting services.

6. Post-Harvest Management: Reducing Losses and Increasing Income.

Post-harvest management is a critical aspect of horticulture that involves handling, storing, and transporting horticultural products. By reducing losses and maintaining product quality, post-harvest management can significantly increase income for farmers and distributors.

7. Medicinal and Aromatic Plants: Unlocking their Potential.

Medicinal and aromatic plants are a valuable resource for the pharmaceutical, cosmetic, and food industries. With the increasing demand for natural products, medicinal and aromatic plants have become a lucrative opportunity for farmers and entrepreneurs.

8. Spices and Condiments: Adding Flavor and Aroma.

Spices and condiments are high-value crops that add flavor and aroma to food. With the growing demand for international cuisine, spices and condiments have become a significant source of income for many farmers and traders.

➤ **Recommended actions to increase farmer income from horticulture:**

1. Invest in post-harvest (cold chain, pack houses, primary processing) to reduce losses and increase farmer share.
2. Strengthen farmer producer organizations (FPOs) and e-market linkages (e-NAM) so

producers can negotiate better prices and sell directly.

3. Encourage high-value cropping in irrigated pockets and provide training on grading/packing to access higher value markets.

➤ **Conclusion**

In the current agricultural environment, horticulture offers a practical and sustainable pathway toward doubling farmers' income. By combining high-value crops, modern technologies, diversification, and market-driven approaches, horticulture can enhance profitability while ensuring nutritional and environmental sustainability. Strengthening infrastructure, extension services, and market access will further accelerate the role of horticulture in transforming farmers' livelihoods.

In conclusion, the diverse branches of horticulture offer a wide range of opportunities for income generation, from fresh produce sales to value-added products and services. By exploring these opportunities and adopting best practices, farmers, entrepreneurs, and professionals can unlock the potential of horticulture and improve their livelihoods.

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Microbial Community Shifts in Biochar-Amended Soils and Their Agronomic Implications

Introduction

If you've ever dug into a healthy field after the first good rain, you already know soil doesn't feel "dead." It smells earthy, crumbles nicely, and seems to breathe. That "life" is not poetry—it's biology. A single teaspoon of productive soil can contain billions of microbes: bacteria, fungi, actinomycetes, algae, protozoa, and a whole crowd of microscopic helpers and troublemakers.

Biochar is often described as a carbon-rich material made by heating biomass (crop residues, wood, shells, etc.) under low oxygen. But for microbes, biochar is not just "carbon." It's more like a new neighborhood being built in a crowded city—one with apartments, hideouts, cafés, storage rooms, and tiny tunnels. When this neighborhood appears, the microbial community doesn't stay the same. It rearranges itself. These microbial community shifts—who increases, who decreases, and who changes behavior—are at the heart of why biochar sometimes boosts yields, sometimes improves nutrient efficiency, and sometimes gives mixed results. Let's unpack this in a simple, human way.

Why biochar changes microbial communities in the first place

Microbes respond to their environment much faster than crops do. Add anything to soil—manure, fertilizer, compost, lime, or biochar—and microbes are the first to "vote" with their population changes.

Biochar influences microbes through several key features:

1) A home with many rooms: pore structure

Biochar has a porous structure. Think of it as a sponge made of carbon. The pores provide:

- Shelter from predators (like protozoa that feed on bacteria)
- Safe zones during dry spells
- Protected spaces for fungal hyphae and bacterial colonies

When microbes find shelter, their survival improves—especially under droughty or hot conditions.

2) A buffet that isn't exactly food: surfaces and charges

Biochar surfaces can hold nutrients because of their charge characteristics (which often increase as biochar ages in soil). This affects microbes in two ways:

- Nutrients can become **more available** in the root zone (good for microbial growth and plant nutrition).
- Some nutrients can also get **temporarily held** on surfaces (which can be good or bad depending on timing and management).

3) Soil pH shifts

Many biochars are alkaline. In acidic soils, that pH increase can feel like switching on a light for microbial activity. Entire microbial groups prefer certain pH ranges. When pH moves, the community composition moves with it.

4) Moisture behavior

Biochar can improve water retention in sandy soils and improve aggregation in many soils over time. More stable moisture means less stress for microbes—especially those sensitive to drying-rewetting cycles.

What kinds of microbial shifts are commonly seen?

Let's be clear: the exact shift depends on feedstock, pyrolysis temperature, soil type, climate, and what else you apply (fertilizer, manure, compost). Still, some patterns show up repeatedly.

A) Bacteria often respond quickly, fungi often respond steadily

After biochar addition leads to fast-growing bacteria may increase early if there are available nutrients and moisture improves, fungi—especially those involved in breaking down complex organic matter—often respond more gradually as the soil structure and habitat become more favourable.

B) More “beneficial” groups tend to gain advantage

Biochar can support groups linked with:

- Nitrogen cycling (especially those involved in ammonium transformations and nitrogen retention)
- Phosphorus solubilization
- Production of plant-growth-promoting substances
- Suppression of some soil-borne pathogens

But again, the key word is “tend.” Soil is complex, and the story depends on context.

C) Microbial diversity often increases, but not

always immediately

In many cases, biochar creates more micro-habitats, which can support a richer community—like adding different kinds of rooms in a house. Over time, this can increase microbial diversity and functional stability.

However, in some situations (for example, very high application rates or biochars with problematic properties), diversity can drop temporarily.

D) The soil food web can become more stable

If biochar improves aggregation and creates protective habitats, the soil food web becomes less “boom-and-bust.” Microbial activity becomes steadier across seasons. This stability matters for nutrient release patterns and crop resilience. Biochar can reshape key soil processes:

1) Nitrogen dynamics: less loss, more efficiency (often)

Nitrogen is famously leaky. It can escape as nitrate leaching, ammonia volatilization (especially from surface urea), gaseous losses through denitrification (including N_2O)

Biochar can influence this by **adsorbing ammonium** and reducing immediate loss, improving aeration and moisture balance, which changes denitrification conditions, supporting microbial communities that regulate nitrogen transformations

2) Phosphorus availability: unlocking what is already there

In many soils, phosphorus gets fixed—held tightly by calcium, iron, or aluminum compounds. Biochar can help indirectly by changing pH in a favorable direction (especially in acidic soils), encouraging P-solubilizing microbes, improving root growth and rhizosphere activity. This is why biochar sometimes shows stronger results when combined with organic inputs or microbial activity enhancers—because the biological

“engine” becomes more active.

3) Carbon cycling: shifting from rapid burn to long-term storage

Biochar itself is relatively stable carbon. But it also changes how microbes handle other organic matter, sometimes microbes become more efficient in using organic substrates, biochar protects organic matter inside aggregates, slowing decomposition, in some cases, a small boost in decomposition happens early (microbes wake up), followed by longer-term stabilization. For farmers, the visible outcome can be: better soil structure, more stable aggregates, improved tilth, and often better root exploration.

Agronomic implications: what does this mean for crop performance?

Microbial shifts are interesting in the lab, but farmers ask a direct question: Will this help my crop? Here are the most practical, field-level implications.

1) Better root environment = better crop establishment

When biochar improves moisture retention, reduces bulk density in some soils, and supports microbial activity, seedlings often establish better—especially under heat and moisture stress. A healthier microbial community around roots can support early nutrient uptake and reduce minor root infections.

2) Improved nutrient efficiency (especially when biochar is integrated, not used alone)

Biochar often performs best when combined with compost or FYM, green manures, Integrated nutrient management (balanced NPK + organics) and site-specific fertilizer strategies Biochar provide habitat and stability, but it doesn’t always provide enough “food” on its own. Pairing it with organics is like building houses and also ensuring there’s a functioning market.

3) Yield responses can be moderate but consistent over time

One reason biochar is sometimes misunderstood is expectations. Biochar is not always a “quick yield booster.” In many soils, its strongest effect is soil conditioning and resilience—which becomes more valuable over seasons.

4) Stronger performance under stress conditions

Biochar-driven microbial shifts often show clearer benefits under drought spells, heat stress, low organic matter soils, sandy or structurally weak soils, acidic soils (when biochar raises pH appropriately). In very fertile soils already rich in organic matter and microbial activity, yield changes may be smaller—but soil health benefits can still matter.

Why results vary: the “biochar is not one thing” reality

Two farmers can apply biochar and get different outcomes. That doesn’t mean one did it wrong—it means biochar is highly variable.

Major reasons for variation:

Temperature matters

Lower pyrolysis temperatures can leave more volatile compounds and “labile” fractions that microbes can use quickly. Higher temperatures make biochar more stable, often more porous, and sometimes more alkaline.

Soil baseline matters

Acidic soils respond differently than alkaline soils. Sandy soils respond differently than clay soils. Low organic carbon soils often show bigger improvements.

Biochar is not just an amendment; it’s a habitat technology for soil life.

By creating protected micro-spaces, moderating moisture and pH, and influencing nutrient retention, biochar changes the rules of survival underground. Microbes reorganize, and their functions shift. When those shifts favor nutrient efficiency, root health, and stable carbon cycling,

crops benefit—sometimes immediately, often gradually, and frequently most clearly under stress.

In a time when farmers face rising input costs, climate uncertainty, and soil degradation, microbial community management is not a luxury topic. It is a practical pathway to resilience. Biochar—used wisely, with organic integration and realistic expectations—can be one of the tools that helps soil biology work *with* the farmer rather than against them.

References

- Lehmann J, Rillig MC, Thies J, Masiello CA, Hockaday WC, Crowley D. Biochar effects on soil biota – A review. *Soil Biology and Biochemistry*. 2011;43(9):1812–1836. doi:10.1016/j.soilbio.2011.04.022
- Deshoux M, Sadet-Bourgeteau S, Gentil S, Chemidlin Prévost-Bouré N. Effects of biochar on soil microbial communities: A meta-analysis. *Science of the Total Environment*. 2023;902:166079. doi:10.1016/j.scitotenv.2023.166079

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AutoCAD: Revolutionizing Landscape Architecture

ABSTRACT

Computer-Aided Design (CAD) technologies have fundamentally transformed landscape architecture by enhancing precision, visualization and interdisciplinary coordination. This paper examines the role of AutoCAD and SketchUp in contemporary landscape design workflows, highlighting their functional capabilities and integration with BIM and GIS systems. AutoCAD, developed by Autodesk in 1982, remains a core drafting and modelling platform widely used for producing accurate 2D plans and increasingly sophisticated 3D representations. Its structured layer management, geometric precision, and comprehensive modification tools enable efficient production of construction-ready drawings. Furthermore, AutoCAD supports interoperability with Building Information Modelling (BIM) platforms and Geographic Information Systems (GIS), allowing designers to incorporate spatial datasets, terrain models and environmental constraints into the planning process.

SketchUp, originally developed by @Last Software and later acquired by Google and subsequently by Trimble Inc., complements AutoCAD by offering an intuitive three-dimensional modelling environment. Its push-pull modelling approach, real-time visualization, and compatibility with rendering engines enhance conceptual development and client communication. Integration with tools such as Google Earth further enables geospatial positioning and contextual analysis.

Together, AutoCAD and SketchUp provide a comprehensive digital framework that supports ideation, technical drafting, visualization and environmental assessment. Their combined use improves workflow efficiency, reduces design errors and strengthens collaboration among architects, engineers, planners and contractors. As urbanization and sustainability demands increase, these digital tools play a critical role in delivering precise, cost-effective and environmentally responsive landscape solutions.

INTRODUCTION

Computer-Aided Design (CAD) has played a transformative role in the evolution of landscape architecture and garden design. Its origins date back to 1957, when Patrick J. Hanratty developed PRONTO, one of the earliest numerical control programming systems. This innovation laid the conceptual groundwork for modern CAD applications. In 1963, Ivan Sutherland introduced Sketchpad, the first interactive computer graphics system, which enabled designers to draw directly on a computer screen and introduced foundational concepts such as graphical interfaces and object-based modelling.

A major milestone occurred in 1982 when John Walker founded Autodesk and released AutoCAD. Initially developed for two-dimensional drafting, AutoCAD made digital design accessible to architects, engineers and planners worldwide. Over time, especially with the introduction of advanced 3D modelling tools around 2000, AutoCAD evolved into a comprehensive platform capable of detailed modelling, rendering and visualization.

In landscape architecture, CAD has replaced traditional hand-drawn plans, significantly improving accuracy, efficiency and flexibility. Designers can now modify layouts, adjust scales and test multiple alternatives without redrawing entire plans. Integration with tools such as SketchUp and Autodesk 3ds Max allows the creation of realistic perspective renderings, vegetation modelling and water feature simulations.

With increasing urbanization and environmental concerns, especially in rapidly developing countries such as China, the demand for sustainable and aesthetically refined landscapes has grown. Modern CAD technologies support GPS-based mapping, terrain modelling and performance evaluation, enabling cost-effective planning of small and medium-scale garden projects. Today, CAD is not merely a drafting tool but an essential digital framework that enhances precision, visualization and sustainability in contemporary landscape design.

NEED OF AUTOCAD DESIGN IN LANDSCAPING

AutoCAD remains one of the most widely used CAD (computer-aided design) tools in landscape architecture because it significantly enhances design precision, efficiency and communication throughout the design process. It allows designers to create detailed 2D drawings and accurate 3D models, which are essential for planning complex

outdoor spaces such as gardens, parks and site layouts. This precision ensures that measurements, dimensions and spatial relationships are correct before any physical construction begins, reducing costly errors and rework on site. AutoCAD's automation of repetitive drafting tasks-like copying elements or mirroring symmetrical designs-greatly improves productivity compared to manual drawing methods. This saves time and enables designers to refine and test multiple alternatives efficiently. The software's layer management system helps organize different design elements (planting, pathways, water features, lighting) so that modifications can be made without disrupting the entire plan. Another major benefit of AutoCAD is its visualization capabilities. The software's ability to generate realistic 3D views or renderings helps clients visualize the proposed landscape more intuitively than flat sketches. This not only enhances client understanding and engagement but also supports clearer communication with contractors and multidisciplinary teams. AutoCAD also integrates with other tools and file formats, making it easier to incorporate geographic data, material specifications, and design details from GIS and other modelling software. This interoperability enhances workflow flexibility and improves collaboration among professionals involved in larger projects. Overall, AutoCAD empowers landscape architects with precision, efficiency, visualization and collaborative flexibility, making it a key tool in modern landscape and garden design workflows.

COMMANDS USED IN AUTOCAD DESIGN

1. Common (General) Commands

These commands are used throughout the drafting process:

- **AUDIT** – Checks and repairs drawing file errors.
- **QSAVE / SAVE / SAVEALL** – Saves the current drawing or all open drawings.
- **CLOSE / CLOSEALL** – Closes one or all open drawing files.
- **RECOVER / RECOVERALL** – Repairs corrupted drawing files.
- **DIST (Distance)** – Measures the distance and angle between two points.
- **LIST** – Displays object properties (layer, coordinates, length, etc.).
- **PREVIEW / PLOT** – Previews and prints drawings.
- **LAYER** – Manages drawing layers for organizing objects.
- **HATCH** – Fills enclosed areas with patterns, gradients, or solid fills.
- **CONE** – Generates a cone using base radius and height.
- **TORUS** – Creates a donut-shaped solid.
- **WEDGE** – Forms a sloped 3D solid.
- **EXTRUDE** – Converts 2D objects into 3D solids by adding height.
- **UNION / SUBTRACT / INTERSECT** – Combines or modifies 3D solids.

2. 2D Drawing Commands

These are fundamental drafting tools for creating plans and layouts:

- **LINE (L)** – Draws straight line segments.
- **CIRCLE (C)** – Creates circles (centre-radius, 2-point, 3-point options).
- **RECTANGLE (REC)** – Draws rectangles by specifying corners.
- **POLYGON** – Creates regular polygons with specified sides.
- **ARC** – Draws curved segments.
- **SPLINE** – Produces smooth, freeform curves.
- **RAY** – Creates a semi-infinite construction line.
- **ARRAY** – Copies objects in rectangular, polar, or path patterns.

3. 3D Modelling Commands

AutoCAD supports solid and surface modelling:

- **BOX** – Creates a 3D rectangular solid.
- **SPHERE** – Creates a sphere using a radius or diameter.
- **CYLINDER** – Draws cylindrical solids.

4. Modify Commands

Used to edit existing objects:

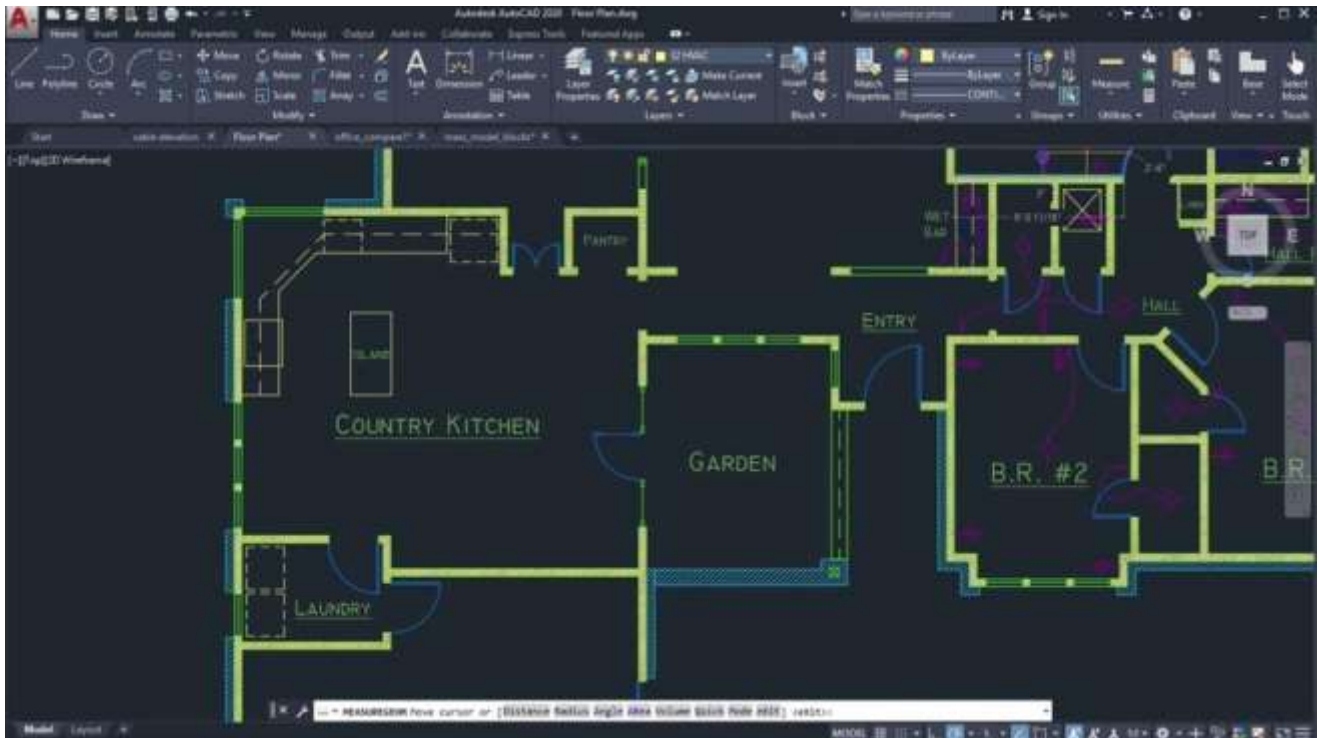
- **MOVE (M)** – Relocates objects.
- **COPY (CO)** – Duplicates objects.
- **ROTATE (RO)** – Rotates objects around a base point.
- **MIRROR (MI)** – Creates mirrored copies.
- **TRIM** – Cuts objects to meet boundaries.
- **EXTEND** – Lengthens objects to meet edges.
- **BREAK** – Removes a portion between two points.
- **FILLET** – Rounds corners.
- **CHAMFER** – Creates bevelled edges.
- **EXPLODE** – Separates grouped objects.
- **JOIN** – Combines objects into a single entity.

5. Functional Keys (Drawing Aids)

- **F1** – Help
- **F3** – Object Snap (OSNAP)
- **F7** – Grid display
- **F8** – Ortho mode
- **F10** – Polar tracking
- **F12** – Dynamic input

Information on BIM and GIS in AutoCAD

AutoCAD functions as a critical intermediary between detailed engineering design (BIM) and large-scale spatial analysis (GIS). While AutoCAD itself is primarily a drafting and modelling platform, it supports BIM workflows through integration with Autodesk's ecosystem—especially Autodesk Revit and Civil 3D—and



facilitates export/import of industry-standard formats such as DWG, DXF and IFC.

1. Role of BIM in AutoCAD-Based Design

Building Information Modelling (BIM) extends beyond 3D geometry by embedding structured attribute data into model elements. For example, a road model may include material specifications, layer thickness, cost estimates and construction schedules. According to Autodesk documentation, BIM supports:

- Clash detection between structural, mechanical and infrastructure components
- Quantity take-offs and cost estimation
- Lifecycle management and maintenance planning
- Improved collaboration through shared data environments

2. Role of GIS in Design Evaluation

GIS platforms such as ArcGIS Pro by Esri analyse spatial relationships and environmental constraints. GIS incorporates datasets such as:

- Digital Terrain Models (DTM)
- Raster and vector environmental layers
- Vegetation and habitat mapping

- Infrastructure networks
- Orthophotos and satellite imagery

3. BIM–GIS Integration (Geode sign Concept)

The coupling of BIM and GIS is commonly referred to as *geode sign*, a planning methodology introduced by Carl Steinitz. It enables real-time feedback between engineering design and environmental analysis. Interoperability tools such as FME (Feature Manipulation Engine) allow ETL (Extract–Transform–Load) processing to convert BIM/CAD models into GIS-compatible multipitch or 3D spatial formats while preserving attributes.

4. Usefulness in AutoCAD Design

The integration provides several advantages:

- Environmental impact assessment during early design stages
- Optimization of infrastructure alignment (roads, railways, utilities)
- Improved sustainability and regulatory compliance
- Multidisciplinary coordination among architects, engineers and planners

- Enhanced 3D visualization within real geographic contexts

Sketchup software

1. Development History (Verified Timeline)

- **1999** – Developed and released by @Last Software.
- **2006** – Acquired by Google. During this period, integration with **Google Earth** significantly increased its visibility.
- **2012** – Sold to Trimble Inc., where it continues to evolve with cloud collaboration, BIM interoperability and construction-oriented features.

Trimble positioned SketchUp more strategically within the Architecture, Engineering and Construction (AEC) ecosystem.

2. Current Versions (as offered by Trimble)

• SketchUp Go

- Web-based modelling (browser version)
- Cloud storage via Trimble Connect
- Basic 3D modelling and viewer tools
- Ideal for conceptual design and mobility

• SketchUp Pro

- Desktop version (Windows/Mac)

- Includes **Layout** for 2D documentation
- Import/export support (DWG, DXF, IFC, 3DS, etc.)
- Extension Warehouse access
- Suitable for architects, landscape designers and interior professionals

• SketchUp Studio

- Includes everything in Pro
- Adds point cloud modelling tools
- Scan-to-BIM workflows
- Advanced interoperability and analysis tools
- Targeted at large-scale AEC and civil engineering projects

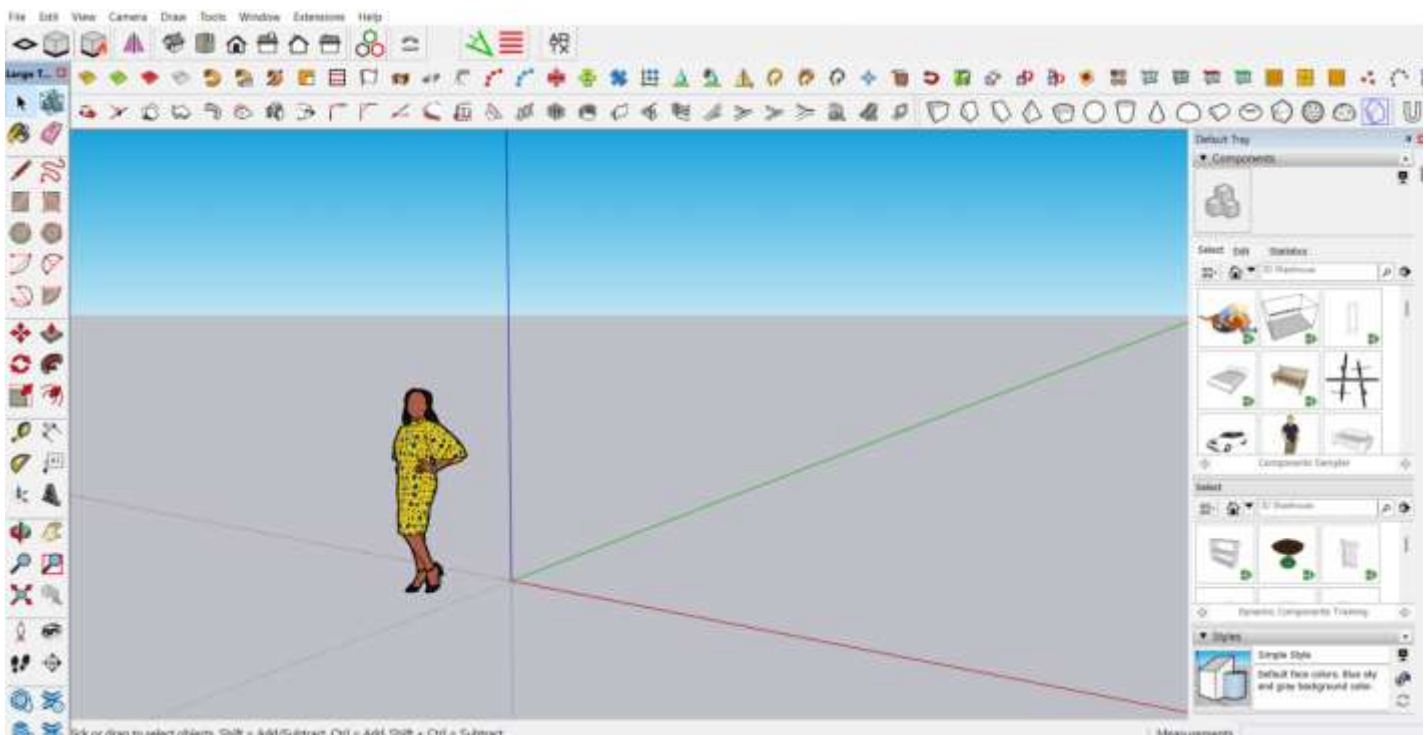
3. Core Functional Capabilities

3D Modelling Engine

- Push–Pull geometry editing
- Surface and solid modelling
- Grouping and component system
- Dynamic Components for parametric behaviour

Visualization

- Multiple style rendering (hidden line, shaded, sketch styles)



- Section cuts and construction documentation
- Compatible with external rendering engines (V-Ray, Escape, Lumion)

Documentation

Layout integration for: Construction drawings, Scaled plans, elevations, sections, Annotated presentations

Geolocation & Mapping

- Direct integration with Google Earth
- Terrain import and real-world positioning
- GIS-compatible workflows

Extensions & Customization

- Access to Extension Warehouse
- Ruby API for plugin development
- Parametric and automation tools available via plugins

CONCLUSIONS

The utilization of AutoCAD and SketchUp in landscape architecture represents a significant evolution from traditional manual drafting to intelligent, data-driven digital design processes. AutoCAD provides the technical backbone of landscape documentation through its precise drafting environment, robust modification commands, and compatibility with BIM and GIS platforms. Its ability to manage complex drawings, automate repetitive tasks, and integrate spatial data ensures accuracy and efficiency throughout the project lifecycle. In large-scale or infrastructure-oriented projects, AutoCAD facilitates coordination between structural, civil, and environmental components, minimizing construction conflicts and enhancing project reliability. Conversely, SketchUp strengthens the conceptual and visualization phase of design. Its intuitive interface and flexible 3D modelling tools allow designers to rapidly translate ideas into spatial representations. This enhances communication with clients and stakeholders by

presenting clear, realistic visualizations of proposed landscapes. The integration of geolocation features and rendering plugins further supports contextual design and aesthetic refinement. When combined with BIM methodologies and GIS-based spatial analysis, these tools enable a more holistic planning approach often described as geodesign. This integrated workflow improves environmental impact assessment, infrastructure optimization, and sustainable decision-making. Ultimately, the adoption of AutoCAD and SketchUp not only increases productivity and technical accuracy but also elevates the quality of landscape outcomes. As digital technologies continue to advance, their role in shaping resilient, efficient, and visually compelling outdoor environments will become even more indispensable in professional landscape practice.

REFERENCES

- BMVI (GERMAN FEDERAL MINISTRY OF TRANSPORT) (Ed.) (2015), Road Map for Digital Design and Construction: Introduction of modern, IT-based processes and technologies for the design, construction and operation of assets in the built environment. BMVI. 20 p.
- Elyashberg, M., & Argyropoulos, C. (2021). Environmental challenges in urban landscape development.
- Autodesk. (n.d.). *AutoCAD user guide*. Autodesk Knowledge Network. <https://help.autodesk.com>
- Bilous, L., Samoilenko, V., Shyshchenko, P., & Havrylenko, O. (2021). GIS in landscape architecture and design. In *Geoinformatics* (Vol. 1, pp. 1–7). European Association of Geoscientists & <https://doi.org/10.3997/2214-4609.20215521034>
- Rosener, B. (2014). 3D modeling programs: Comparison of SketchUp and Blender. In *Proceedings of the 12th International Conference on Education and Information Systems, Technologies and Applications* (EISTA 2014)

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NANOPARTICLE SYNTHESIS: FROM ATOMIC BUILDING BLOCKS TO NANOSCALE MATERIALS

Abstract

Nanotechnology deals with materials that are incredibly small but powerful enough to transform major fields of science. A key part of nanotechnology is understanding how nanoparticles are synthesized because their size, shape and purity determine the behaviour and the place of utility of the material. Nanoparticle synthesis generally follows two main approaches: building them from atoms (bottom-up) or breaking larger materials into nano-sized particles (top-down). This article explains the major chemical, physical, and biological methods used for nanoparticle production, highlighting how each technique works, its advantages, and its applications. By exploring these methods, readers gain a clearer picture of how tiny particles create big opportunities in science and technology.

Keywords: Nanoparticle synthesis, chemical method, physical method, green synthesis, top down approach, bottom up approach

Introduction

Nanotechnology is one of the most rapidly advancing fields in modern science, influencing medicine, agriculture, engineering, physics, electronics and environmental science. Tiny things are said to have great impact and nanoparticles are the perfect example of it. These materials measure between 1 to 100 nanometers, possessing unique physical, chemical, and biological properties making them more reactive and efficient than their larger counterparts. Thus nanoscale increases surface area, enhance reactivity and improves their performance across various applications. Understanding how these nanoparticles are synthesized is crucial for developing advanced technologies. Their synthesis falls under three major categories; chemical, physical and biological methods. These methods also fit into two fundamental strategies: bottom-up approaches (constructive) that build particles atom-by-atom and top-down approaches (destructive) that break bulk materials into nanoscale particles.

Chemical Methods

Chemical approaches are among the most common and versatile strategies. They generally rely on controlled reactions to produce nanoparticles with precise size and shape. Popular chemical methods include: chemical vapour deposition (CVD), sol-gel synthesis, thermal decomposition, laser pyrolysis, chemical reduction and co-precipitation. These techniques are widely used because they allow excellent control over the composition and uniformity of the nanoparticles.

- **Chemical vapour deposition (CVD)**

CVD is a method in which a thin film of nanoparticles is deposited onto a substrate inside a reaction chamber. Reactant gases are introduced into the chamber, which is heated to around 500–1000°C, causing chemical reactions that lead to the formation and deposition of a uniform, highly pure and strong nanoparticle film. However, the process is expensive due to the specialized equipment required, and it generates toxic gaseous by-products.

- **Sol–gel synthesis**

Sol–gel synthesis is a wet chemical process. A chemical precursor (metal oxides or metal chlorides) is dispersed in a host liquid by shaking, stirring or sonication to form a sol, a mixture containing both liquid and solid phases. The sol then undergoes phase separation to form a gel, which is a solid macromolecular network within a solvent. Depending on the drying method, the gel can be converted into an aerogel (supercritical drying), xerogel (thermal drying) or cryogel (freeze drying). Finally, calcination of the dried gel yields nanoparticles. This versatile method allows the synthesis of a wide variety of nanoparticles.

- **Thermal decomposition**

Thermal decomposition involves heating metal–organic precursors with surfactants in high-boiling organic solvents, where the applied heat breaks the precursors into metal atoms that nucleate and grow into uniform, monodisperse nanoparticles. The temperature at which decomposition occurs is specific to each material, and the process often results in the formation of secondary products alongside the nanoparticles. This method is widely used for producing highly crystalline nanoparticles with excellent size and shape control which is ideal for magnetic materials, catalysis, biomedical imaging, and electronic applications.

- **Laser pyrolysis**

For large-scale production of nanoparticles, pyrolysis is commonly used, where the precursor (in liquid or vapour form) is burned inside a high-temperature furnace. The combustion breaks down the precursor and generates nanoparticles as the by-product. Advanced pyrolysis techniques use lasers or plasma to achieve the required high temperatures. This method is simple, efficient, cost-effective and suitable for continuous, high-yield nanoparticle production.

- **Chemical reduction**

In the chemical reduction method, metal ions from a precursor salt are converted into neutral metal atoms using a reducing agent. These atoms then come together to form nanoparticles. A stabilizer is usually added to prevent clumping and to help control the size and shape of the particles. By adjusting factors like temperature, concentration, and mixing speed, the properties of the nanoparticles can be precisely tuned.

- **Co-precipitation**

In co-precipitation method precipitating agent is added, which bring metal ions together forming solid nanoparticles. As the pH rises, the ions react and form insoluble metal hydroxides or oxides, which then grow into nanoparticles. The process is usually left stirring or added with stabilizers to prevent clumping. By controlling pH, temperature and ion concentration, uniform nanoparticles can be produced easily, making co-precipitation a simple and fast method.

Physical Methods

Physical methods focus on breaking down bulk materials into nanoscale particles or using physical forces to generate them. Major physical techniques include: ball milling, laser ablation, evaporation and condensation, arc discharge, sputtering and ultra-sonication. These methods are useful when nanoparticles cannot be easily

produced through chemical methods.

- **Ball milling**

In ball milling, the precursor material (bulk powder) and the hardened milling balls are loaded into a sealed milling chamber, where parameters such as speed, time, ball-to-powder ratio and inert gas are adjusted. As the mill rotates, high-energy impact and shear forces cause repeated collisions between the balls and powder. Therefore, repeated collision gradually breaks the bulk powder into nano particles. This method offers a simple, solvent-free, low-cost method useful for preparing alloys, composites, and fine powders.

- **Laser ablation**

Laser ablation involves striking a metal target immersed in a liquid with a high-energy laser beam, generating a plasma plume that leads to nanoparticle formation. Since no stabilizers or chemical reagents are needed, this method is viewed as a green and eco-friendly alternative. It is a technique that produces stable nanoparticles in both water and organic solvents.

- **Evaporation and condensation**

Evaporation-condensation method involves heating a metal in high temperature furnace until it evaporates, and then the vapour is allowed to cool and condense the content into nanoparticles inside an inert gas atmosphere. This physical, chemical-free process produces highly pure nanoparticles with controlled size by adjusting parameters.

- **Arc discharge**

In the arc discharge method, two electrodes of the target material are placed close together and a high electric current is passed between them, creating an intense arc that vaporizes the material; the vapour then cools and condenses into nanoparticles. This method produces highly crystalline nanoparticles and is widely used due to its simplicity and ability to

generate high-quality products like carbon nanotubes.

- **Sputtering**

Sputtering produces nanoparticles by bombarding a target material with high-energy ions, causing atoms to be ejected and deposited as a thin nanoparticle layer on a substrate. The deposited film is often annealed afterward to enhance its structural and functional properties. Factors such as film thickness, annealing temperature and duration, and the nature of the substrate play key roles in determining the final size and shape of the nanoparticles.

- **Ultra-sonication**

In ultrasonication, the precursor is first dissolved in an appropriate solvent. A reducing or stabilizing agent may be added to control particle size. The mixture is then exposed to an ultrasonic bath or probe sonicator, where ultrasonic waves break down the precursor through cavitation, leading to the nucleation and formation of nanoparticles.

Biological Methods

Biological method is known as green synthesis; biological approaches use natural sources to produce nanoparticles in an eco-friendly manner. These methods employ: plant extracts, microorganisms, algae, biomolecules and enzymes. In the biological method, the overall process remains similar, while only the source of the biological reducing agent differs.

After source preparation, a metal ion solution is prepared and mixed with the biological extract. The biomolecules present in the source act as natural reducing and capping agents, converting metal ions into nanoparticles, usually indicated by a characteristic colour change depending on the material. The reaction mixture is then incubated, followed by centrifuged washed and dried to obtain purified nanoparticles.

Conclusion

Nanoparticle synthesis is fundamental to the advancement of nanotechnology, as the method of preparation directly influences particle size, morphology, stability, and functional performance. Chemical methods provide precision, physical methods offer high purity, and biological approaches introduce sustainability and eco-friendliness. Each technique has distinct advantages and limitations, and selecting the appropriate method depends on the required application and material properties. As research progresses, the focus is shifting toward greener, scalable, and more efficient synthesis routes that balance performance with environmental responsibility, paving the way for broader and safer applications of nanoparticles across diverse fields.

References

- Rane, A. V., Kanny, K., Abitha, V. K., & Thomas, S. (2018). Methods for synthesis of nanoparticles and fabrication of nanocomposites. In *Synthesis of inorganic nanomaterials* (pp. 121-139). Woodhead publishing. <https://doi.org/10.1016/B978-0-08-101975-7.00005-1>
- Rao, B. G., Mukherjee, D., & Reddy, B. M. (2017). Novel approaches for preparation of nanoparticles. In *Nanostructures for novel therapy* (pp. 1-36). Elsevier. <https://doi.org/10.1016/B978-0-323-46142-9.00001-3>
- Dhand, C., Dwivedi, N., Loh, X. J., Ying, A. N. J., Verma, N. K., Beuerman, R. W., ... & Ramakrishna, S. (2015). Methods and strategies for the synthesis of diverse nanoparticles and their applications: a comprehensive overview. *Rsc Advances*, 5(127), 105003-105037 DOI: [10.1039/C5RA19388E](https://doi.org/10.1039/C5RA19388E)

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“From Flowers to Livelihoods: Post-Harvest Value Addition as a Tool for Women Empowerment”

Introduction

Floriculture has emerged as one of the most dynamic and high-value sectors of Indian agriculture. With increasing demand for cut flowers, loose flowers, and ornamental plants for religious, social, and commercial purposes, flower cultivation is gaining importance as a profitable enterprise for farmers. In addition to domestic consumption, the export of flowers and floral products has opened new opportunities for income generation, especially in peri-urban and rural areas.

Despite its economic potential, the floriculture sector faces significant post-harvest challenges. Flowers are highly perishable commodities, and improper handling after harvest often leads to substantial losses. Lack of timely harvesting, inadequate grading, poor packaging, absence of cold storage, and inefficient transportation result in reduced flower quality, shortened vase life, and heavy economic losses. It is estimated that a considerable percentage of flowers produced in India are lost or downgraded due to poor post-harvest management practices.



Post-harvest operations in floriculture are labour-intensive and require careful handling rather than heavy machinery. These activities include cleaning, sorting, grading, packaging, value addition, and marketing—areas where women can play a crucial role. However, the contribution of women in post-harvest management of flowers remains largely untapped and under-recognized. With proper training, access to resources, and institutional support, women can actively participate in post-harvest and value-addition activities, transforming floriculture into a sustainable source of income and empowerment.

Post-Harvest Management in Flowers

Post-harvest management in floriculture refers to all operations carried out after the harvesting of flowers until they reach the consumer. Since flowers are highly delicate and perishable, proper post-harvest handling is essential to maintain their freshness, appearance, and market value. Efficient post-harvest practices not only reduce quantitative and qualitative losses but also increase the shelf life and profitability of floral produce.



The major post-harvest operations in flowers include harvesting at the right stage, removal of field heat, cleaning, grading, sorting, packaging, storage, and transportation. Harvesting at the appropriate stage of flower development is crucial, as premature or delayed harvesting can significantly affect flower quality and vase life. Immediate removal of excess moisture and damaged plant parts helps in preventing microbial infection and physical damage.

Grading and sorting are important steps that determine the market price of flowers. Uniform size, colour, and freshness are preferred in the market, especially for cut flowers and value-added floral products. Proper packaging using suitable materials such as corrugated boxes, sleeves, or baskets protects flowers during transportation and reduces mechanical injury. Where available, cold storage and cool-chain facilities further help in extending the shelf life of flowers.

Post-harvest operations in floriculture are largely skill-based and labour-intensive, making them highly suitable for women's participation. These activities do not require heavy physical labour and can be carried out at the household level, community centres, or through women self-help groups. With basic training

and access to simple infrastructure, women can efficiently manage post-harvest handling and significantly reduce losses, thereby increasing overall returns from floriculture.

Value Addition Opportunities in Floriculture

Value addition in floriculture involves converting raw flowers into products with higher market value, longer shelf life, and better consumer appeal. Through value addition, farmers and rural entrepreneurs can earn higher returns compared to selling fresh flowers alone. For women, value addition offers a promising avenue for income generation, entrepreneurship, and skill development.



One of the most common value-added activities in floriculture is the preparation of flower garlands, floral strings, and bouquets. These products are in constant demand for religious functions, weddings, cultural events, and festivals. With proper training in flower arrangement and handling, women can easily engage in this activity at the household or community level.

Dry flower production is another important value-addition opportunity. Flowers such as rose, marigold, lily, statice, and baby's breath can be dried using simple techniques like air drying or solar drying. Dried flowers are used in decorative items, potpourri, wall hangings, greeting cards, and handicrafts, offering year-round income and reducing seasonal dependence. Floral crafts and decorative products further enhance the income potential of value addition. Items such as

table centrepieces, wreaths, decorative baskets, and eco-friendly floral products have increasing demand in urban markets, hotels, and event management sectors. Additionally, extraction of natural pigments, dyes, and essential oils from selected flowers provides scope for small-scale processing units with higher profit margins.

Value addition activities require limited space, moderate investment, and flexible working hours, making them particularly suitable for women and self-help groups. By adopting value-addition practices, women can reduce post-harvest losses, improve product quality, and transform floriculture into a sustainable livelihood enterprise.

Role of Women in Post-Harvest Management and Value Addition of Flowers:

Women play a vital role in floriculture, particularly in post-harvest management and value-addition activities. These operations require precision, care, and skill rather than heavy physical labour, making them well suited for women's active participation. Traditionally, women have been involved in activities such as flower harvesting, cleaning, garland making, and sorting, but their contribution often remains informal and unrecognized.

In post-harvest management, women can effectively handle operations like cleaning, grading, sorting, bundling, and packaging of flowers. Their attention to detail helps in maintaining uniformity and quality, which is essential for better market prices. Proper handling by trained women workers also reduces post-harvest losses and improves the shelf life of flowers.



Value addition offers even greater opportunities for women empowerment. Activities such as bouquet preparation, dry flower production, floral crafts, potpourri making, natural dye extraction, and essential oil processing can be carried out at the household level or through women self-help groups. These enterprises require limited infrastructure and allow flexible

working hours, enabling women to balance household responsibilities with income-generating activities.

Women self-help groups (SHGs) play a crucial role in strengthening floriculture-based enterprises. Collective production, shared resources, and group marketing improve bargaining power and reduce individual risk. SHGs also facilitate access to government schemes, bank credit, training programs, and market linkages. With institutional support, women can move from wage labour to entrepreneurship in floriculture.

Participation in floriculture post-harvest and value-addition activities enhances women's financial independence, decision-making power, and social status. It contributes not only to household income but also to rural employment generation and inclusive agricultural development. Empowering women through floriculture thus represents a sustainable and socially beneficial approach to strengthening the agricultural economy.



Government Subsidies and Loan Schemes Supporting Women Entrepreneurs:

To encourage women entrepreneurship in agriculture and allied sectors, the Government of India has introduced several financial assistance schemes in the form of subsidies, soft loans, and credit-linked support. These schemes play a crucial role in helping women establish post-harvest and value-addition enterprises in floriculture by reducing initial investment barriers and improving access to institutional credit.

One of the most widely used schemes is the **Pradhan Mantri Mudra Yojana (PMMY)**, which provides collateral-free loans to women entrepreneurs under the Shishu, Kishor, and Tarun categories. These loans are suitable for small-scale floriculture activities such as

bouquet making, dry flower units, garland preparation, and floral craft enterprises. Many banks also offer concessional interest rates for women borrowers under this scheme.

The **Stand-Up India Scheme** supports women entrepreneurs by providing bank loans ranging from ₹10 lakh to ₹1 crore for setting up new enterprises in manufacturing, processing, and agri-allied sectors. This scheme is particularly useful for women planning to establish organized post-harvest units, flower processing centres, or value-added floral product enterprises.

Under the **Prime Minister's Employment Generation Programme (PMEGP)**, women entrepreneurs are eligible for higher credit-linked subsidies for establishing micro-enterprises in rural and urban areas. Floriculture-based post-harvest and value-addition units qualify under this scheme, making it easier for women to start enterprises with partial government subsidy support.

The **Mahila Udyam Nidhi Scheme**, operated by SIDBI, provides soft loans to women entrepreneurs for setting up small-scale industries. This scheme supports women engaged in agri-processing and value-added activities by offering affordable financial assistance for infrastructure development and equipment purchase.

In addition to central schemes, women can also benefit from support provided through **Self-Help Groups (SHGs)**, **National Rural Livelihood Mission (NRLM)**, and training programs conducted by **Krishi Vigyan Kendras (KVKs)** and state horticulture departments. These institutions play a vital role in capacity building, skill development, and market linkage support.

Access to government subsidies and institutional finance empowers women to transform floriculture post-harvest activities into sustainable enterprises, contributing to income generation, employment creation, and overall rural development.

Economic and Social Impact of Floriculture Value Addition on Women

Value addition in floriculture has a significant economic and social impact on women involved in post-harvest and allied activities. By converting raw

flowers into market-ready and value-added products, women are able to generate additional income beyond traditional farm labour. This supplementary income plays a crucial role in improving household financial stability, especially in small and marginal farming families.

Economically, floriculture-based value addition provides opportunities for both part-time and full-time employment. Activities such as garland making, bouquet preparation, dry flower production, and floral crafts ensure regular income, even during off-seasons. Women engaged in these enterprises often experience reduced dependency on middlemen, as value-added products fetch better prices in local and urban markets. Group-based enterprises through self-help groups further enhance income by reducing production costs and improving market access.

Socially, participation in floriculture value addition contributes to increased confidence and self-reliance among women. Financial independence strengthens their role in household decision-making, including education, health care, and farm investments. Women entrepreneurs involved in floriculture also gain recognition within their communities, which enhances their social status and leadership roles.

Floriculture value addition encourages skill development, creativity, and entrepreneurship among women. Training programs and exposure to markets help women acquire technical and managerial skills, enabling them to transition from labourers to enterprise owners. Collective activities through SHGs promote cooperation, mutual support, and social cohesion.

Moreover, women-led floriculture enterprises contribute to rural employment generation and inclusive agricultural growth. By reducing post-harvest losses and increasing profitability, these activities support sustainable agricultural development while promoting gender equity. Thus, floriculture value addition serves as a powerful tool for both economic empowerment and social transformation of women in rural and peri-urban areas.

Value-Added Floriculture Products for Women Entrepreneurs:

1. Flower Garlands and Floral Strings

High demand in temples, weddings, festivals, and cultural events throughout the year. Daily local markets ensure regular sales.

Provides quick returns and daily income

Requires minimal equipment and investment

Ideal entry-level business for rural women

2. Bouquets and Floral Arrangements

Growing demand in urban markets, hotels, corporate offices, events, and celebrations.

Higher profit margins than loose flowers

Enhances creativity and skill development

Suitable for both fresh and artificial flowers

3. Dry Flowers and Dried Floral Products

Strong demand in home décor, handicraft markets, gift shops, and online platforms.

Long shelf life and reduced spoilage

Year-round income generation

Utilizes surplus and unsold fresh flowers

4. Potpourri and Floral Fragrance Products

Used in households, hotels, wellness centres, and gift items.

Simple processing methods

Attractive packaging increases value

Suitable for home-based enterprises

5. Floral crafts and decorative items:

Increasing demand for eco-friendly décor in events, exhibitions, and lifestyle markets.

Encourages innovation and design skills

Low raw material cost

High value in niche markets

6. Natural Dyes and Pigments from Flowers

Rising demand in textile, cosmetics, food colouring, and handicraft sectors.

Eco-friendly alternative to synthetic dyes

Supports sustainable and organic markets

Potential for small scale processing units

7. Essential Oils and Floral Extracts

Used in perfumes, aromatherapy, cosmetics, and pharmaceuticals.

High market value products

Export-oriented opportunities

Suitable for group-based enterprises with training



8. Floral Jewelry and Accessories

Popular in weddings, cultural functions and fashion events

Seasonal high-demand product

Requires creativity and minimal tools

Strong market among youth and event planners

9. Seedling and Nursery Raising of Ornamental Plants

Steady demand from landscapers, home gardeners, and institutions.

Long-term income source

Encourages entrepreneurship in floriculture

Can be combined with other floral activities

10. Value-Added Eco-Friendly Products

Growing interest in biodegradable décor and sustainable floral products.

Environment-friendly income option

Aligns with green initiatives

Adds social value along with economic benefits

Conclusion

Post-harvest management and value addition in floriculture offer a powerful pathway for enhancing farm income while promoting women empowerment. Flowers, being highly perishable, require careful handling after harvest to minimize losses and maintain quality. When combined with value-addition

practices, post-harvest operations can significantly increase the economic returns from floriculture.

Women are naturally positioned to play a key role in this sector due to the skill-oriented and labor-intensive nature of post-harvest activities. Through engagement in value-added enterprises such as garland making, bouquet preparation, dry flower products, floral crafts, and processing of floral extracts, women can transform floriculture into a sustainable livelihood option. These activities not only generate income but also encourage entrepreneurship, creativity, and skill development.

Government initiatives, including subsidies, credit-linked schemes, and training programs, further strengthen the participation of women in floriculture-based enterprises. Access to institutional finance, self-help groups, and market linkages enables women to move from informal labor to organized entrepreneurship. Such support systems reduce financial risks and enhance long-term sustainability.

Overall, floriculture value addition contributes to economic independence, improved social status, and enhanced decision-making power for women, while also reducing post-harvest losses and strengthening the agricultural economy. Promoting women-led post-harvest and value-added floriculture enterprises can play a significant role in achieving inclusive growth, rural development, and gender equity in Indian agriculture.

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7 PLANTS YOU SHOULD ALWAYS GROW NEXT TO SUCCULENTS, FOR THRIVING AND STYLISH ARRANGEMENTS

Introduction:

Unlike other houseplants, where often much time and effort are spent trying to maximise their wellbeing and abundance, the best indoor succulents require very little care, and little watering, to thrive. When it comes to companion planting, the plants that will be happy bedfellows with succulents must require the same levels of water, light, and nutrients, as well as be aesthetically complementary.

Here are seven plants you should always grow next to succulents for maximum visual impact and minimal work.

All of these plants will want around 6-7 hours of light per day. An east, or preferably south-facing, windowsill should guarantee your succulent and its companion get enough sunlight.

1. Rosemary (*Salvia rosmarinus*)

Grow rosemary (Salvia rosmarinus) in the kitchen so it can be snipped and used in culinary creations. Planting it with succulents and leaving in a sun-cloaked area will make for a very beautiful indoor pot. Rosemary is at the top of my list of must-grow essential herbs, for its culinary uses but also for its aesthetic ones, since it is superabundant, utterly delicious, and very beautiful. Success with rosemary can be achieved when grown in direct sunshine and with good drainage



2. Red Valerian (Centranthus ruber)



Red valerian likes very sharp drainage and very little watering. It can grow outdoors, where it will self-seed readily, or indoors, where it can be picked and used as a cut flower.

If growing indoors, using a pot with good drainage is essential. Be sure to add perlite to any pots to ensure good soil aeration. Perlite, like this organic perlite from Amazon, will enhance the drainage without compressing the roots.

It works well planted alongside larger succulents as it resents being overwatered and thoroughly enjoys staying dry for prolonged periods.

You may well find that what you consider a light watering causes root rot, so proceed with caution when watering. If you are growing in pots, putting them onto pot feet, such as these non-slip ones from UFelice at Amazon, can help reduce the risks of root rot.

3. Santolina virens 'Lemon Fizz'



Santolina Lemon Fizz, commonly known as 'Cotton Lavender', is the most gorgeous, luminous shade of acid green and looks completely beautiful with succulents.

It's one of the very best rock garden plants, or plants for a dry border, since it loves light watering. Its soft feathery fronds are a wonderful foil for more structural drought-tolerant plants such as succulents and sedums, and it loves to live with herbs, like creeping thyme, lavender, and sage. Santolina is a true sunworshipper, so if you are growing it outdoors, it will need to be in zones 6 and above, and pick a sunny spot.

If you're growing indoors, note that it will only thrive in an extremely sunny position, so ensure it lives in a sun-drenched spot and the soil drains effectively.

It will only enjoy an indoor life if it has lean, gritty soil, so I highly recommend using some bonsai pumice available at Amazon in the potting mix.

4. Pennisetum setaceum 'Fireworks'

Perfect for adding texture and for complying with succulent needs, Pennisetum is a wonderful drought-tolerant ornamental grass that can be grown both indoors and outdoors, and is a doddle to grow and keep happy.



Pennisetum, often known as 'Fountain Grass', provides year-round color in the form of beautiful soft plumes, which serve as a necessary contrast to succulent's beefy qualities.

It can be grown as a perennial year after year in zones

9 - 11, or indoors if placed in a sunny spot and potted up with a quality soil like [this Rosy Soil fast-draining potting soil](#) available at [Amazon](#), which is fortified with beneficial fungi & microbes.

5. *Mammillaria bombycina*

Mammillaria bombycina, commonly known as the Silken Pincushion Cactus, can be kept on a similar regime of near-total neglect and is quite a showstopping, statuesque beauty.

The bright-green to grey-green stems are covered in spines, and in the spring, the most darling rose pink flowers erupt from them.

Generally, it is grown indoors, where it can live its life without want for anything, though it can be grown outdoors in zones 9-11. Still, it requires sandy, well-draining soil.



5. *Pelargonium dasyphyllum*

This pelargonium is a stem succulent species within the *Pelargonium* genus, belonging to the Geraniaceae (*Geranium*) family.

The best way to think about it, to my mind, is that it is a pelargonium that behaves like a succulent, making it an excellent roommate for succulents.

Both *Pelargoniums* and succulents need bright, direct light, so place them in the sunniest window in your home. Their main requirements are warmth and sunshine, and of course, as I keep rhapsodizing about all of these plants, well-draining soil.



6. Lemon Thyme (*Thymus citriodorus*)

Succulents and herbs are the perfect companion plants. Lemon thyme's cultural and care needs are very similar to succulents'; they like plenty of sunlight and prefer low-fertility soil with very good drainage.

As befits its Mediterranean roots, lemon thyme is a very [drought-tolerant herb](#), so it won't sulk that the pot is getting little water.

The dainty, beautifully fragrant leaves of lemon thyme contrast wonderfully with the stocky, thick leaves of succulents, and cascade down the side of pots.

Knowing how to [grow thyme indoors](#) is extremely easy, so long as there is, you guessed it, good drainage.



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Standardization of Sustainable Harvesting Practices for *Dioscorea deltoidea* in the North-Western Himalayas

Abstract

Dioscorea deltoidea Wall. ex Griseb. (Nepal Yam) is an endangered perennial climber native to the North-Western Himalayas and a primary source of diosgenin, a steroidal sapogenin essential to the pharmaceutical industry. Despite its commercial value and medicinal significance in treating gastrointestinal, urogenital, and inflammatory disorders, the species faces extinction due to unsustainable harvesting practices, specifically local collectors uprooting immature rhizomes without replanting. This study evaluated the regenerative success of *D. deltoidea* in different forest areas of Uttarakhand using the rhizome cutting method. Samples were selected across various forest divisions and categorised into three treatment groups based on node count: fragments with two nodes, one node, and zero nodes (n=15 per group). Regeneration was measured by the percentage of successful shoot emergence. Additionally, phenological monitoring was conducted to determine the correlation between foliar yellowing, seed dispersal, and optimal harvest timing. Findings indicate that rhizome fragments with two nodes achieve the highest regenerative success rate (80%), whereas fragments with zero nodes fail to regenerate entirely. To ensure species persistence, the study suggests that harvesting should be limited to 50% of the rhizome and restricted to the October–November months, following seed dispersal and leaf senescence. Implementing these node-based regeneration protocols and seasonal restrictions is vital for balancing industrial demand with biodiversity conservation.

Key words: *Dioscorea deltoidea*, Sustainable harvesting, Rhizome, Uttarakhand, Diosgenin



Fig. *Dioscorea deltoidea* Plant



Fig. *D. deltoidea* Rhizome

Introduction

Dioscorea deltoidea

Synonyms	<i>Tamus nepalensis</i> , <i>Dioscorea nepalensis</i> ,
Common Name	Nepal Yam
Vernacular Names	• Sanskrit: Varahikand • Hindi: Shingli-mingli, Baniatakari, Harvish, Janj, Jung kinch • Nepali: Bhyaakur Kukur Tarul, Kaande Bhyaakur
IUCN Status	Endangered

Introduction: *D. deltoidea* Wall. Ex Kunth. (Dioscoreaceae) is commonly known as singli-mingli, Kins and Ganj. Underground rhizomes of *Dioscorea*, commonly known as wild yam. (Bhandari et al., 2003) It is a perennial climber growing up to 3 m. It grows in the North-Western Himalayas from Kashmir, Punjab and Himachal Pradesh, eastward to Nepal and China at altitudes ranging 1,000-3,500 m amsl. (Bano et al., 2021) However, due to increasing market demand and ecological damage, this species of have been gradually declining in nature. The species is also included in the list of endangered plant species in India, Nepal, Pakistan, and other Asian countries (Jain, 1997). *Dioscorea* has been identified as of very high importance in pharmaceutical firms, and the plant is mainly collected from the wild in Northern Himalaya region. *Dioscorea* is endangered in natural habitats due to illicit harvesting and over-use by local people for trading and domestic purposes. (Rana & Samant, 2011)

Geographical Distribution

It grows in the North-Western Himalayas, from Kashmir, Himachal Pradesh and Uttarakhand eastward to Nepal and China, at altitudes ranging from 1,000-3,500 m amsl. It is mainly found under the bushes of *Berberis spp* (Daruhaladi) and *Principia utilis* (Bhenkal).

Botanical Description

D. deltoidea stems are perennial, glabrous, climber, twining to the left, slender branches and

unarmed. Leaves are alternate, diverse in shape and size (5–18 cm long), acuminate, membranous, reticulate, rounded and sub-angular lobes, with a long petiole as a blade (~25 cm). Male spikes are 8–40 cm long, solitary, lax, slender, branched with a laxpanicle, rarely in pairs. Flowers are solitary or in clusters with ~2 mm diameter, 6 stamens, short and didymous anthers. Female spikes are 8–16 cm long, are solitary, with few flowers and are distant. Seeds are variable in shape and size, winged, and sometimes only on one side. Rhizomes are elongated, cylindrical, woody, branched and horizontal (~10 cm), covered with long, tough filiform roots. Roots are tubers, tough, yellow and are ~26 cm in length. (Semwal et al., 2021)

Phytochemistry and uses

Different phytochemicals are found in *Dioscorea deltoidea* rhizomes which are reported by different workers. These include diosgenin, 25-D-spirostan-3,5 diene, smilagenone, stigmasterol, B-sitosterol, dioscorin, dioscin and campastrol. Root contains phytosterols, alkaloids, tannin and rich source of starch. (Mustafa et al., 2021). Diosgenin is a chemical substance found in *Dioscorea* and is used commercially in the pharmaceutical industry. Traditionally, the species is used by different communities to alleviate a wide variety of ailments, including gastrointestinal and urogenital disorders, diarrhoea, irritability, abdominal pain, joint pain, wounds, intestinal worms, anaemia, and ophthalmic conditions. The tubers of *Dioscorea* are used in the management of several diseases such as gastrointestinal disorders, sore throat from struma, diarrhoea, irritability, abdominal pain, wounds, burns and anaemia. (Rana et al., 2020).

Flowering and Fruiting

- Flowering usually occurs in May to June, and fruiting occurs from June to September

Important Plant Parts Used

- Roots and root bark (important in Dashamoola), Pods and Seeds, Leaves and stem bark
- **Demand and supply:**

Table : *D. deltoidea* Regenerative Success Rate %

Treatments	(N) Total number of samples	(NS) Number of rhizome fragments successfully regenerated from N	NS/N	Regenerative Success Rate (%)
Rhizome fragment with two nodes	15	12	12/15	80%
Rhizome fragment with one nodes	15	8	8/15	53.33%
Rhizome fragment with Zero nodes	15	0	0/15	0%

Root tubers of this plant are high in demand in both national and international market. These are also sold in local market at the rate of 300 to 500/kg and usually harvested from natural habitat.

Details

Prevalent harvesting practices:

Due to intense competition among the collectors, the rhizomes of *D. deltoidea* are harvested before maturity. In order to collect more rhizomes, the collectors dug the roots up from the soil without following any scientific harvesting technique and damaged the plants, which helps in the regeneration of the roots. No care is taken to replace the rhizomes into the soil.

Standardization of sustainable Harvesting Practices



Fig: Destructive Harvesting of *Dioscorea deltoidea* rhizome by local people

For Rhizome harvesting of *Dioscorea deltoidea* three treatments were applied.

- Rhizome fragment with two nodes
- Rhizome fragment with one nodes
- Rhizome fragment with Zero nodes

The Table outlines the regenerative success rates of *D. deltoidea* rhizome fragments with varying numbers of nodes. Rhizome fragments with two nodes had the highest success, with 12 out of 15 samples regenerating, resulting in an 80% success

rate. Fragments with one node showed moderate success, with 8 out of 15 regenerating, giving a success rate of 53.33%. However, rhizome fragments with zero nodes showed no regeneration, with a 0% success rate, as none of the 15 samples successfully regenerated. Successful regeneration occurred in both rhizomes with one or two nodes. No emergence (or regeneration) was recorded from any rhizome fragment with zero nodes.



Fig: Sustainable harvesting of *D. deltoidea*, Only 50 % the tuber should be harvested, leaving the tuber

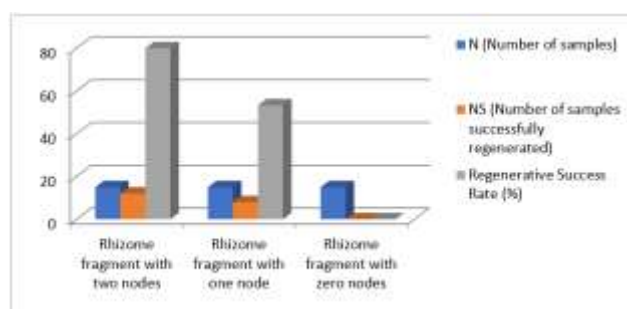


Fig. Regenerative Success Rate % of *D. deltoidea*

Selection of plant/tree for harvesting: The rhizomes of *D. deltoidea* should be uprooted only after seeding is over to allow for natural regeneration.

Characteristics of plant parts to be harvested:

The leaves, on maturity, turns yellowish in colour, which indicates that the rhizomes of *D. deltoidea* have become matured and the seeds have shed for regeneration.

Time and age of harvesting (period- season/month): The roots of *D. deltoidea* are harvested in the months of October- November after seeding has occurred to ensure natural regeneration.



Fig: Yellowish in color of leaves indicates rhizomes ready for harvesting

Extent of harvesting (quantity/ amount): Only 50 % of the rhizome should be harvested, leaving rest in the soil for natural regeneration

Conclusion

D. deltoidea is one of the most important medicinal tuber species in the Himalayan region and is used for different purposes. However, due to increasing market demand and ecological damage, this specie have been gradually decreasing in nature. The study concludes that the survival of the endangered *Dioscorea deltoidea* is strictly dependent upon shifting from destructive extraction to a sustainable harvesting method. Research data reveals a direct correlation between rhizome fragmentation and survival, with a two-node rhizome fragment yielding an 80% regeneration success rate, whereas fragments with zero nodes result in total population loss. To balance pharmaceutical demand for diosgenin with species conservation, harvesting must be restricted to the post-seeding months of October and November, signaled by the natural yellowing of the foliage. By implementing a 50% retention protocol—where half the rhizome remains in situ with at least two viable nodes—the species can maintain its perennial cycle, ensuring that this high-value medicinal resource is not driven to extinction by current unscientific collection practices.

Reference:

- Bano H., Rather R A, Javeed I. Bhat A., Bhat T A., Azad H, Bhat S A., Hamid F and Bhat M. A. 2021. Effect of pre-sowing treatments using phytohormones and other dormancy breaking chemicals on seed germination of *Dioscorea deltoidea* Wall. Ex Griseb.: an Endangered Medicinal Plant Species of North Western Himalaya. Eco. Env. & Cons. pp. (S253-S260)
- Bhandari, M. R., Kasai, T., and Kawabata, J. (2003). Nutritional evaluation of wild yam (*Dioscorea* spp.) tubers of Nepal. Food Chemistry, 82(4), 619–623. [https://doi.org/10.1016/S0308-8146\(03\)00019-0](https://doi.org/10.1016/S0308-8146(03)00019-0)
- Jain, A. 1997. Vulnerable and threatened plants of economic value. *Dioscorea deltoidea*. - MFP News 7(2): 12.
- Mustafa, A., Ahmad, A., Tantray, A. H., and Parry, P. A. (2018). Ethnopharmacological potential and medicinal uses of miracle herb *Dioscorea* spp. Journal of Ayurvedic and Herbal Medicine, 4, 79–85.
- Rana, D., Bhatt, A., Lal, B., Parkash, O., Kumar, A., and Uniyal, S. K. (2020). Use of medicinal plants for treating different ailments by the indigenous people of Churah subdivision of district Chamba, Himachal Pradesh, India. Environment, Development and Sustainability, 23, 1162–1241. <https://doi.org/10.1007/s10668-020-00617-0>
- Rana, M., and Samant, S. (2011). Diversity, indigenous uses and conservation status of medicinal plants in Manali wildlife sanctuary, north western Himalaya. Indian Journal of Traditional Knowledge, 10(3), 439–459.
- Semwal, P., Painuli, S., Cruz-Martins, N. *Dioscorea Deltoidea* Wall. Ex Griseb: A Review of Traditional Uses, Bioactive Compounds and Biological Activities. Food Biosci. 2021, 41, 100969. <https://doi.org/10.1016/j.fbio.2021.100969>.

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ARTICLE ID: 57**CULTIVATING A RESILIENT FUTURE WITH
CLIMATE-SMART AGRICULTURE****Abstract**

Climate change and food and nutrition insecurity represent two of the most pressing development challenges of our time. The global agrifood system currently contributes one-third of all greenhouse gas emissions, serves as the leading source of methane emissions and biodiversity loss and consumes approximately 70% of freshwater resources. With the global population projected to reach 9.7 billion by 2050, food demand will increase substantially, creating pressure that has historically led to agricultural expansion and unsustainable resource use perpetuating a vicious cycle of environmental degradation and rising emissions. Climate-Smart Agriculture (CSA) emerges as a transformative approach to reorienting agricultural development within the context of climate change. Defined by the Food and Agriculture Organization (FAO) as agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces or removes greenhouse gases (mitigation) where possible and advances national food security and development goals, CSA rests upon three interconnected pillars: productivity, adaptation and mitigation. This article explores innovative agricultural solutions that integrate traditional knowledge, eco-friendly practices and appropriate technologies, positioning farmers not merely as food producers but as climate warriors essential to building a sustainable future.

Introduction

As we navigate the complexities of 2025, agriculture stands at the critical intersection of innovation and necessity. The challenges confronting global food systems have never been more daunting: erratic rainfall patterns disrupt planting seasons; soil degradation diminishes productivity and rising input costs strain farming communities worldwide. Meanwhile, emissions from agriculture continue to increase in developing countries - a troubling trend that demands immediate reversal. Growing up as a farmer in a drought-prone region of central India has provided firsthand witness to climate change's impacts on agriculture. These experiences underscore the pressing need for solutions that work at the grassroots level while contributing to global sustainability goals. Climate-Smart Agriculture offers a promising pathway forward—one that honours traditional farming wisdom while embracing eco-friendly innovations and appropriate technologies. Its principal goal is to achieve food security and broader development objectives through three interlinked pillars:

1. **Sustainably Increasing Productivity and Incomes:** Enhancing food and nutrition security by boosting agricultural output and the incomes of those who depend on farming.
2. **Building Resilience and Adapting to Climate Change:** Strengthening the capacity of agricultural systems and livelihoods to withstand climate-related shocks, such as droughts, floods, and changing weather patterns.
3. **Reducing and/or Removing Greenhouse Gas Emissions:** Where possible, mitigating the impact of agriculture on the climate by reducing emissions and enhancing carbon storage in soils and biomass.

As we navigate 2025 and beyond, agriculture finds itself at the powerful intersection of innovation and necessity. Farmers are no longer just cultivators; they are emerging as climate warriors, harnessing technology and sustainable methods to protect the planet while securing food for billions. In an era marked by unpredictable rainfall, degrading soil health, and escalating input costs, sustainable and climate-smart practices are not merely an option—they are the bedrock of a resilient and productive agricultural future. This comprehensive guide will delve into the top eco-friendly and technology-driven practices that can empower every farmer to thrive in this new landscape, ensuring we preserve the earth for generations to come.

❖ The Three Pillars of Climate-Smart Agriculture (CSA)

Climate-Smart Agriculture (CSA) is built on three interconnected pillars that work together to ensure food security in a changing climate.

Productivity – Growing More, Sustainably

CSA aims to **increase agricultural productivity and farmer incomes** from crops, livestock, and fisheries—without harming the environment. The goal is to improve **food and nutritional security** while protecting natural resources.

A key concept here is **sustainable intensification**—producing more from the same land area while conserving soil, water, and biodiversity. For example, improved seed varieties, precision nutrient management, and integrated pest management can boost yields responsibly.

Adaptation – Building Resilience to Climate Risks

CSA reduces farmers' exposure to **short-term risks** (like droughts, floods, heat waves) and strengthens their **long-term resilience**. It enhances farmers' ability to adapt and thrive despite climate-related shocks and stresses.

Special attention is given to protecting **ecosystem services**—such as soil fertility, water regulation, and pollination—which are essential for sustaining productivity and enabling adaptation. Practices like crop diversification, agroforestry, and water harvesting are common adaptation strategies.

Mitigation – Reducing Greenhouse Gas Emissions

Whenever possible, CSA works to **reduce or remove greenhouse gas (GHG) emissions** from agriculture. This means:

- Reducing emissions per kilogram or calorie of food produced
- Preventing deforestation caused by agricultural expansion
- Managing soils and trees to maximize carbon sequestration

Practices such as conservation tillage, improved manure management, and agroforestry help agriculture act as part of the climate solution.



Importance of Climate-Smart Agriculture (CSA)

Climate-Smart Agriculture (CSA) is vital in an era of irregular rainfall, rising temperatures, and frequent droughts. It strengthens agriculture by making farming systems more resilient, productive, and sustainable. Its importance can be summarized as follows:

- 1. Improved Climate Resilience:** CSA helps farmers cope with climate variability through climate-resilient crop varieties, better water management, and improved soil practices. These approaches maintain stable production even during droughts or floods while also lowering greenhouse gas emissions through practices like agroforestry and carbon sequestration.
- 2. Better Soil Health:** Healthy soils are the foundation of sustainable farming. CSA promotes practices such as cover cropping, reduced tillage, and organic amendments to enhance soil fertility,

structure, and moisture retention while reducing erosion.

3. Efficient Water Management

Water scarcity is a growing concern, especially in dry regions. CSA encourages rainwater harvesting, mulching, and drip irrigation to improve water-use efficiency and reduce wastage.

4. Sustainable Pest and Disease Control

By adopting crop rotation, biological control, and resistant varieties, CSA reduces dependence on chemical pesticides, protects beneficial organisms, and supports ecological balance.

5. Reduced Food Loss and Waste

Minimizing losses across the supply chain improves resource efficiency, lowers greenhouse gas emissions, and strengthens food security.

6. Economic Sustainability for Farmers

CSA enhances productivity while reducing risks and input costs. Higher and more stable yields improve farm income, enabling farmers to invest in better technologies and secure their livelihoods.

In essence, CSA builds a resilient and environmentally responsible agricultural system capable of feeding present and future generations.

Best Practices for Climate-Smart Agriculture

Smart Irrigation Systems: Saving Every Drop

Water remains the lifeblood of agriculture, yet inefficiencies in irrigation result in millions of litres wasted annually. Smart irrigation technologies are revolutionizing how farmers manage this increasingly scarce resource, enabling precise application that maximizes crop benefits while minimizing waste.

Leading Smart Irrigation Practices for 2025:

1. **Drip Irrigation:** Delivers water directly to plant roots through a network of tubes and emitters, reducing water wastage by up to 60% compared to conventional flood irrigation methods.
2. **IoT Moisture Sensors:** These underground devices continuously measure soil hydration levels and automatically trigger or halt irrigation based on real-time moisture data, ensuring crops receive water only when needed.
3. **Smart Sprinklers:** Controlled via mobile applications, these systems enable farmers to schedule and monitor irrigation remotely, ensuring uniform water distribution across fields while responding to changing weather conditions.

By integrating Internet of Things (IoT) technology with precision agriculture principles, modern platforms empower farmers with actionable insights about irrigation timing and quantity, simultaneously improving yields and

conserving water resources.

Soil Health and Organic Management

Productive agriculture begins beneath the surface. Healthy soils teeming with organic matter and beneficial microorganisms produce robust crops with greater resilience to pests, diseases, and climate stresses. However, decades of chemical-intensive farming have left many agricultural soils depleted of essential nutrients and organic carbon.

Sustainable Soil Management Practices for 2025:

1. **Bio-fertilizers and Organic Compost:** These natural amendments restore soil fertility by introducing beneficial microorganisms and increasing organic matter content, improving soil structure and water-holding capacity.
2. **Crop Rotation:** Alternating crop families across growing seasons prevents nutrient depletion, breaks pest and disease cycles, and naturally balances soil fertility without synthetic inputs.
3. **Soil Testing Kits:** Modern testing tools provide farmers with data-based recommendations for nutrient management, preventing both under-application and wasteful over-application of fertilizers.
4. **Green Manuring:** Growing leguminous crops specifically to incorporate them into the soil fixes atmospheric nitrogen organically, enriching soil for subsequent plantings.

Through organic soil management approaches, farmers can reduce input costs, boost long-term productivity, and reverse the degradation caused by intensive conventional farming.

Renewable Energy: Powering the Future of Farming

Agriculture's dependence on fossil fuels has contributed both to rising production costs and to greenhouse gas emissions. The transition to renewable energy sources offers farmers a pathway to greater energy independence while reducing their environmental footprint.

Leading Renewable Energy Solutions for Agricultural Operations:

1. **Solar-Powered Pumps:** Photovoltaic systems power irrigation pumps and farm lighting, eliminating fuel costs and emissions while providing reliable energy in remote locations.
2. **Biogas Plants:** These systems convert farm waste—animal manure, crop residues, and organic byproducts—into methane for cooking, heating, or electricity generation, creating value from materials otherwise discarded.
3. **Small-Scale Wind Turbines:** In suitable locations, wind energy can power remote farm operations, diversifying energy sources and reducing grid dependence.

By adopting clean energy technologies, farmers insulate themselves from fuel price volatility, reduce their carbon footprint, and build more resilient, self-sufficient operations.

Leveraging AI and IoT for Smart Farming

Advanced technologies have moved from optional luxuries to essential tools for modern agriculture. Artificial Intelligence, the Internet of Things, and machine learning algorithms are fundamentally reshaping how farmers monitor, analyze, and respond to conditions in their fields.

Transformative Smart Farming Innovations for 2025:

1. **Agricultural Drones:** These aerial platforms capture high-resolution imagery of crops, identifying pest infestations, nutrient deficiencies, and irrigation

problems before they become visible to the human eye.

2. **AI-Based Analytics:** Machine learning algorithms process historical and real-time data to predict yields, forecast pest and disease risks, and recommend optimal planting and harvesting windows.
3. **IoT Environmental Monitoring:** Networks of sensors track soil moisture, ambient humidity, temperature, and light levels, providing continuous streams of data that inform management decisions.
4. **Integrated Digital Platforms:** Mobile applications consolidate data from multiple sources into unified dashboards, delivering precision recommendations for fertilizer application, irrigation scheduling, and pest management tailored to specific field conditions.

These technologies work best when integrated into cohesive systems that transform raw data into actionable insights, enabling faster, more accurate decisions that simultaneously increase profitability and sustainability.

Crop Diversification and Rotation

Monoculture farming—growing the same crop year after year on the same land—exposes farmers to significant risks. Market fluctuations, crop-specific pests and diseases, and climate variability can devastate livelihoods built around single commodities. Diversification spreads these risks while delivering multiple agronomic benefits.

Why Diversification Matters:

1. **Nutrient Management:** Different crops extract and contribute different combinations of soil nutrients. Rotating deep-rooted crops with shallow-rooted

varieties, or legumes with cereals, maintains balanced soil fertility naturally.

2. **Pest and Disease Suppression:** Many pests and pathogens are crop-specific. Rotating host crops with non-host species interrupts their life cycles, reducing reliance on chemical pesticides.
3. **Climate Resilience:** A diversified portfolio of crops increases the likelihood that at least some will perform well under variable weather conditions, providing income stability when particular crops fail.

Practical examples include rotating water-intensive rice with nitrogen-fixing pulses, or alternating oilseeds with cereal grains—practices that maintain soil health while ensuring consistent returns across seasons.

Composting and Waste Utilization

Every farming operation generates organic waste—crop residues, animal manure, spoiled produce, and processing byproducts. Historically, much of this material has been burned, discarded, or underutilized, representing both a lost resource and an environmental problem. Composting transforms these waste streams into valuable agricultural inputs.

Effective On-Farm Waste Management Methods:

1. **Vermicomposting:** Employing earthworms to accelerate decomposition produces nutrient-rich compost while managing organic wastes efficiently.
2. **Crop Residue Recycling:** Incorporating straw, stalks, and leaves into soil as organic mulch improves moisture retention, suppresses weeds, and gradually releases nutrients.

3. **Biogas Production:** Anaerobic digestion of animal manure and wet organic wastes generates combustible methane for energy while producing nutrient-rich slurry that serves as excellent fertilizer.

These approaches reduce air pollution from residue burning, improve soil fertility through organic matter addition, and support circular economic principles where waste from one process becomes input for another.

Predictive Climate Forecasting

Perhaps no single factor affects farm outcomes more profoundly than weather. Yet climate variability has become increasingly unpredictable, with traditional forecasting methods proving inadequate for the challenges farmers face. Artificial intelligence-powered forecasting tools now offer unprecedented accuracy in predicting local conditions.

Practical Benefits of Advanced Climate Forecasting:

1. **Anticipating Rainfall Patterns:** Farmers receive advance warning of planting windows, dry spells, and excessive rainfall events, allowing them to time operations for maximum success.
2. **Temperature Projections:** Knowing when heat waves or frost events are likely enables protective measures such as adjusting irrigation, applying protective covers, or harvesting early.
3. **Pest and Disease Early Warning:** Many outbreaks follow predictable weather patterns. Forecasting tools can alert farmers to elevated risks, enabling preventive action before infestations become established.
4. **Input Optimization:** With accurate forecasts, farmers avoid wasting seeds,

fertilizers, and pesticides on operations likely to fail due to unfavorable conditions.

Integrated platforms that deliver these forecasts directly to farmers through mobile interfaces ensure that climate data translates into timely, appropriate action.

Government and Agri-Tech Partnerships

Sustainable agriculture transformation cannot occur through individual farmer action alone. Supportive policies, institutional frameworks, and public-private partnerships are essential to scaling climate-smart practices across millions of holdings.

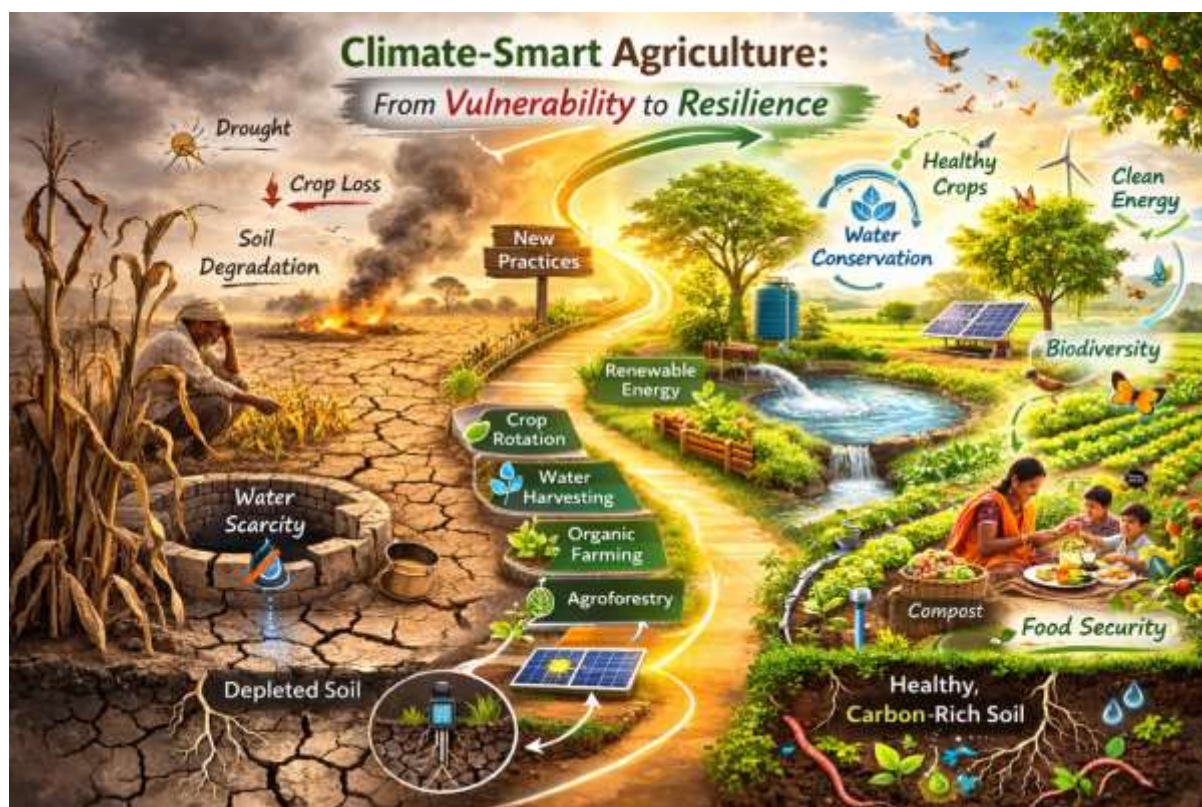
Key Policy Initiatives Driving Agricultural Transformation:

1. **PM-KUSUM Scheme:** This national program promotes solar-powered irrigation by providing subsidies for pump installation and supporting farmers in selling surplus power to grids.

2. **Soil Health Card Mission:** By providing farmers with personalized nutrient recommendations based on soil testing, this initiative encourages balanced fertilization and reduces over-application of synthetic inputs.

3. **Digital Agriculture Mission:** This framework supports agricultural technology startups, promotes digital infrastructure in rural areas, and encourages innovation in precision farming tools.

The most effective outcomes emerge when these government initiatives partner with technology platforms that extend their reach. Digital tools can deliver scheme benefits directly to farmers, simplify application processes, and provide the data feedback loops that help policymakers refine and improve programs over time. Through such collaborations, climate-smart agriculture transitions from promising concept to on-the-



ground reality for farming communities nationwide.

References

1. Food and Agriculture Organization (FAO). (2014). *Farmers' battle to cope with climate change could spark rural renewal*. UN News.
2. Lipper, L., et al. (2014). *Climate-smart agriculture for food security*. Nature Climate Change, 4(12), 1068-1072. [Cited in Lipper et al. 2014 reference within provided content]
3. Food and Agriculture Organization (FAO). (2013a). *Climate-Smart Agriculture: Sourcebook*. FAO, Rome. [Cited in FAO 2013a reference within provided content]
4. Labios, R. (2025). *ASEAN Climate-Smart Agriculture Guidelines*. FAO Regional Office for Asia and the Pacific. In ASEAN Climate Leadership Program III. SEARCA.
5. Kunt, Y. E. (2025). *Development of IoT and AI based Smart Irrigation System (B.Sc. Thesis)*. Mugla Sitki Kocman University, Türkiye. arXiv:2506.11835.
6. *Sustainable Soil Management: The Dynamic Impact of Combined Use of Crop Rotation and Fertilizers from Agri-Food and Sulfur Hydrocarbon Refining Processes Wastes*. (2025). Land, MDPI.
7. Nawutekateka, G., & Kansime, G. (2025). *Nakaseke farmer powering farm with solar, biogas, ingenuity*. New Vision, Uganda.
8. Gagliardi, M., Lamonaca, F., Maurmo, D., Ruga, T., Vocaturo, E., & Zumpano, E. (2025). *Reconstructing Agricultural Environments: Smart Farm Development Through Metrology, AI and Remote Sensing*. CNR Institutional Research Information System.
9. Delandmeter, M., Basso, B., et al. (2025). *Boosting ecosystem services and farm economics with crop diversity and livestock integration using a validated modeling approach*. PNAS Nexus.
10. *Innovative Composting Process for Enhancing Organic Waste Management in Urban Areas*. (2025). Jimma University, Ethiopia.
11. K, Jahana. (2025). *Integrating AI and Machine Learning into Agricultural Meteorology for Sustainable and Climate-Smart Farming*. Journal of Experimental Agriculture International, 47(9), 300-311.
12. *Digital Farmer IDs, Crop Survey Now Used for Benefit Transfer*. (2025, June 16). Financial Express Delhi.
13. Government of India. *PM-KUSUM Scheme*. Ministry of New and Renewable Energy.
14. Government of India. *Soil Health Card Mission*. Ministry of Agriculture and Farmers Welfare.
15. Government of India. *Digital Agriculture Mission*. Ministry of Agriculture and Farmers Welfare.
16. Campbell, B. (2025). *Climate change, food security, and nutrition linkages*. Clim-Eat. In ASEAN Climate Leadership Program III.
17. Borja, C. (2025). *Private sector role in scaling CSA*. Grow Asia. In ASEAN Climate Leadership Program III.

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FROM KITCHEN SCRAPS TO GARDEN GOLD: BOKASHI FOR ORGANIC WASTE MANAGEMENT

Introduction

Imagine transforming your kitchen leftovers into a powerful fertilizer that can help your plants thrive, all while helping combat climate change. This is not science fiction, it is Bokashi, a Japanese fermentation technology that is quietly revolutionizing how we think about organic waste. As the global community grapples with the staggering reality that one-third to half of all food produced worldwide is lost or wasted, innovative solutions like Bokashi offer a beacon of hope for a more sustainable future.

In India, an average household discards approximately 55 kilograms of food annually, accumulating to a nationwide total of 78.2 million tonnes, with an estimated value of ₹92,000 crore. Beyond the economic impact, this waste decomposes in landfills, generating methane, a greenhouse gas 86 times more potent than carbon dioxide over 20 years. India has been identified as one of the world's largest methane emitters, with overflowing landfills serving as major contributors alongside agricultural practices. Bokashi presents an elegant, low-cost solution that transforms a problem into an opportunity.

About bokashi

The word “Bokashi” comes from Japanese, meaning “fermented organic matter”. Unlike traditional composting, which relies on aerobic decomposition, Bokashi is an anaerobic fermentation process. Developed in Japan and refined over decades, this method uses beneficial microorganisms to pickle organic waste.



Figure 1. Bokashi bin (left) and fermented bokashi tea (right).

At its core, Bokashi involves inoculating organic waste with Effective Microorganisms (EM), a mixed culture of beneficial, naturally occurring microbes including lactic acid bacteria (LAB), purple non-sulphur bacteria, yeasts and actinomycetes. These microorganisms work together in an airtight environment to ferment the waste, producing two valuable end products that are solid pre-compost and a nutrient-rich liquid called “Bokashi tea”.

The science behind the magic

The effectiveness of Bokashi lies in the sophisticated microbial community it harnesses. Lactic acid bacteria become the most active and dominant group during fermentation, creating an acidic environment (low pH) that serves multiple purposes. First, it quickly suppresses pathogens, making even contaminated food waste safe to recycle. Second, it preserves nutrients that would otherwise be lost to the atmosphere in traditional composting. The fermentation process typically takes 10 to 20 days in a sealed container. During this time, the microorganisms break down complex organic compounds into simpler, plant-available nutrients. The C:N ratio remains relatively high compared to traditional compost, which stimulates microbial activity in the soil when the finished product is applied.

Properly managed Bokashi produces a pleasant pickled smell rather than the rotting odour associated with decomposing wastes. Bokashi can process a wider range of materials, including cooked foods, meats, and dairy, which are problematic in compost bin. The practical application of Bokashi is remarkably simple, making it accessible for households, schools, and even industrial-scale operations.

Preparation of bokashi

Step 1: Creating the EM starter

The process begins by preparing the inoculant. A typical formulation combines:

- 1 kg of corn bran (as a carrier material)
- 200 mL of dechlorinated water
- 50 mL of molasses (providing an initial energy source for microbes)

- 50-150 mL of Effective Microorganism solution

These ingredients are mixed thoroughly and allowed to ferment for 7 days in a sealed container. The result is a slightly moist, pleasantly sour-smelling material teeming with beneficial microbes.

Step 2: Fermenting food waste

The prepared Bokashi starter is layered with kitchen waste in an airtight container. For every 2 cm of food waste, a generous sprinkling of Bokashi starter is added. The waste is compressed firmly to eliminate air pockets, then the container is sealed. Over the next 14 days, the magic happens. Microbes ferment the waste and liquid begins to collect at the bottom. The 500g of fruit waste can produce 120-125 mL of Bokashi tea over 14 days, with most production occurring within the first 8 days. This liquid byproduct, when diluted 1:100 with water, creates an



Figure 2. Process of making bokashi.

excellent liquid fertilizer for plants.

Step 3: Completing the cycle

After 14 days of fermentation, the solid material is not quite finished. It must be buried in soil for an additional 30 days, where soil microbes complete the decomposition process. The result is a rich, dark, nutrient-dense organic fertilizer ready to nourish plants.

Effect on plant health

Biofertilization

The rapid decomposition of organic compounds during fermentation makes nutrients more readily available to plants. Nitrogen, phosphorus, potassium, calcium, and magnesium are all present in forms that plants can easily absorb.

Biocontrol

Lactic acid bacteria, dominant in mature Bokashi, act as biological control agents through three mechanisms that are, producing antimicrobial compounds that suppress pathogens, competitively colonizing plant tissues to exclude harmful organisms and modulating plant immune responses. Bokashi amendments can reduce the incidence of soft rot disease in lettuce and cabbage, decrease blossom-end rot in tomatoes and help manage seed rot and damping-off in cucumbers.

Bio-stimulation

Plants treated with Bokashi often show enhanced physiological parameters, including increased photosynthetic capacity. This translates to more vigorous growth and potentially higher yields.

Effect on soil health

Organic matter accumulation

Unlike composting, which releases much of its carbon as CO₂, Bokashi retains organic carbon that can be sequestered in soil. This improves soil structure, water holding capacity, and cation exchange capacity.

Enhanced microbial activity

The high C:N ratio of Bokashi stimulates native soil microorganisms, creating a thriving underground ecosystem. This increased biological activity improves nutrient cycling and soil aggregates.

Heavy metal immobilization

The EM-treated organic matter contains significantly lower concentrations of bioavailable heavy metals, forming immobile complexes that are not harmful to plants or the environment.

Pesticide decomposition

The microbial community in Bokashi appears to accelerate the breakdown of pesticide residues in soil, helping to remediate contaminated agricultural land.

Challenges and limitations

No technology is without limitations, and honest assessment requires acknowledging potential drawbacks. The pre-compost from Bokashi is acidic and cannot be used directly on plants. It must be incorporated into soil, where further decomposition occurs. This two-stage process may be more complex than some gardeners prefer. The initial investment in EM solutions and the ongoing need for bran or another carrier material represents a small ongoing cost, though this is typically offset by fertilizer savings.

Conclusion

Bokashi technology represents a beautiful convergence of ancient wisdom and modern science. The traditional Japanese practice of fermenting organic matter has been refined and validated through rigorous research, revealing sophisticated mechanisms that benefit plants, soil and the environment simultaneously. The challenges of our time, such as climate change, soil degradation, resource depletion, and waste management, demand solutions that address multiple problems simultaneously. Bokashi does exactly that, it diverts waste from landfills, reduces greenhouse gas emissions, produces valuable fertilizer, improves soil health and enhances crop growth. It is low-cost, accessible, and scientifically proven. Whether adopted by a family in a city apartment with a few potted plants on a balcony, or by a farmer managing hectares of cropland, Bokashi offers a tangible way to participate in creating a more sustainable food system. Each kitchen scrap transformed becomes not waste, but resource, not a problem, but part of the solution.

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COST-EFFECTIVE AND SUSTAINABLE FARMING THROUGH INTEGRATED USE OF BIOGAS SLURRY AND FERTILIZERS

Introduction

Achieving increased crop output while preserving soil health and environmental safety is a dual problem facing modern agriculture. For farmers, rising fertiliser costs, dwindling soil fertility, and growing worries about groundwater contamination are urgent problems. Continuous application of chemical fertilisers alone has increased output temporarily, but over time, it has undermined soil biological activity, reduced organic matter, and created nutrient imbalances. In the quest for environmentally sustainable farming methods, the use of organic residues particularly biogas slurry may offer a viable alternative to inorganic fertilisers (Tang *et al.*, 2022). 15% to 20% less synthetic fertiliser can be used when bio-slurry is used (Kumar *et al.*, 2015; Feng 2024).

Concurrently, biogas plants are proliferating in rural regions, creating clean electricity and biogas slurry as a byproduct. Slurry can be utilised as a valuable organic nutrient source rather than being disposed of as garbage. According to scientific study, the most ecological and economic option for farmers is to combine biogas slurry with chemical fertilisers.

The nutrient-rich residue left over after bovine manure, crop residues, or other organic wastes are anaerobically digested in a biogas plant is known as biogas slurry. Organic matter partially breaks down during digestion, nutrients are transformed into forms that are more accessible to plants, and weed seeds and diseases are greatly decreased. BGS is inexpensive, safe to use near humans and animals, and eco-friendly (Islam *et al.*, 2016). The main benefit of the slurry is that it is a very effective fertiliser that can boost crop development and enhance soil health. 93% water, 4.5% dry matter, and 2.5% inorganic materials make up biogas slurry. According to Aita *et al.* (2007) and Giacommini *et al.*, 2009 organic waste typically contains significant concentrations of macronutrients such N, P, K and Ca. About 1.4–1.8% nitrogen, which encourages vegetative growth, 1.0–1.2% phosphorus, which aids in root development, and 0.8–1.0% potassium, which enhances grain filling, are normally present. It also contains vital micronutrients that raise the general quality of crops and is high in organic carbon, which improves soil structure. However, the type of feed material utilised in the biogas plant may affect the precise nutrient makeup. By increasing microbial biomass, organic matter, and enzyme activity, BGS enhances soil health (Guerrero *et al.*, 2007; Nagdev *et al.*, 2024a).

Table 1: Comparison of Nutrient Management Practices

Practice	Fertilizer Cost	Yield Level	Soil Health	Long-Term Profit
100% Chemical Fertilizer	High	High (Short-term)	Declines	Moderate
100% Biogas Slurry	Low	Moderate	Improves	Moderate
Integrated Use	Moderate	High & Stable	Improves	High

Why integrated use is better ?

While using only slurry improves soil but might not provide adequate nutrients for high-yield crops, using solely chemical fertilisers may boost yield at first but eventually deteriorate soil health (Table 1). Combining organic manure with inorganic fertiliser could result in higher yields (Nagdev *et al.*, 2024b). On the other hand, the combined application of chemical fertilisers and biogas slurry preserves modest input costs, guarantees high and consistent yields, enhances soil health, and eventually increases long-term profit. The cost can be recouped in three to four years, according on the economic value of the biogas slurry (Devkota 2001).

Benefits

1. Lower fertiliser cost: 50% of the nitrogen fertiliser needed can be substituted by biogas slurry. This keeps agricultural output high while lowering input costs.
2. Better soil health: It boosts microbial and enzyme activity, improves soil structure, and adds more organic matter. This promotes soil fertility over the long run.
3. Increased yield stability: Consistent crop growth is ensured by a balanced nutrient supply from organic and inorganic sources. As a result, yields are steady and reliable.
4. Environmental safety: It lessens groundwater pollution and nitrate leaching. This method encourages environmentally friendly and sustainable farming.

Field implementation

To ascertain the field's nutrient condition, soil testing is the first step in the field implementation process. Before planting, biogas slurry is added to the soil to enhance it with organic matter. During the stages of crop growth, the leftover chemical fertiliser is applied in divided quantities. To optimise its advantages, biogas slurry can be employed in a variety of ways. It can be added to

the soil to increase fertility from the very beginning of growth and used as a basal application prior to sowing. To provide even fertiliser distribution, it can also be used with irrigation water. Slurry can also be added to compost to improve its overall fertiliser value and nutrient content. Crop growth is routinely tracked, and yield and profit are assessed following harvest to see how well the integrated approach is working.

Economic and livelihood benefits to farmers

Farmers' livelihood security is strengthened and substantial economic gains are obtained through integrated nutrient management with biogas slurry. With a 50% substitution rate, farmers may significantly lower input expenditures without sacrificing crop productivity. Over time, farm profitability rises when slurry and chemical fertilisers are used in balance to produce larger and more consistent yields. Long-term productivity is increased and excessive external inputs are not required in subsequent seasons when soil health is improved.

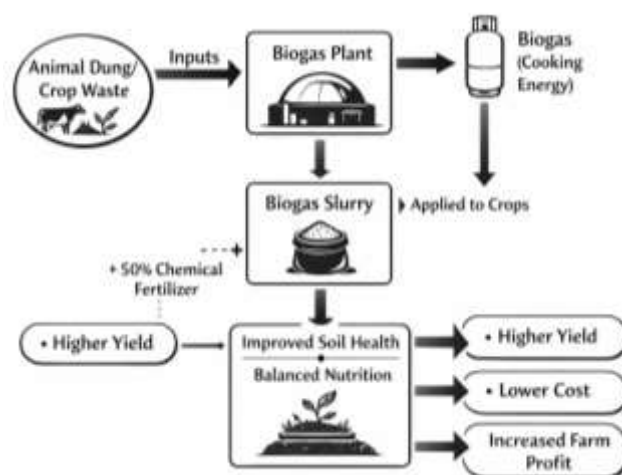


Figure:1 Model of 50:50 Integrated Nutrient Management on farm

50:50 nutrient replacement model: According to the 50:50 Nutrient Replacement Model, biogas slurry can replace 25–50% of the crop's nitrogen needs, with chemical fertilisers providing the

remaining nitrogen (Figure 1). This well-rounded strategy guarantees crops both immediate and long-term nutrient availability. In order to maintain the right nutrient balance and maximise crop productivity, phosphorus and potassium are applied in accordance with soil test recommendations. Because it gives crops both an immediate and long-term source of nutrients, the combined application of organic and mineral fertilisers is preferable. It increases nutrient utilisation efficiency, boosts microbial and enzyme activity, and improves soil health. This method preserves soil fertility and the environment while maintaining agricultural productivity.

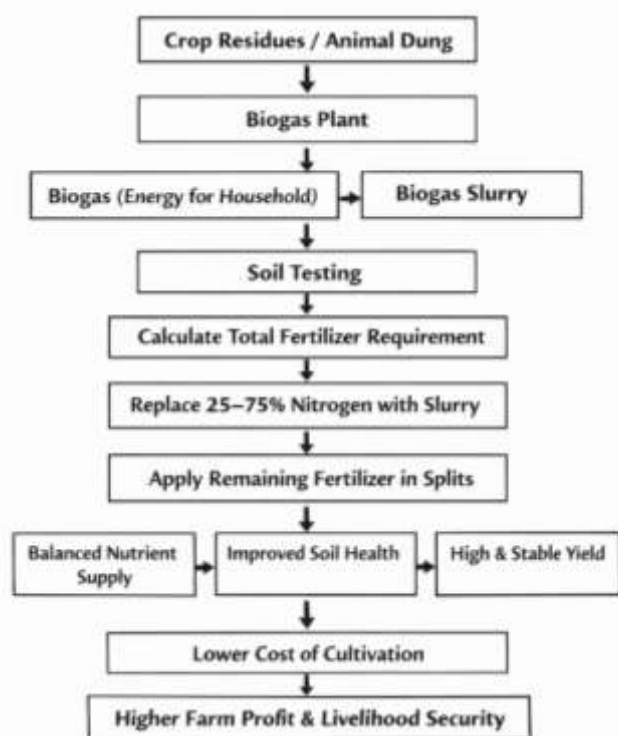


Figure 2: Integrated Use of Biogas Slurry and Fertilizers for soil health development, higher crop productivity, environmental safety, economic benefits and livelihood security

Recommendations for farmers

Instead of using chemical fertilisers exclusively, farmers should implement a balanced approach to nutrient management. 50% of the

nitrogen requirement should be replaced by biogas slurry, which is a valuable nutrition supply. This integrated approach encourages sustainable income generation, enhances the cost-benefit ratio, and reduces production risks. Farming households experience increased economic resilience and livelihood stability as a result of better soils and consistent harvests over time. To guarantee appropriate fertiliser delivery based on crop requirements, routine soil testing is crucial. In order to assess the profitability and efficacy of the integrated system, farmers need also keep an eye on yield and economic returns (Figure 2).

Conclusion

Biogas slurry-based Integrated Nutrient Management (INM) offers a sustainable, cost-effective, and well-balanced approach to contemporary agriculture. Biogas slurry can replace 50% of artificial nitrogen to improve soil organic matter, increase microbial and enzyme activity, and guarantee both short-term and long-term nutrient availability. This method lowers fertiliser expenditures while maintaining high and consistent crop yields. Additionally, it reduces environmental hazards including groundwater contamination and nutrient leaching, fostering ecological equilibrium. Integrated nutrient utilisation increases the long-term profitability of farms and improves the livelihood security of farming households by increasing soil fertility and reducing production costs.

References

1. Aita, C., Giacomini, S. J., & Hübner, A. P. (2007). Soil nitrate as affected by pig slurry application under no-till corn. *Soil Biology and Biochemistry*, 38, 1413–1421.
2. Devkota, G. P. (2001). *Biogas technology in Nepal – A sustainable source of energy for rural people*. Kathmandu.

3. Feng, G., Hao, F., He, W., Ran, Q., Nie, G., Huang, L., Wang, X., Yuan, S., Xu, W., & Zhang, X. (2024). Effect of biogas slurry on the soil properties and microbial composition in an annual ryegrass–silage maize rotation system over a five-year period. *Microorganisms*, 12(4), 716.
4. Giacomini, S. J., Aita, C., Miola, E. C. C., & Recous, C. (2009). Carbon mineralization of straw and pig manure with and without incorporation in soil. *Revista Brasileira de Ciência do Solo*, 32, 2661–2668.
5. Guerrero, C., Moral, R., Gomez, I., Zornoza, R., & Arcenegui, V. (2007). Microbial biomass and activity of an agricultural soil amended with the solid phase of pig slurries. *Bioresource Technology*, 98, 3259–3264.
6. Islam, R., Hossain, M. N., Fakruddin, M., Rabbi, K., & Baten, M. A. (2016). Effect of solid waste slurry from biogas plant on soil parameters and yield of spinach (*Spinacia oleracea* L.). *Journal of Agriculture and Ecology Research International*, 5(1), 1–11.
7. Kumar, S., Malav, L. C., Malav, M. K., & Khan, S. A. (2015). Biogas slurry: Source of nutrients for eco-friendly agriculture. *International Journal of Extensive Research*, 2, 42–46.
8. Nagdev, R., Khan, S. A., & Dhupper, R. (2024b). Assessment of physico-chemical properties of biogas slurry as an organic fertilizer for sustainable agriculture. *Journal of Experimental Biology and Agricultural Sciences*, 12(4), 634–644.
9. Nagdev, R., Khan, S. A., Dhupper, R., Shalwee, & Sharma, S. (2024a). Impact of integrated application of biogas slurry and organo-mineral amendments on soil microbial biomass and enzymes activity under rice–wheat cropping system (RWCS). *Journal of the Indian Society of Soil Science*, 72(4), 462–471.
10. Tang, J., Yin, J., Davy, A. J., Pan, F., Han, X., Huang, X., & Wu, D. (2022). Biogas slurry as an alternative to chemical fertilizer: Changes in soil properties and microbial communities of fluvo-aquic soil in the North China Plain. *Sustainability*, 14(22), 15099.

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ARTICLE ID: 60**PLANT PATHOGEN DETECTION: EXPLORING MODERN
TECHNIQUES AND FUTURE DIRECTIONS****ABSTRACT**

Phytopathogens are major constraints to crop production, causing severe yield losses and threatening global food security. Early and accurate diagnosis of plant diseases at initial stages is essential for effective field-level management and timely control measures. In recent years, plant disease diagnosis has become more precise due to the development of rapid, sensitive, and reliable detection technologies. This need has become more critical under changing climatic conditions, which may allow pathogens to emerge in new and previously unaffected regions. Traditional diagnostic methods mainly depend on visual assessment of disease symptoms, observation of pathogen signs, and culturing techniques. Although useful, these methods are time-consuming, require skilled personnel, and often lack sensitivity at early infection stages. Recent advancements in plant pathogen detection include DNA-based diagnostics, isothermal amplification methods, probe-based assays, post-amplification detection techniques, next-generation sequencing, immunoassays, and spectroscopic approaches. These modern tools provide high specificity, sensitivity, and faster results compared to conventional methods. Techniques such as lateral flow assays enable rapid on-site detection, while non-invasive methods like spectroscopy allow disease monitoring without damaging plant tissues. Isothermal amplification methods, such as loop-mediated amplification, offer simple, rapid, and field-friendly alternatives to conventional PCR, with higher sensitivity and minimal equipment requirements. The integration of portable and field-deployable diagnostic devices has opened new possibilities for real-time disease monitoring directly at the farm level. Such technologies can empower farmers, extension workers, and researchers to detect diseases early, reduce chemical inputs, and minimize economic losses. Continued innovation, along with improved data sharing and global collaboration, will further strengthen plant disease surveillance systems. The selection of an appropriate diagnostic method depends on factors such as the target pathogen, available infrastructure, cost, and local technological accessibility. Overall, ongoing advancements in plant pathogen detection are transforming modern agriculture and contributing to sustainable disease management and long-term food security.

Keywords: Phytopathogen, Early disease diagnosis, Molecular diagnostics, Plant disease management

Introduction

Crop productivity is expected to need to expand by sixty to hundred per cent from present levels to meet the demand for food and energy from an increasing human population by 2050. Various biotic and abiotic stress during crop growth significantly reduce crop yield across the globe. It is estimated that nearly seventy per cent yield loss occur globally due to pest attack among which disease itself contributes twenty to twenty per cent [Thakur et al., 2017](#).

2- 74% yield loss has been reported globally in case of rice due to various fungal diseases. Wheat diseases cause 90% and more loss globally and rust disease itself affect 94.4 per cent of production area and contribute to \$5.6 billion loss annually [Kayim et al., 2022](#).

Seed-borne fungal diseases cause fifty per cent yield loss in the case of maize and five to fifty per cent yield reduction in sugarcane due to *Colletotrichum falcatum*. Biotic stress leads to 31-42% yield loss in pulse crops globally due to various plant pathogens and 31-42% post-harvest losses.

More than eighty per cent yield loss has been reported in oil seeds due to various seed infections. The perishable nature of vegetable crops causes fifteen to twenty per cent loss under field conditions, 30- 40% loss during packaging, storage, transit and nearly forty to sixty per cent loss due to various post-harvest diseases every year [Tripathi et al., 2016](#).

Recent epidemic events highlight the urgency of search for efficient diagnostic tools for phytopathogen detection, diagnosis and management in an era marked by climate change and intensified global trade. In addition to people and goods, a large number of harmful organisms, such as viruses, phytoplasmas, bacteria, fungi, insects, nematodes, and weeds, travel undisturbed

through space and time. These organisms spread widely throughout the world and pose serious challenges to agriculture. Thus, to manage disease infections at various stages of development, decrease the hazard of disease spread, and avoid the introduction of new ones, detection of plant pathogen at the earliest is becoming increasingly vital in plant health monitoring.

According to FAO estimates, twenty per cent to more than forty per cent of global crop productivity is mislaid as a result of pests, which also negatively impact the major food crops (rice, wheat, corn, potatoes, soy, and cotton) at the national and regional levels in the various continents [Crippa et al., 2022](#).

Crop losses are correlated with production conditions, with higher losses in areas of high food insecurity (with newly and re-emerging pests and diseases) and lower losses in areas of high food surplus. According to estimates, historical diseases like the Irish famine in Ireland, the great Bengal famine in India, and the coffee rust endemic in Sri Lanka had a significant negative social and economic impact on human life. Despite all precautions and sophisticated management techniques, plant diseases result in approximately sixteen to twenty per cent of global crop losses.

According to Savary *et al.*, 2019, disease-related crop yield losses ranged from twenty to forty per cent. Additionally, it is estimated that post-harvest losses from poor quality will range between thirty and forty per cent. To increase productivity and ensure the sustainability of agricultural production, it is crucial to reduce the enormous losses that have been observed during crop growth, harvest, and postharvest processing. Pests are being controlled internationally through efforts like phytosanitary measures and meticulous phytosanitary surveillance.

However, there is still a lot that can be done on the diagnostic front to halt the spread of

pathogenic organisms globally in its tracks. One solution might be the creation of portable devices that can simultaneously detect multiple phytopathogen while meeting requirements for quick response, heterogeneity, complexity of analysis, and user-friendliness. Decision times would be drastically shortened by the advance of various on-field molecular techniques, reducing the spread of phytopathogen to additional plants or their introduction into new regions.

2. Diagnostic methods for phytopathogens

Traditional methods:

Pathogens	Traditional detection techniques	References
Fungi	Microscopy, Histology, Serology, Incubation Method, Seedling Symptoms Test	Ray <i>et al.</i> , 2017
Bacteria	Microscopy, Culture Methods, Biochemical Tests, Gram staining	Buja <i>et al.</i> , 2021
Viruses	Cell Culture, Serological Tests, Microscopy, Complement Fixation	Devi <i>et al.</i> , 2024
Phytoplasma	Symptom Profiling, DAPI Staining, Serological Tests, Dodder Transmission Studies	Nair and Manimekalai, 2021
Nematodes	Light Microscopy, Staining Techniques, Extraction from Soil and Plant Samples, Morphometric Analysis	Shao <i>et al.</i> , 2023

MODERN METHODS:

1. Immunological or serological methods- Lateral flow immunoassays (LFIA)
2. Nucleic acid amplification method- LAMP, RCA, HDA
3. Nucleic acid hybridization method- CRISPR-Cas, Micro-arrays
4. Nucleic acid sequencing methods- Next generation sequencing, Metagenomics sequencing
5. Biosensors
6. Non-invasive detection methods

1) Immunological or serological methods

Lateral flow immunoassays (LFIA)

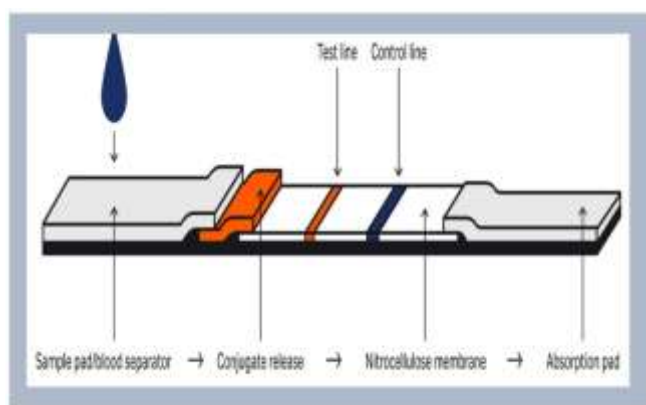
- LFIA or simply a "strip test," is a widely used diagnostic technique that is based on the principle of immunology.
- A rapid and simple method for detecting the presence or absence of specific analytes, such as antigens or antibodies in a sample.
- A device that use capillary action to detect the presence or absence of a target substance.

Components of lateral flow immunoassay

- **Sample pad:** Distribute the sample and direct it to the conjugate pad.
- **Conjugate pad:** Hold the detector particles and keep them functionally stable until the test is performed.



- **Nitrocellulose membrane:** Display the test result and determine parameters like speed, sensitivity, and specificity of the test.
- **Test line:** Indicates the presence or absence of the target molecule in the sample.
- **Control line:** Indicates that the test has returned a valid test result.
- **Absorption pad:** Wick the fluid through the membrane and to collect the processed liquid.



Workflow of LFIA

- The sample is applied on the adsorbent sample pad, which fuse with buffer salts and surfactants that make the sample suitable for interaction with the detection system.
- The sample pad ensures that the analyte present in the sample will be capable of binding to the capture reagents of conjugates and on the membrane.
- The sample migrates through the conjugate release pad, which contains antibodies that are specific to the target analyte and are conjugated to coloured or fluorescent particles—most commonly colloidal gold and latex microsphere.
- The sample, together with the conjugated antibody bound to the target analyte, migrates along the strip into the detection zone. This is a porous membrane (usually composed of nitrocellulose) with specific biological components immobilized in lines.

Their role is to react with the analyte bound to the conjugated antibody.

- Recognition of the sample analyte results in an appropriate response on the test line, while a response on the control line indicates the proper liquid flow through the strip.
- Liquid flows across the device because of the capillary force of the strip material and, to maintain this movement, an absorbent pad is attached at the end of the strip. The role of the absorbent pad is to wick the excess reagents and prevent backflow of the liquid.

Applications of LFIA

- Detection of *Xanthomonas campestris* pv. *musacearum* by Hodgetts *et al.*, 2015.
- Development of a lateral flow immunoassay for rapid diagnosis of potato blackleg caused by *Dickeya* spp. by Safenkova *et al.*, 2017.
- Detection of *Xanthomonas arboricola* pv. *pruni* by Lopez-Soriano *et al.*, 2017.
- On-site detection of *Banana bract mosaic virus* in banana plants by Selvarajan *et al.*, 2020.

Commercially available LFIA devices

Device/Product	Company	Target application
AgriStrip	BIOREBA, Switzerland	Pathogens of ornamental crops
Rapid plant disease tests	Pocket Diagnostic, UK	Erwinia
Alert Test Kits	Neogen Corporation	Pythium, Phytophthora, Rhizoctonia
ImmunoStrip	Agdia, Elkhart	Plant virus

2. Nucleic acid amplification method

a. Loop Mediated Isothermal Amplification (LAMP)

LAMP is a nucleic acid amplification method initially designed and developed by Notomi

and coworkers to amplify a specific DNA region of *hepatitis B virus* (HBV) under isothermal conditions.

- There is no need for heat denaturation of double stranded DNA, DNA polymerase possess the strand displacement activity.
- Amplification takes place at single temperature between 60-65°C.
- It is based on auto cycling and DNA strand displacement activity mediated by Bst polymerase from
- *Geobacillus stearothermophilus*.

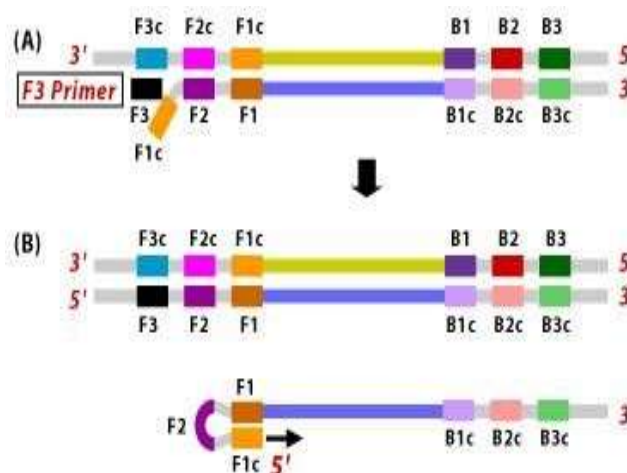
Design of primers and workflow of LAMP

Two sets of internal primers such as forward inner primer, backward inner primer, and backward loop primer, and another set of two outer primers (F3 and B3) are used to identify six unique sequences on the nucleic acid. Forward inner primer and backward inner primer cover double distinct sequences matching to sense and anti-sense strands of the targeted DNA of an organism.



The combination of primers and strand-displacing polymerase activity leads to the formation of a piece of single stranded DNA, which at both ends forms a dumb bell-like structure, due to the

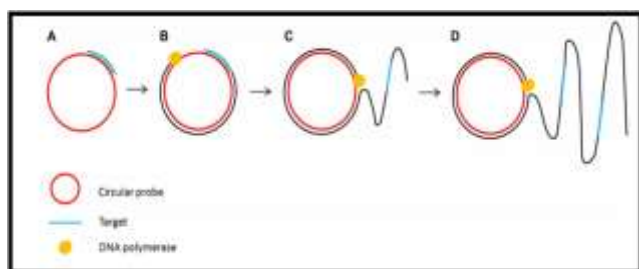
intramolecular complementarity of the inner primers. These dumb bell structures are target for binding of the inner primers and outer primers. Due to this self-priming ability in combination with the stranddisplacing polymerase, new amplified DNA is generated continuously.



b) Rolling Circle Amplification (RCA)

- It is also an isothermal amplification.
- It specifically amplifies circular ssDNA.
- The techniques mainly require a circular template, homologous buffer, deoxynucleotide triphosphates, DNA polymerase, and DNA primers.
- Amplification is carried out by using phi29 DNA polymerase with specific strand displacement activity.
- The strand displacement activity allows the newly synthesized DNA to displace the previously generated DNA releasing ssDNA.
- The enzymatic process of primer extension combined with strand displacement generates a long single stranded DNA.

Workflow of RCA

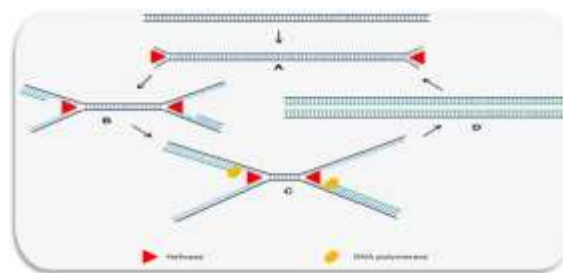


- (A) A primer complementary to a region of a circular probe anneals to the circular template.
- (B) DNA polymerase along with strand displacement activity initiates the DNA synthesis.
- (C) Strand displacement allows the continuation of DNA synthesis along the circular template.
- (D) DNA synthesis continues to generate a long ssDNA product.

c) Helicase Dependent Amplification (HDA)

- It is an alternative isothermal technique developed by New England Biolabs in 2004.
- Similar to the standard PCR but it does not require heat denaturation to separate the double stranded DNA
- Helicase helps in unwinding DNA double-strands and the technique does not rely on thermocycling
- HDA uses DNA helicase to generate single stranded DNA for primer annealing followed by primer extension at isothermal conditions
- Single stranded binding protein (SSB) and MutL endonuclease are added to the reaction to prevent rehybridization of complementary ssDNA strands to reform the dsDNA.
- Detectable amounts of PCR amplicons for downstream analysis are generally generated within 60 min by the HDA method

Workflow of HDA



- A. Helicase opens the dsDNA.
- B. The primers anneal to the target sequences.
- C. Primer extension by DNA polymerase
- D. The newly formed dsDNAs are opened by helicase and the process starts again.

Applications of nucleic acid amplifications methods

Methods	Applications	References
LAMP	Detection of <i>potato leaf roll virus</i> and <i>Fusarium oxysporum</i> methods LAMP assay for the detection of <i>Indian Citrus Ringspot Virus</i>	Ahmadi <i>et al.</i> , (2013) Kokane <i>et al.</i> , (2021)
RCA	RCA technique has been used for pathogenic <i>Fusarium</i> identification Used for the detection of various pathogens such as <i>Neofabraea</i> spp. causing apple bull's-eye rot	Davari <i>et al.</i> , (2012) Xu <i>et al.</i> , (2019)
HDA	Identification of the <i>tomato spotted wilt virus</i>	Wu <i>et al.</i> , (2016)

3. Nucleic acid hybridization method

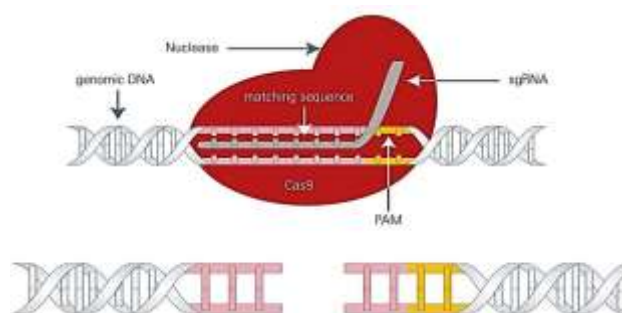
- The ability of DNA strands to hybridize with the respective complementary DNA strands which is a useful means of detection.

- The use of labeled sequence-specific probes that hybridize to a specific genetic sequence of a particular pathogen, which enables detection of that pathogen.

a) CRISPR-Cas-based detection systems

- CRISPR/Cas: Clustered Regularly Interspaced Short Palindromic Repeats and
- CRISPR-associated nucleases
- It is evolved in archaea and bacteria as an adaptive immune system against invading foreign nucleic acids originating from viral or plasmid pathogens.
- The technology usually rely on DNA extraction and subsequent binding of the Cas protein to a pathogen-specific DNA motif
- The system primarily comprises two components: guide RNA (gRNA) and Cas nuclease
- The Cas protein, which possesses nuclease activity, identifies the target DNA through guide RNA– DNA pairing

Workflow of CRISPER – Cas technology



- Isolation of nucleic acids from the infected plant samples/vectors
- Isothermal amplification of target nucleic acid through a recombinase polymerase amplification (RPA) reaction
- Cas nuclease detection
- Recognition of amplified target
- Cas 12a and Cas 13a are activated with (ss)Dnase and ssRNase activity respectively to

degrade fluorescent reporter for qualitative or quantitative detection of pathogen

b) Micro-array technology

- Orderly arrangement of thousands of identified sequenced genes printed on an impermeable solid support usually, glass silicon chip or nylon membrane.
- Thousands of spots each representing a single gene and collectively the entire genome
- It measures the gene expression
- Principle and working of micro-array technology
- The principle of DNA microarrays lies on the hybridization between the nucleic acid strands.
- There are four major steps involved in microarray experiment

Work flow of Micro-array technology

1. Extraction: DNA or RNA is extracted from the cells or tissues of interest.
2. Labeling: The extracted nucleic acids are labeled with fluorescent dyes.
3. Hybridization: The labeled nucleic acids are then applied to the microarray. They hybridize or bind, to the complementary DNA probes on the array.
4. Detection: The microarray is scanned to detect the fluorescent signals.

Applications in plant pathogen detection

Methods Applications References

CRISPER/CAS

- Application of CRISPR/Cas for diagnosis and management of viral diseases of banana
- Base editors for citrus gene editing
- Exploring CRISPR/Cas9 Gene Editing Applications for Enhancing Disease

Resistance in Sugar Beet Tripathi et al., 2021

Micro - array

- Detection of various sugar beet root rot pathogens, *Aphanomyces cochilioides*, *Botrytis cinerea* and *Penicillium expansum* Liebe et al., 2016

4. Nucleic acid sequencing methods

- DNA/RNA sequencing has emerged as a useful tool for the identification of microorganisms.
- By sequencing specific genetic markers and comparing the resulting sequence(s) to a reference database, the identity of a microorganism can be determined.

Nucleic acid sequencing methods includes:

- a) Next generation sequencing
- b) Metagenomics sequencing

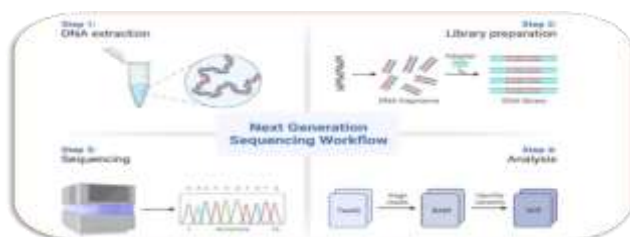
a) Next generation sequencing

- Technologies developed after Sanger (first generation) sequencing are known as next generation sequencing.
- It determine the order of nucleotides and amino acids in DNA and polypeptide that doesn't require prior knowledge of the target pathogens but still provides species-specific results.

Principle

- NGS platforms can simultaneously process millions to billions of DNA fragments. This parallel processing dramatically reduces the time required to sequence entire genomes or transcriptomes.

Workflow of NGS



Metagenomics sequencing

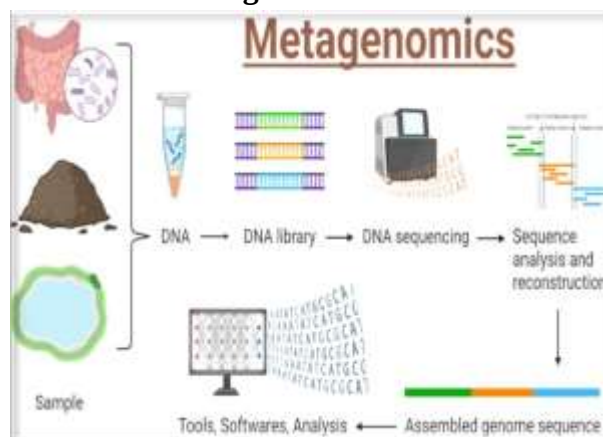
- It is the study of metagenomes, genetic material recovered directly from environmental samples



Principle

It is the study of the genome of microbial communities in bulk environmental samples directly without culturing individual species. This allows detailed analysis of microbial communities and overcomes the limitations of traditional laboratory culture methods

Workflow of Metagenomics



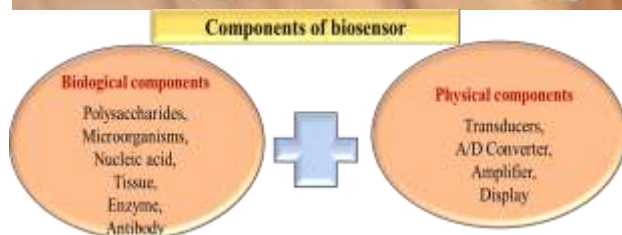
Applications in Plant Pathogen Detections

Methods	Applications	References
Next generation sequencing	NGS platforms has been used for identification of cotton leafroll dwarf virus, citrus yellow vein clearing virus, cassava brown streak virus, grapevine leaf roll associated virus-3, maize chlorotic mottle virus	Villamor <i>et al.</i> , 2016
		Prajapati <i>et al.</i> , 2022

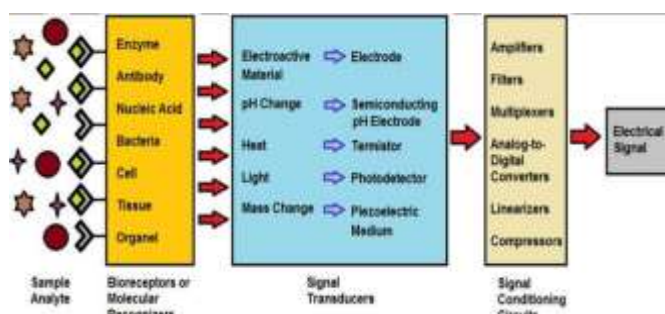
	Illumina Hi Seq 2000, a NGS platform used to fully sequence the garlic virus A genome, comprising of 8793 nucleotides	
Metagenomics sequencing	Metagenomic sequencing for identification of <i>Xylella fastidiosa</i> from leaf samples	Roman-Reyna <i>et al.</i> , 2021

4. Biosensors

- It is an analytical device used for the detection of a chemical substance, that combines a biological component with a physiochemical detector.
- Leland C. Clark is known to the father of biosensors.



Workflow of biosensors



Types of biosensors

Types	Principle	Applications
1. Electrochemical Biosensors	Measures electrical signals generated by the interaction between the target analyte and the biological recognition element (e.g., enzyme, antibody).	Used for detecting pathogens like bacteria, viruses, and fungi in plants.
2. Optical Biosensors	Use light to detect changes in the optical properties of the biological recognition element upon interaction with the target analyte	Gold nanoparticle-based optical immunosensors have been developed for detecting Karnal bunt in wheat.
3. Piezoelectric Biosensors	Detect changes in mass or mechanical properties on a piezoelectric crystal surface when the target analyte binds to the biological recognition element	Effective for detecting various plant pathogens, including fungi and bacteria, by measuring frequency changes in the crystal.
4. Thermal Biosensors:	Measure the heat changes associated with biochemical reactions between the target analyte and the biological recognition element.	Used for detecting metabolic changes in plants infected by pathogens, providing insights into the disease state
5. Magnetic Biosensors	Use magnetic particles as labels for the detection of target analytes. The interaction between the target and the magnetic particles is measured using magnetic fields.	Detecting plant pathogens in complex samples, such as soil or plant tissues

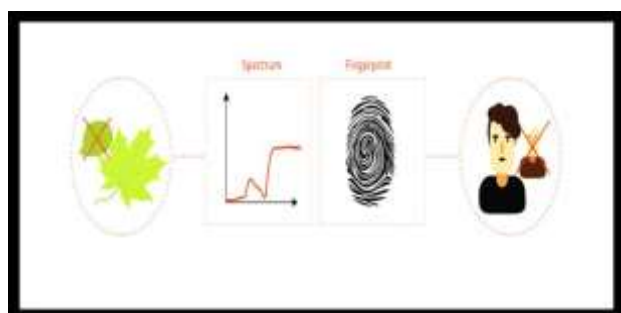
5. Non-invasive detection methods

Non-invasive detection methods means it does not require any sample manipulations.

- This diagnostic technique is based on the identification of biotic or abiotic modifications in the structure and

chemical composition of plant molecules.
Each biotic or a biotic stress causes unique changes in the plant

- These stressed or diseased plants produce a different spectral signature compared to that of healthy plants. These signatures can be identified by the spectrum of the material.



Advantages and Limitations

METHODS	ADVANTAGES	DISADVANTAGES
LFIA	Easy to use, portable, low cost Provide results in 10 minutes	Limited to liquid sample only Cross reactivity
LAMP	More robust in the presence of PCR inhibitors Minimal sample preparation is required	Complex primer design process Non optimal primers may lead to false positive results
RCA	Less prone to non-specific amplification than PCR Easy exponential amplification	Primer is complex to design RNA amplification is complex Work only with the circular nucleic acid template.
HDA	Primer design is simple Robust to biological	Enzymes are expensive Complicate buffer

	substances	optimization
CRISPR-Cas	Do not require high- tech Equipment Provide results in a timely fashion	Require tedious sample preparation steps. Costly and analysis time is more.
Microarray	Provides data for thousands of genes in real time Single experiment generates many results easily	Expensive to create The DNA chips do not have very long shelf life Require long time for result analysis
Nucleic acid sequencing	High sensitivity and specificity Early and broad detection	Costly and time- consuming Robust data is not easy to manage
Biosensors	Low cost and easy to use Highly specific for analyte Fast, reliable and repeatable	Temperature and pH parameter influence the performance Tedious measurement conditions
Non- invasive methods	Non- destructive diagnostic sampling Capabilities of detecting multiple diseases in real time	Algorithm need to develop for each plant disease Cost of instrument and complexity Need of fast computers for handling large amount of data

Future directions in plant pathogen detection

- Continued integration of high-throughput sequencing technologies into routine diagnostic practices will enable more rapid and comprehensive identification of plant pathogens, including emerging and previously unknown threats.

- The development of portable and field-deployable diagnostic devices will empower farmers and researchers to conduct real-time monitoring and early disease detection directly in the field.
- Efforts to improve data sharing and collaboration among researchers and institutions worldwide will foster a global network for plant pathogen surveillance and knowledge sharing.

Conclusion

In conclusion, it is clear that the ideal detection method is not yet available, and the choice of which detection method should be used is widely dependent on the target pathogen, the available budget, the sample matrix, as well as the technological availability of that area. However, continuous efforts are made to develop new technologies that will be adopted in modern plant disease monitoring.

References

- Ahmadi S, Almasi M A, Fatehi F, Struik P C and Moradi A, 2013, Visual detection of Potato Leafroll Virus by one-step reverse transcription loop-mediated isothermal amplification of DNA with hydroxynaphthol blue dye. *Journal of phytopathology*, 161(2): 120-124.
- Andreason S A, Arif M, Brown J K, Ochoa-Corona F and Wayadande A, 2020, Exploring the Use of High-Resolution Melting Analysis and Helicase-Dependent Amplification for Discrimination of *Bemisia tabaci* (Hemiptera: Aleyrodidae) Cryptic Species and *Trialeurodes vaporariorum*. *Journal of Economic Entomology*, 113(5): 2511-2520.
- Buja I, Sabella E, Monteduro A G, Chiriaco M S, De Bellis L, Luvisi A and Maruccio G, 2021, Advances in plant disease detection and monitoring: From traditional assays to in-field diagnostics. *Sensors*, 21(6): 21-29.
- Crippa M, Solazzo E, Guizzardi D, Van Dingenen R and Leip A, 2022, Air pollutant emissions from global food systems are responsible for environmental impacts, crop losses and mortality. *Nature Food*, 3(11): 942-956.
- Davari M, van Diepeningen A D, Babai-Ahari A, Arzanlou M, Najafzadeh M J, van der Lee T A and de Hoog G S, 2012, Rapid identification of *Fusarium graminearum* species complex using Rolling Circle Amplification (RCA). *Journal of microbiological methods*, 89(1): 63-70.
- Devi B M, Guruprasath S, Balu P, Chattopadhyay A, Thilagar S S, Dhanabalan K V, Choudhary M, Moparathi S and Jailani A A K, 2024, Dissecting Diagnostic and Management Strategies for Plant Viral Diseases: What Next?. *Agriculture*, 14(2): 284.
- Hodgetts, J., Hall, J., Karamura, G., Grant, M., Studholme, D.J., Boonham, N., Karamura, E. and Smith, J.J., 2015. Rapid, specific, simple, in-field detection of *Xanthomonas campestris* pathovar *musacearum* by loop-mediated isothermal amplification. *Journal of Applied Microbiology*, 119(6), pp.1651-1658.
- Hodgetts, J., Hall, J., Karamura, G., Grant, M., Studholme, D.J., Boonham, N., Karamura, E. and Smith, J.J., 2015. Rapid, specific, simple, in-field detection of *Xanthomonas campestris* pathovar *musacearum* by loop-mediated isothermal amplification. *Journal of Applied Microbiology*, 119(6), pp.1651-1658.
- Huang J, Zhou Y, Li J, Lu A and Liang C, 2022, CRISPR/Cas systems: Delivery and application in gene therapy. *Frontiers in Bioengineering and Biotechnology*, 10: 942325.
- IntechOpen.
- Kayim M, Nawaz H and Alsalmo A, 2022, Fungal diseases of wheat, In *Wheat-Recent Advances*.
- Kokane A D, Kokane S B, Warghane A J, Gubyad M G, Sharma A K, Reddy M K and Ghosh D K, 2021, A rapid and sensitive reverse transcription-loop-mediated isothermal amplification (RT-LAMP) assay for the detection of Indian Citrus Ringspot Virus. *Plant disease*, 105(05): 1346-1355.
- Liebe S, Christ D S, Ehricht R and Varrelmann M, 2016, Development of a DNA microarray-based assay for the detection of sugar beet root rot pathogens. *Phytopathology*, 106(1): 76-86.
- Lopez-Soriano P, Noguera P, Gorris M T, Puchades R, Maquieira A, Marco-Noales E and Lopez M M, 2017, Lateral flow immunoassay for on-site detection of *Xanthomonas arboricola* pv. *pruni* in symptomatic field samples. *Public Library of Science One*, 12(4): 176-201 (NAAS:9.70).

- Misra V, Mall A K, Pandey H, Srivastava S and Sharma A, 2023, Advancements and prospects of CRISPR/Cas9 technologies for abiotic and biotic stresses in sugar beet. *Frontiers in Genetics*, 14: 1235855.
- Nair S and Manimekalai R, 2021, Phytoplasma diseases of plants: molecular diagnostics and way forward. *World Journal of Microbiology and Biotechnology*, 37(6): 102.
- Prajapati M R, Manav A, Singh J, Singh M K, Ranjan K, Kumar A, Kumar P, Kumar R and Baranwal V K, 2022, Identification of Garlic virus A infecting *Allium sativum* L. through next generation sequencing technology. *The Journal of Horticultural Science and Biotechnology*, 97(1): 96-105.
- Ray M, Ray A, Dash S, Mishra A, Achary K G, Nayak S and Singh, S, 2017, Fungal disease detection in plants: Traditional assays, novel diagnostic techniques and biosensors. *Biosensors and Bioelectronics*, 87: 708-723.
- Román-Reyna V, Dupas E, Cesbron S, Marchi G, Campigli S, Hansen M A, Bush E, Prarat M, Shiplett K, Ivey M L L and Pierzynski J, 2021, Metagenomic sequencing for identification of *Xylella fastidiosa* from leaf samples. *Msystems*, 6(5): 10-1128.
- Safenkova, I.V., Zaitsev, I.A., Varitsev, Y.A., Byzova, N.A., Drenova, N.V., Zherdev, A.V. and Dzantiev, B.B., 2017. Development of a lateral flow immunoassay for rapid diagnosis of potato blackleg caused by *Dickeya* species. *Analytical and bioanalytical chemistry*, 409(7), pp.1915-1927.
- Savary S, Willocquet L, Pethybridge S J, Esker P, McRoberts N and Nelson A, 2019, The global burden of pathogens and pests on major food crops. *Nature ecology & evolution*, 3(3): 430-439.
- Selvarajan, R., Kanichelvam, P.S., Balasubramanian, V. and Subramanian, S.S., 2020. A rapid and sensitive lateral flow immunoassay (LFIA) test for the on-site detection of banana bract mosaic virus in banana plants. *Journal of Virological Methods*, 284, p.113929.
- Shao H, Zhang P, Peng D, Huang W, Kong L A, Li C, Liu E and Peng, 2023, Current advances in the identification of plant nematode diseases: From lab assays to in-field diagnostics. *Frontiers in Plant Science*, 14: 1106784.
- Thakur P, Breger L S, Lundblad M, Wan O W, Mattsson B, Luk K C, Lee V M, Trojanowski J Q and Björklund A, 2017, Modeling Parkinson's disease pathology by combination of fibril seeds and α -synuclein overexpression in the rat brain. *Proceedings of the National Academy of Sciences*, 114(39): 8284-8293.
- Tripathi L, Ntui V O, Tripathi J N and Kumar P L, 2021, Application of CRISPR/Cas for diagnosis and management of viral diseases of banana. *Frontiers in Microbiology*, 11: 609-784.
- Tripathi S, Patil B L and Verma R, 2016, Viral diseases of banana and their management. *Plant viruses: Evolution and management*, 289-308.
- Villamor D E V, Mekuria T A, Pillai S S and Eastwell K C, 2016, High-throughput sequencing identifies novel viruses in nectarine: Insights to the etiology of stem-pitting disease. *Phytopathology*, 106(5): 519-527.
- Wu X, Chen C, Xiao X and Deng M J, 2016, Development of reverse transcription thermostable helicase- dependent DNA amplification for the detection of tomato spotted wilt virus. *Journal of AOAC International*, 99(6): 1596-1599.
- Xu Y, Lv Z, Yao C and Yang D, 2022, Construction of rolling circle amplification-based DNA nanostructures for biomedical applications. *Biomaterials Science*, 10(12): 3054-3061.
- Xu, H., Zhang, S., Ouyang, C., Wang, Z., Wu, D., Liu, Y., Jiang, Y. and Wu, Z.S., 2019. DNA nanostructures from palindromic rolling circle amplification for the fluorescent detection of cancer-related microRNAs. *Talanta*, 192, pp.175-181.