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Magazine

AGRIVOLTAICS: THE NEXT FRONTIER IN SUSTAINABLE AGRICULTURE

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FROM THE FOUNDER & CEO'S DESK

Dear Readers,

Welcome to the latest issue of Just Agriculture—a publication dedicated to empowering, informing and inspiring the agricultural community. The landscape of agriculture continues to evolve, we are witnessing significant advancements in technology, sustainability practices, and global trends that are reshaping the way we produce, consume, and think about food, from precision farming to the integration of AI in crop management, innovation is at the heart of the agricultural revolution. However, alongside these opportunities, challenges like climate change, supply chain disruptions and labor shortages remain pressing concerns that require our collective action and resilience.

At Just Agriculture, we are committed to being a bridge between these emerging technologies and the farmers, agribusinesses and stakeholders who will shape the future of agriculture. In this issue, we delve into topics that matter most: sustainable farming practices, the rise of agri-tech and the crucial role of policy in ensuring a thriving agricultural ecosystem. We also highlight success stories from across the globe, demonstrating how



adaptability and innovation are driving positive change.

I believe that the future of agriculture is bright, but it requires all of us—farmers, scientists, policymakers and consumers—to work together toward a common goal: ensuring food security, environmental sustainability and the well-being of future generations.

Thank you for your continued support and for being a part of this incredible journey. I hope this issue inspires you as much as it has inspired us to bring it to you.

Dr. D.P.S. BADWAL
Founder & CEO,
Just Agriculture-the Magazine

Publisher & Editor:

Dr. D.P.S. Badwal on behalf of Just Agriculture Communications Group & printed at Just Agriculture Publications, Jalandhar.

FROM THE CHIEF EDITOR'S DESK

Dear Readers,

The journey of agriculture is a story of resilience, innovation, and enduring hope. As we present this issue of Just Agriculture, we reaffirm our commitment to strengthening farmers, researchers, agricultural entrepreneurs, and institutions through meaningful knowledge exchange.

This edition explores emerging opportunities through Jute 2.0: Emerging Innovations in Value Addition and Product Diversification and examines the transformative role of technology in Digital Agriculture: Revolutionizing Indian Farming Through Technology. It also highlights the integration of renewable energy and farming in Agrivoltaics: The Next Frontier in Sustainable Agriculture.

We further showcase farmer-focused development through Haryana's Horticulture Department: Pioneering Farmer-Centric Growth, Innovation and Agricultural Diversification. Kisan Drones: A New Era of Precision Crop Protection explores the role of drones in efficient crop management, while El Niño Effect on the Indian Farming System and How to Tackle Upcoming Farming Challenges presents strategies for strengthening climate



resilience. Finally, Wheat Biofortification: To Combat Malnutrition highlights the importance of nutrient-rich crops in improving food and nutritional security.

At Just Agriculture, we remain committed to connecting research, innovation, and practical action. I extend my sincere gratitude to our authors, reviewers, editorial team, and the farming community whose dedication continues to inspire us.

Let us continue sowing innovation and cultivating a sustainable agricultural future.

Dr. Sushila Hooda
Chief Editor,
Just Agriculture-The Magazine

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table of



01

JUTE 2.0: EMERGING INNOVATIONS IN VALUE ADDITION AND PRODUCT DIVERSIFICATION

Sahabat Alam

02

DIGITAL AGRICULTURE: REVOLUTIONIZING INDIAN FARMING THROUGH TECHNOLOGY

Sunil Kumar, Ved Prakash, M. Arif, Jagan Singh Gora, Parmod Kumar, Nalawade Rohit Dilip, Ranjit HP, Deepshikha and Akshay Singh Aswal



03

AGRIVOLTAICS: THE NEXT FRONTIER IN SUSTAINABLE AGRICULTURE

PREETY VERMA AND ANANYA KUMAR

contents

04

**Haryana's Horticulture
Department: Pioneering Farmer-
Centric Growth, Innovation and
Agricultural Diversification**
Sushank



05

**KISAN DRONES: A NEW ERA OF
PRECISION CROP PROTECTION**

Gagan Kumar M, Pundalik D Pammar,
Santosh Halagatti

06

**EL NINO EFFECT ON THE INDIAN
FARMING SYSTEM AND HOW TO
TACKLE UPCOMING FARMING
CHALLENGES**

Dr. Harshit Paliwal, Dr. Manisha S. Shinde,
Dr. T.A Desai, Dr. Darmeshkumar M. Dabhi,
Dr. Dimpal A. Patel



07

**WHEAT BIOFORTIFICATION:
TO COMBAT FROM MALNUTRITION**

Raj karan Tripathi, Vaishali Singh,
Avneesh Tripathi, Soni Yadav, Nitin Gaur

JUTE 2.0: EMERGING INNOVATIONS IN VALUE ADDITION AND PRODUCT DIVERSIFICATION

Sahabat Alam

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INTRODUCTION

Jute is a natural fibre. It is commonly called the “golden fiber” for its color and luster. It is the cheapest and at the same time one of the strongest natural fibers. Thus, jute fiber can be termed as the “ fiber of the future”. It is a long barky fiber that can be made into coarse, strong yarns. Jute is one of the least expensive natural fibres. It is ranked second only to cotton in terms of production volume and has an array of uses. Jute fiber, is one of the most valuable natural fibers that are extracted from the outer bark (bast) of the jute plant stem. It is cheap, biodegradable, renewable, and eco-friendly, thereby making it one of the most suitable natural fibers for sustainable development. The fiber has remarkable tensile strength, very low extensibility, and good breathability. Due to wide versatility, the fiber used in a variety of packaging material, agro-textiles, geotextiles, home furnishing, crafts, and other industrial applications. The flexibility of blending with any other

fibers in manufacturing process makes it the second most vital vegetable fibre next to cotton in terms of usage, availability, international utilization and fabrication. Jute cultivation is confined to the eastern and north eastern States coming under humid and sub humid regions. In 2025–26, India cultivated jute on 541 thousand hectares and produced 8,342 thousand bales (Office of the Jute Commissioner, 2025–26). India has been the world's leading producer of raw Jute for many years, but in 2020, Bangladesh surpassed India. As per statistics available on FAOSTAT till 2023, it contributes nearly 51% of the world's total raw Jute production, while India's share has dropped to around 45%. In India, three states—Assam, Bihar, and West Bengal make up 98% of the country's jute cultivation area. The productivity of the West Bengal is 2794 kg/ha which is above than the national average 2697 kg/ha (Department of Agriculture & Farmers Welfare, Status Paper on Jute 2025. Govt.



of India). However, the Indian jute industry mainly depends on West Bengal due to the higher number of mills, there are 111 composite jute mills out of which the state of West Bengal has 82 jute mills (Ministry of Textiles. (2025). Annual Report 2024–25. Government of India). In the world jute is grown mainly India, Bangladesh, Thailand and China are one of the major producers of jute fiber. The yield of jute higher in China (4042 Kg/ha) than India (2645 Kg/ha) and slightly lower in Bangladesh (2452 Kg/ha). The countries having higher yield of jute than the world's average productivity (2537 Kg/ha) countries like China, India, Egypt and Bhutan (Directorate of Jute Development, 2025).



WHY JUTE NEEDS REINVENTION

For decades, jute mainly used for manufacturing conventional products like gunny bags, hessian, sacking, twine, and ropes. Although these products have important role in agriculture and trading activities, but their market growth remained relatively stagnant due to changing consumer demands and increasing competition from synthetic materials. The long-term sustainability and profitability of the jute sector, it is essential to go beyond traditional uses and embrace innovation through Jute 2.0. Several global trends have accelerated the need for this transformation

1. Growing concern over plastic pollution:

According to the Wastech (2022), Central Pollution Control Board report⁷ India

produced around 3.47 million tonnes of plastic garbage per year, with per capita waste increasing from 700 gms to 2500 gms during the past five years. The widespread use of petroleum-based plastics resulted in severe environmental problems, including land and marine pollution, microplastic contamination, and threats to biodiversity.

2. Limitations of traditional jute products:

Conventional jute products are largely confined to low-value packaging, rope applications that limiting farmers income and industrial profitability. Nowadays, jute travelled a long journey from "Sacks" to "Sophistication". Developing high-value, diversified products unlock new domestic and international markets.

3. Changing consumer preferences:

Consumers are becoming more environmentally conscious and increasingly prefer products made from natural, biodegradable, and ethically sourced materials. This shift has expanded the market for jute-based lifestyle products. Consumers are now getting more concerned about the environment pollution and thus prefer to use natural products.

4. Transition towards a circular economy:

Modern industries are increasingly adopting circular economy principles that emphasize reducing waste, reusing materials, and recycling resources. The recent TERI study of jute bags in India demonstrates that jute functions as 100% recyclable natural material which provides better environmental benefits (IBEF, 2025).

5. Climate change and sustainable development:

Climate change intensified the demand for renewable, low-carbon, and biodegradable materials. As per report by the International Jute Study Group (IJSJG, 2013), 1 ha of jute plants consumes about 15 MT CO₂ and liberates 11 MT of O₂ in only 120 days.

6. Restrictions on single-use plastics:

Many countries, including India, have introduced regulations and bans on several single-use plastic products. The Plastic Waste Management Amendment Rules, 2021, also prohibit manufacture, import, stocking, distribution, sale and use of plastic carry bags having thickness less than 75 microns and thickness less than of 120 microns. These policy measures created significant opportunities for jute-based diversified eco-friendly alternatives products.



WHAT ARE DIVERSIFIED JUTE PRODUCTS (JDPS)?

Diversified Jute Products (JDPs) are value-added products manufactured from jute fibre using modern technologies and innovative processing methods. Innovative new products developed with high value-addition by the researchers now a days, viz., home textiles, jute composites, jute geo-textiles, paper pulp, technical textiles, chemical products, handicrafts and fashion accessories etc. These products developed for new, alternative and non-traditional use of

jute having potential of wider use and application. The MSP of Raw Jute for Marketing season 2026-27 is an increase of Rs.275/- per quintal over the previous Marketing season 2025-26. Government has increased MSP of Raw jute Rs.5,925/- per quintal in 2026-27. This stable supply of quality jute serves as the foundation for value addition and the manufacture of diversified jute products (JDPs), thereby supporting the vision of Jute 2.0.



WHAT ARE DIVERSIFIED JUTE PRODUCTS (JDPS)?

1. Textile Sector:

Modern technologies such as fibre blending, finishing, printing, etc. have expanded utility of jute in the textile sector. . Nowadays, jute fiber is used for making value-added products like shopping bags, luggage, upholstery fabrics, carpets,

blankets, flooring, wall hangings, and clothing. These innovative applications have increased the commercial value of jute and strengthened its as a sustainable, eco-friendly alternative to synthetic textiles.

2. Non-Textile Sector:

Jute is increasingly being utilized in non-textile applications, particularly in the automobile industry. Jute-based nonwoven fabrics and composites are used for manufacturing door panels, headliners, floor panels, and interior trim components. Their lightweight, biodegradable, and eco-friendly properties make them a sustainable substitute to synthetic.

3. Jute Geo-textiles:

Jute geo-textiles are biodegradable fabrics used for soil conservation and erosion control. They provide an eco-friendly alternative to synthetic geo-textiles and widely used in rail and road way constructions, slope stabilization, embankment reinforcement, and land reclamation, strengthening of sub-grade soils, protection of banks of rivers, etc.. Besides preventing soil erosion, jute geo-textiles improve soil health and

support vegetation establishment as they naturally decompose over time. Jute geo-textiles applied in geotechnical and civil engineering, in both developed and developing countries, and the global demand is growing.

4. Agro-textiles:

Jute agrotexiles are a type of natural technical textile that is typically woven or non-woven. Jute agro-textiles are widely used jute non-woven used as agricultural mulch for cultivation of vegetables like bhindi, mung, kolai, maize, marigold and dahlia. Horticultural pots using jute non-woven used for growing and transportation of seedlings. In modern agriculture Jute agro textile used for mulching, nursery irrigation mats, biodegradable seedling pots, and seed bags. Being biodegradable, they offer an environmentally friendly alternative to synthetic agricultural materials.



5. Home Textiles:

Jute is used to manufacture a variety of home textile products, including cushion covers, sofa covers, table mats, napkins, blankets, aprons, curtains, and prayer mats. These products are durable, biodegradable, and aesthetically appealing, making them a sustainable alternative to synthetic home furnishing materials.

6. Floor Coverings:

Jute-based nonwoven fabrics and blended materials are used in floor coverings, carpets, and rugs. These products combine durability, comfort, and aesthetic appeal while being more affordable than many conventional flooring materials. Their eco-friendly and biodegradable nature makes them an attractive and sustainable choice for homes, offices, and commercial spaces.

7. Fashion Bags:

Jute used for manufacturing stylish and eco-friendly fashion bags. Modern designs, gift bags, attractive prints, embroidery, and decorative embellishments have increased the demand for hand and shopping bags, carrier bags in the form of travel bags, fancy bags, and range of different bags are available both domestic and international markets. These bags combine durability, sustainability, and aesthetic appeal.

8. Hand-made Paper:

Jute fibre also used for producing eco-friendly handmade paper and paper-based products. These include greeting cards, stationery, archival paper, and decorative items. With the growing demand for sustainable alternatives to conventional paper products, jute handmade paper has significant potential in both domestic and international markets.

9. Interlining for Garments and Footwear:

Jute nonwoven fabrics are used as interlining materials in garments and footwear. They provide strength, insulation, and durability.

10. Protective Clothing:

Jute is used to manufacture protective aprons, gloves, and other safety gear for workers in industries such as oil refineries, engineering plants and fire services. Its durability and heat-resistant properties make it suitable for various industrial safety applications.

11. Decorative Jute Stick Particle Board:

Jute sticks, an important by-product of jute cultivation, used to manufacture decorative particle boards for furniture, interior decoration, wall panels, partitions, and cabinets. Jute particles board made from jute sticks are excellent sound absorbing materials. Jute felts are used in auto-interior. These boards are lightweight, durable, cost-effective, and eco-friendly, providing a sustainable alternative to conventional wood-based panels.

12. Lifestyle and Decorative Products:

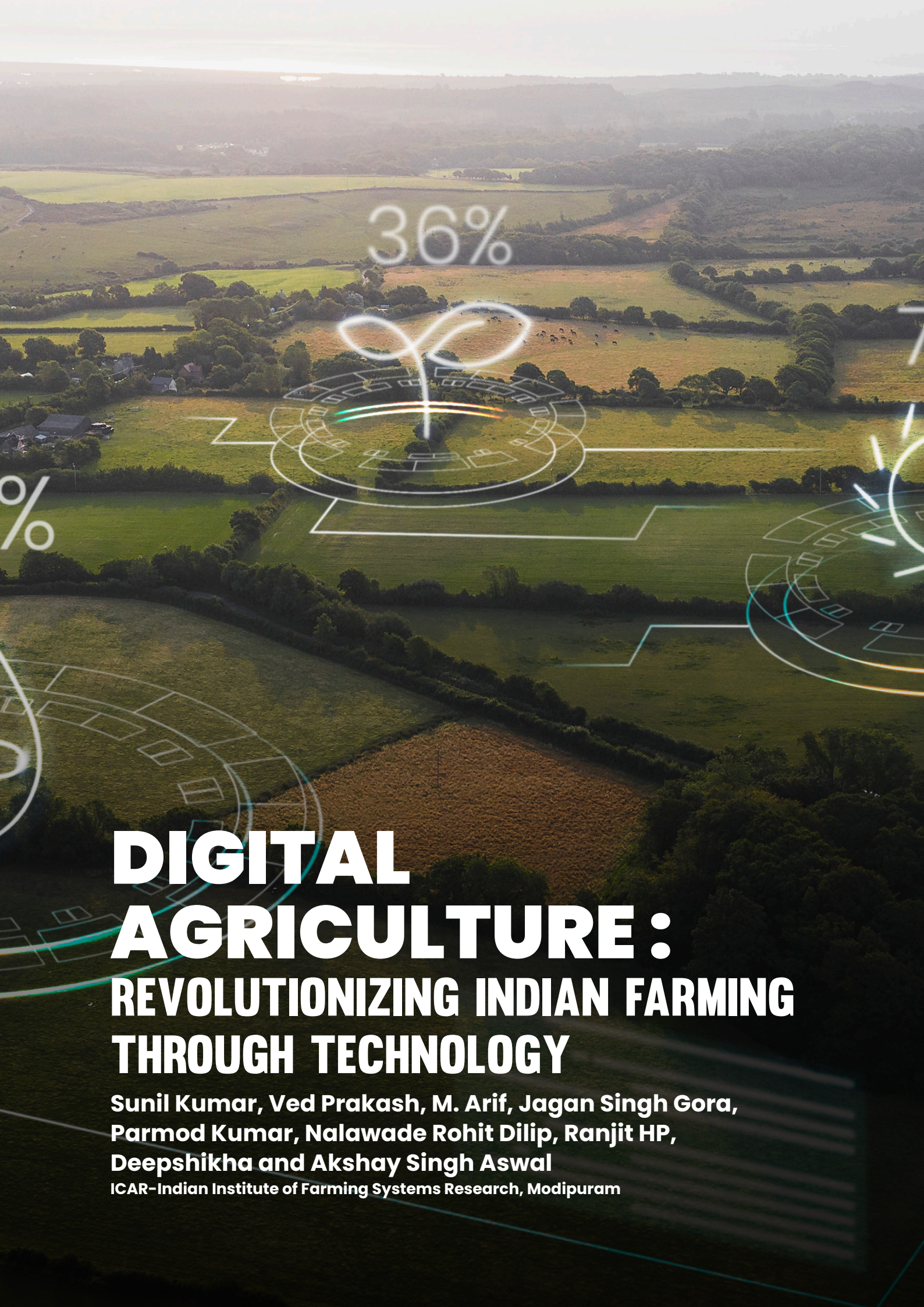
Jute is widely used to manufacture a variety of eco-friendly lifestyle products, including lamp shades, hats, footwear, candle holders, jewellery boxes, and decorative accessories. Jute fabrics are also widely used to produce products like as toys, decorative bags, table lamps, wall hangings,. Their unique appearance, durability, and sustainability have made these products increasingly popular in both domestic and international markets.



India is the leading jute goods-producing country globally, accounting for about 75% of estimated world production. Diversified Jute Products (JDPs) have emerged as an important contributor to India's jute exports. The exports of Indian jute and jute products have increased over the years. During FY23 (up to July 2022), India's jute diversified products (JDP) export contribution stood at US\$ 160.38 million (Rs. 13,202.54 million). The top five destinations for jute diversified product exports from India are the USA, France, the UK, the Netherlands, and Spain. So, Globally, demand for diversified jute products is growing particularly in developed country markets where peoples are becoming conscious about carbon footprint of consumer goods.

CONCLUSION

Jute 2.0 represents a new era of innovation, sustainability, and value addition of jute based products. With increasing global demand for eco-friendly products, diversified jute products offer immense opportunities for farmers, entrepreneurs, and industries. Continued research, supportive government policies, and market-driven innovations will further strengthen India's position as a global leader in sustainable jute production and diversified jute products. Production and commercialization of value-added jute products created additional employment opportunities and assisted in alleviating poverty in India especially in the eastern part of the India.



DIGITAL AGRICULTURE: REVOLUTIONIZING INDIAN FARMING THROUGH TECHNOLOGY

**Sunil Kumar, Ved Prakash, M. Arif, Jagan Singh Gora,
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INTRODUCTION

Digital agriculture refers to the use of information and communication technologies (ICTs) and data-driven tools to improve every stage of the agricultural value chain—from soil preparation and seed selection to harvesting, storage, and marketing. It is transforming traditional farming practices into a more precise, efficient, and sustainable model. In a country like India, where agriculture supports the livelihood of nearly 60% of the population, digital agriculture presents an unparalleled opportunity to boost productivity, ensure food security, and enhance farmers' income.

This technological shift encompasses tools such as mobile applications, satellite imagery, geographic information systems (GIS), artificial intelligence (AI), machine learning (ML), drones,

yield, and minimize environmental impacts. Digital Agriculture will play a key role in knowledge exchange, targeted recommendations, market integration and access to finance to make agriculture a profitable enterprise and attractive for youth. The digital revolution is changing the face of agriculture, with the zeros and ones that make up binary code set to become the most important tools for farmers worldwide. Highly automated tractors and combines equipped with a vast array of sensors are already traversing farmers' fields. Drones and satellites are likewise helping farmers work more efficiently by generating millions of relevant data points. Farmers can predict influences affecting yields and respond more quickly to changes, so that they can prompt action to future change.



APPLICATIONS OF DIGITAL AGRICULTURE

1. Precision Farming

Precision agriculture uses digital tools to optimize farming practices by tailoring them to specific field conditions. Sensors, drones, and GPS technology collect data about soil health, crop requirements, and weather conditions. This information allows for the precise application of water, fertilizers, and pesticides, resulting in higher yields with lower resource use.

For example, variable rate technology (VRT) enables farmers to apply inputs only where needed, while remote sensing tools help monitor crop health and detect pest infestations early. In India, many start-ups and agri-tech companies are offering these services to smallholder farmers at affordable rates.

2. Information and Communication Technology (ICT) Tools

ICTs have significantly enhanced the accessibility and dissemination of agricultural knowledge. Farmers now receive real-time updates about weather conditions, pest outbreaks, crop prices, and government schemes through mobile apps, SMS services, and community radio. Popular mobile platforms like Kisan Suvidha, IFFCO Kisan, and AgriApp provide farmers with weather forecasts, market prices, and best farming practices in local languages. Internet-enabled kiosks and call centers further extend the reach of agricultural advisory services, especially in remote regions.



ICT Tools in Agriculture:

- E-mail
- Portal
- Interactive expert system
- Internet browser
- Call centers
- Radio
- Television
- Video conferencing

3. Drones and Satellite Imagery

Drones are being increasingly used for aerial crop monitoring, spraying pesticides, and assessing flood or drought impacts. High-resolution satellite imagery combined with GIS and remote sensing technologies enables timely detection of crop diseases, soil moisture deficits, and weed outbreaks.

In India, the National Remote Sensing Centre (NRSC) under ISRO provides satellite-based agricultural data to state agencies for crop forecasting and insurance assessments.

4. Artificial Intelligence and Machine Learning

AI and ML are revolutionizing digital agriculture through predictive analytics. These technologies analyze historical and real-time data to forecast yield, assess risks, and offer tailored recommendations. AI-driven chatbots are also providing 24/7 customer support to farmers. For instance, Microsoft's AI-based sowing app in Andhra Pradesh helped increase yields by 30% by advising farmers on the best sowing time based on rainfall predictions.

RISK IN AGRICULTURE

Risk is an important aspect of the farming business. The uncertainties inherent in weather, yields, prices, Government policies, global markets, and other factors that impact farming can cause wide swings in farm income. Risk management involves choosing among alternatives that reduce financial effects that can result from such uncertainties.

- Production risk
- Post harvest risk
- Market risk
- Ecological

Production Risks

Production risks relate to the possibility that your yield or output levels will be lower than projected. Major sources of production risks arise from adverse

weather conditions such as drought, freezes, or excessive rainfall at harvest or planting. Production risks may also result from damage due to insect pests and disease despite control measures employed, and from failure of equipment and machinery such as an irrigation pump. Strategies to manage production risks include:

- Follow recommended production practices.
- Diversify enterprises by growing different crop varieties and completely new crops.
- Expand production through more intensive growing practices or by planting more acreage.
- Purchase crop insurance coverage to

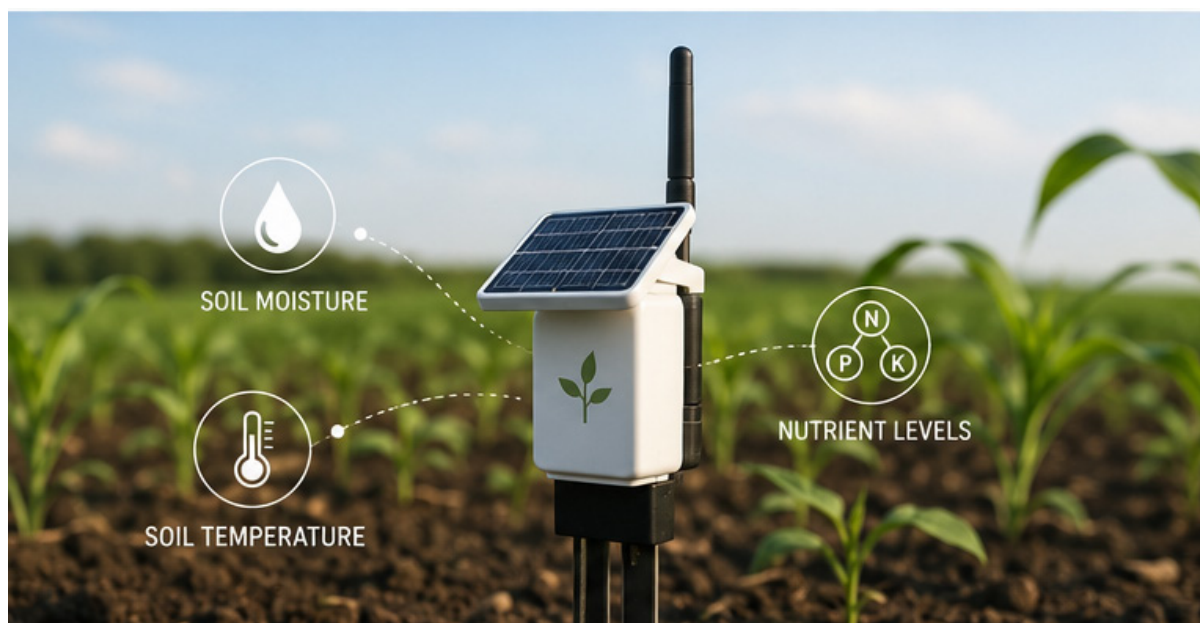
stabilize income during times of loss.

- Adopt risk mitigating practices such as drip irrigation, tile drainage, trap crops or resistant varieties.
- Consider site selection - use fields less susceptible to frost or pests and rotate crops.
- Maintain equipment and keep facilities in good working condition

Post-Harvest Risks

The total loss due to poor post-harvest processing of agricultural products in India when valued in terms of monetary reflects a tremendous loss in the economy. Post-harvest losses of rice, wheat, sugarcane, pulses, oil seed, vegetables fruits and root crops due to inadequate processing and preservation. Foodstuff: Products edible by human beings; more specifically, the part fit for human consumption. In tropical countries, 75 percent of basic food comes from cereals and pulses. The remaining vegetable-based food is often supplied as roots and tubers particularly cassava, yam, taro,

plantain, potato and sweet potato. In the food chain, quantities of food are usually expressed in terms of weight. Grains and seeds: Cereals, pulses and oilseeds grown in most climates and latitudes for human consumption. The main cereals are wheat, maize, rice, barley, sorghum, millet, oats and rye. Pulses cover the various species of pea, bean, broad bean and lentil; and oilseeds cover soya, groundnut, sesame, rapeseed and sunflower. Post-harvest: The post-harvest covers the period that runs from exit from the field to the time of culinary preparation. For various reasons, it allows the straw and grain to dry fully. Harvesting may be delayed sometimes for months, as happens particularly with maize and rice in such cases it is referred as post-production verbally in order to indicate the link between harvesting and post-harvest operations. Food loss: Food loss refers to total modification or decrease of food quantity or quality which makes it unfit for human consumption.



Marketing Risks

Marketing risks relate to the possibility that you will lose the market for your products or that the price received will be less than expected. Lower sales and prices due to increased numbers of competing growers or changing consumer preferences are common sources of marketing risk. Marketing risks can also arise from loss of market access due to a wholesale buyer or processor relocating or closing, or if a product fails to meet market standards or packaging requirements.

Strategies to manage marketing risks include:

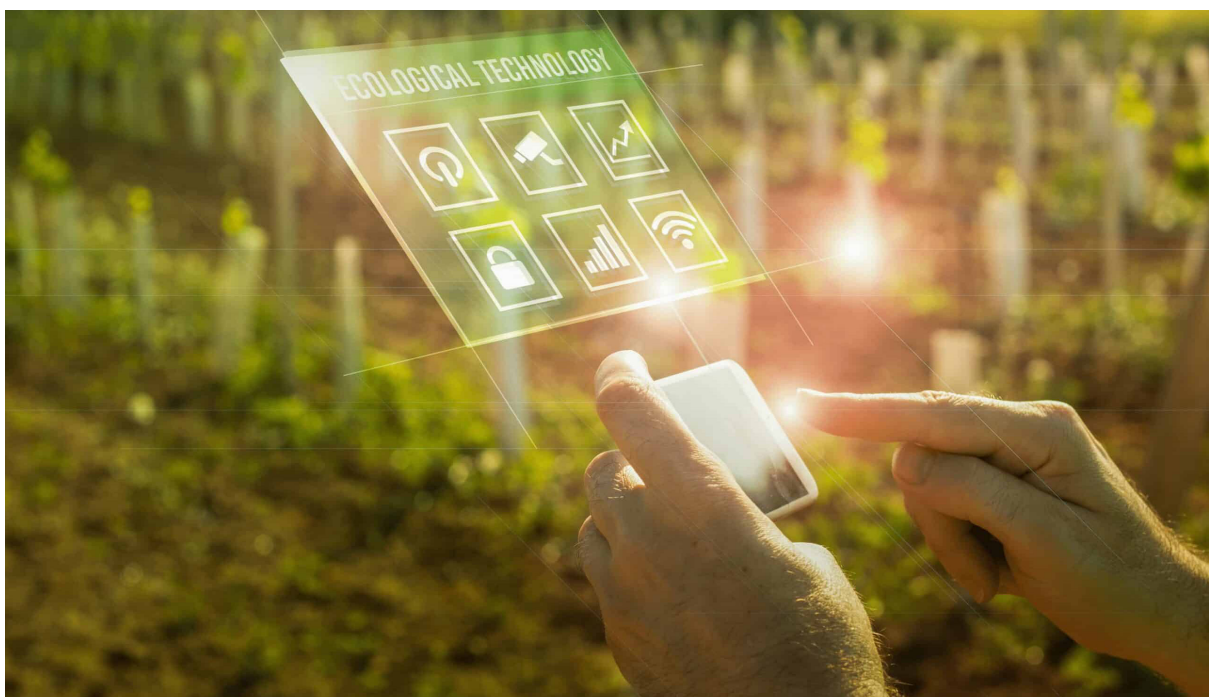
- Develop a marketing plan with realistic sales forecasts and target prices.
- Form or join a marketing cooperative to enhance prices and guarantee a market.
- Increase direct marketing efforts to capture a higher price.
- Market through multiple channels or outlets to reduce reliance on a single

market.

- Enter into sales or price contracts with buyers.
- Spread harvest and sales over the season by scheduling planting and considering storage.
- Conduct essential market research - understand your customers' needs and preferences.
- Purchase Whole-Farm Revenue Protection to cover unexpected decline of market price during the insurance year.

Ecological Risks:

In part, legal risks relate to fulfilling business agreements and contracts. Failure to meet these agreements often carry a high cost. Another major source of legal risk is tort liability - causing injury to another person or property due to negligence. Lastly, legal risk is closely related to environmental liability and concerns about water quality, erosion and pesticide use. Strategies to manage legal



risks include:

Review business insurance policies and carry sufficient liability coverage.

Choose a different business legal structure - a sole proprietorship is not always best.

Understand business contracts and agreements - ask questions if you are unsure.

Develop good relationships with neighbors and address their concerns.

Use good agricultural practices to limit environmental risk.

Know and follow State and Federal regulations related to your farming operation.

CHALLENGES IN ADOPTING DIGITAL AGRICULTURE

Despite its potential, several challenges hinder the widespread adoption of digital agriculture in India:

- **Digital Divide:** Many farmers, especially in remote and tribal areas, lack access to smartphones, the internet, or the digital literacy required to use agricultural apps.
- **High Initial Costs:** Technologies like drones, sensors, and precision farming equipment can be expensive for smallholder farmers.
- **Data Privacy and Security:** As digital tools collect massive volumes of data,

there are concerns about data misuse and ownership.

- **Limited Infrastructure:** Poor connectivity, lack of electricity, and underdeveloped rural infrastructure impede smooth implementation.
- **Fragmented Land Holdings:** The small size of Indian farms limits the scalability of certain precision technologies.

Addressing these challenges requires government support, private-sector partnerships, and investments in rural infrastructure and capacity-building.



GOVERNMENT INITIATIVES SUPPORTING DIGITAL AGRICULTURE

The Indian government has taken numerous steps to integrate digital technologies in agriculture:

1. Digital Agriculture Mission (2021–2025)

This mission aims to support projects based on AI, blockchain, remote sensing, GIS, and drones to modernize Indian agriculture. It promotes public-private partnerships and data sharing through a federated farmer database.

2. National e-Governance Plan in Agriculture (NeGP-A)

Launched to deliver information services to farmers through digital platforms, NeGP-A includes components like mKisan and Farmers' Portal, which provide personalized advisories and market data via SMS and web.

3. e-NAM (National Agriculture Market)

eNAM is a pan-India electronic trading portal that connects Agricultural Produce Market Committees (APMCs) across states, allowing farmers to sell produce transparently at competitive prices. It reduces dependency on middlemen and improves market access.

4. mKISAN Portal

The mKISAN platform enables dissemination of information to farmers through SMS in their local languages. Advisories cover weather alerts, pest management, fertilizer usage, and government schemes.

5. Kisan Call Centers (KCCs)

Operational across India, these centers offer expert advice to farmers in regional



languages, bridging the knowledge gap between extension services and field-level challenges. Agriculture extension services along with facilitation to farmers are the mandate of Agriculture Department everywhere in the country. Continuing fragmentation of land holdings and the increasing number of small holdings are creating challenges for the extension function from the viewpoint of input supply, transfer of technology, ensuring general awareness, etc. One-on-one contact via extension services is now becoming practically difficult, and a shift towards the group approach is becoming inevitable. For speedy transmission of technology and latest technical updates to farmers, for resolving their diverse problems, an innovative means, namely, the KISAN CALL CENTRE, was established in Madhya Pradesh under Rashtriya Kisan Vikas Yojna (RKVY) during 2008-09. After fulfilling all necessary formalities, the Govt of Madhya

Pradesh, Department of Farmer Welfare & Agriculture Development, in coordination with SIAET, chose Indian Society of Agriculture Business Professionals (ISAP), as a partner. The responsibility of ensuring smooth functioning of the KCC was been entrusted to ISAP. KCC in the state started to function in Bhopal in September 2008.

- To facilitate farmers of the state to get information/solutions to their problems through use of the Toll Free Number 1800-233-4433.
- To provide technical inputs to farmers.
- To serve as a feedback mechanism for the policy makers.
- To forge strong Research Extension Farmer Linkages.
- The Kisan Call Center established in the state functions from 7am to 7pm every day. It comprises a 15-seater computerized answering system working in two shifts, i.e., 7am to 1pm and 1pm to 7pm.

KISSAN CREDIT CARD OBJECTIVE:

The scheme aims at providing adequate and timely credit for the comprehensive credit requirements of farmers under single window for their cultivation and other needs as indicated below:

- To meet the short term credit requirements for cultivation of crops
- Post harvest expenses
- Produce Marketing loan
- Consumption requirements of farmer household
- Working capital for maintenance of farm assets, activities allied to agriculture, like dairy animals, inland fishery and also working capital required for floriculture, horticulture etc.
- Investment credit requirement for agriculture and allied activities like pump sets, sprayers, dairy animals, floriculture, horticulture etc.

FUTURE PROSPECTS AND RECOMMENDATIONS

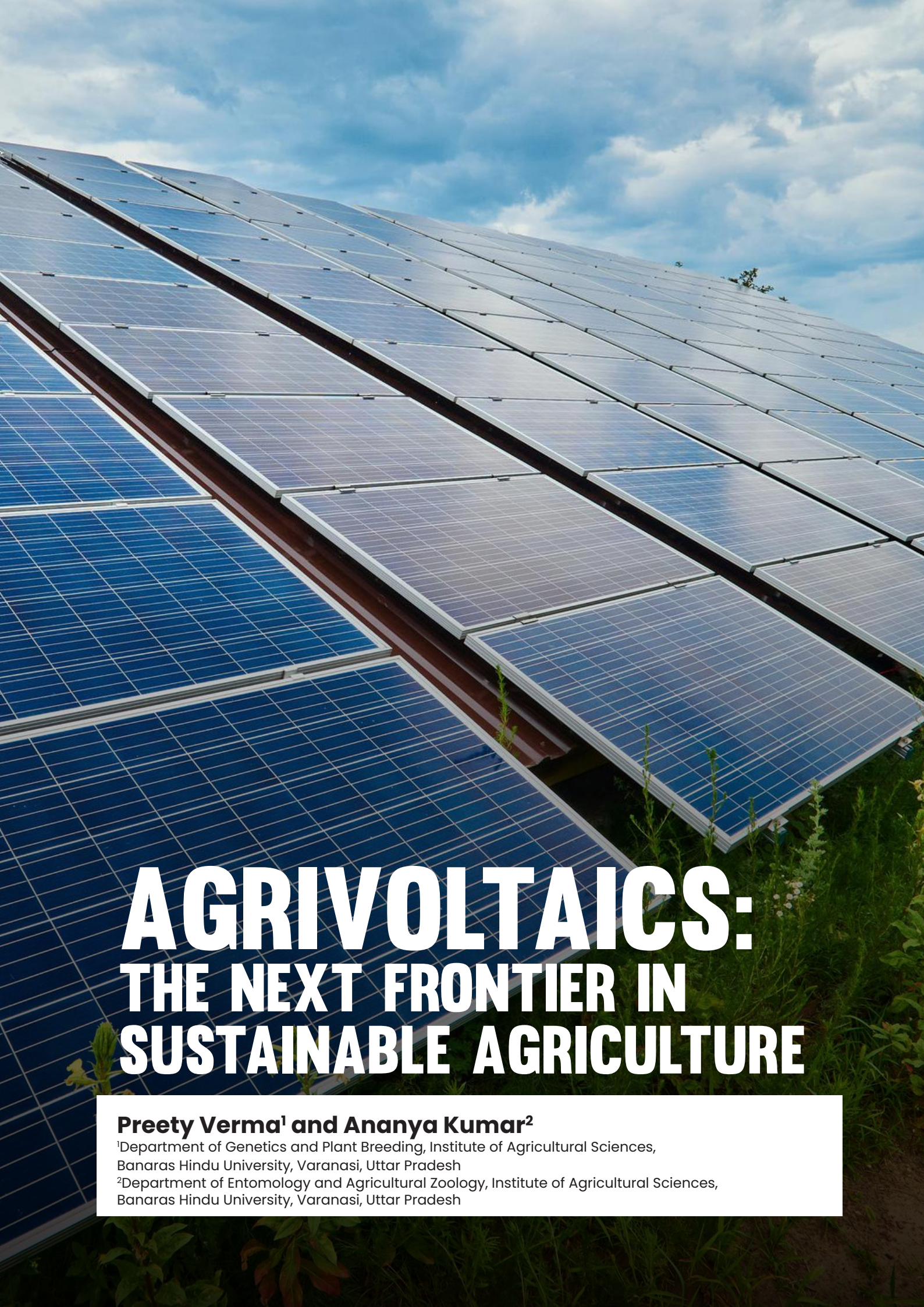
The future of agriculture in India lies in its ability to harness the power of digital technologies. To fully realize this potential:

- **Improve Digital Infrastructure:** Ensure reliable internet connectivity and electricity in rural areas.
- **Promote Public-Private Partnerships:** Collaborate with agri-tech start-ups, research institutions, and NGOs to scale up innovations.
- **Train Farmers:** Conduct digital literacy programs to educate farmers on using apps and tech tools.
- **Subsidize Technology:** Offer financial incentives and subsidies for purchasing digital equipment and services.
- **Strengthen Data Governance:** Create secure frameworks for ethical data use and protect farmers' privacy.



CONCLUSION

Digital agriculture is more than a technological upgrade—it is a paradigm shift toward more sustainable, data-driven, and farmer-centric practices. By integrating digital tools into farming operations, India can boost agricultural productivity, improve climate resilience, and uplift rural livelihoods. For this transformation to be inclusive and impactful, coordinated efforts from governments, industry, academia, and farmers themselves are essential.



AGRIVOLTAICS: THE NEXT FRONTIER IN SUSTAINABLE AGRICULTURE

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INTRODUCTION

Modern agriculture is highly dependent on fossil fuels for various operations, including fertilizer production, irrigation, mechanization, transportation, and post-harvest processing. Although these energy-intensive practices have substantially increased agricultural productivity, they have also become a major source of greenhouse gas (GHG) emissions. The continuous combustion of fossil fuels, together with deforestation, industrialization, and other human activities, has significantly increased the atmospheric concentration of greenhouse gases such as carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and fluorinated gases. Among these, carbon dioxide is the largest contributor to global warming and is considered one

of the primary drivers of climate change. The increasing global population has intensified the demand for food, water, and energy, leading to greater consumption of fossil fuels and further escalation of greenhouse gas emissions. This growing dependence on conventional energy sources has raised serious environmental concerns, including rising global temperatures, altered rainfall patterns, frequent extreme weather events, and declining agricultural productivity. Consequently, there is an urgent need to transition towards renewable and sustainable energy sources that can meet increasing energy demands while minimizing environmental degradation. Renewable energy technologies, particularly solar and wind energy, have



emerged as promising alternatives to fossil fuels because they generate electricity with minimal greenhouse gas emissions. Their widespread adoption can reduce the carbon footprint of various sectors, including agriculture, while contributing to climate change mitigation and long-term environmental sustainability. Among these renewable energy-based innovations, agrivoltaics has gained considerable attention as an effective approach for simultaneously addressing food security, clean energy production, and sustainable land management.



Agrivoltaics is an integrated land-use system in which photovoltaic (PV) panels are combined with agricultural production on the same piece of land. The concept was first proposed by Goetzberger and Zastrow in 1981 with the objective of improving land-use efficiency by producing both agricultural commodities and solar electricity simultaneously. Unlike conventional land-use systems that often compete for space between agriculture and energy production, agrivoltaics allows these two sectors to coexist, thereby maximizing the land equivalent ratio and enhancing

overall economic returns. As global demand for both food and renewable energy continues to increase, agrivoltaics has emerged as a practical solution for improving land productivity while reducing dependence on fossil fuels. The presence of photovoltaic panels modifies the field microclimate by reducing excessive solar radiation, lowering canopy and soil temperatures, conserving soil moisture, and improving water-use efficiency. These changes can reduce heat stress in crops and, under suitable environmental conditions, enhance crop growth and productivity. Although the installation of solar panels may slightly reduce either agricultural production or electricity generation individually, the combined productivity and economic return of the integrated system are generally higher than those obtained from separate land-use practices. In addition to supporting sustainable crop production, agrivoltaic systems generate clean electricity, reduce greenhouse gas emissions, improve energy security, and provide decentralized power generation for rural and remote communities where access to centralized electricity grids is limited.



CLASSIFICATION OF AGRIVOLTAIC SYSTEMS

Agrivoltaic systems can be classified according to the agricultural enterprise integrated with photovoltaic energy generation:

Livestockvoltaics

Livestockvoltaics integrates livestock production with photovoltaic systems by allowing animals to graze beneath elevated solar panels. Depending on the animal species involved, these systems may be referred to as cowvoltaics, sheepvoltaics, or goatvoltaics. Besides producing renewable electricity, livestockvoltaic systems improve pasture utilization and contribute to soil health. Grazing animals enhance soil carbon sequestration through the incorporation of plant residues into the soil, while manure deposition increases soil organic matter, nutrient availability, and microbial activity, thereby improving overall soil fertility.

Crop-Based Agrivoltaics

Crop based agrivoltaics is the most widely adopted form of agrivoltaic system, in which crops are cultivated beneath or between photovoltaic panels. The system accommodates a wide range of crops, including cereals, vegetables, fruits, forage crops, and medicinal plants. Specialized forms such as fruitvoltaics and veggievoltavics integrate fruit orchards and vegetable cultivation with solar energy generation, respectively. These systems

improve overall land productivity by enabling simultaneous food production and renewable energy generation while creating a more favorable microclimate for crop growth.

Aquavoltaics

Aquavoltaics combines floating photovoltaic systems with aquaculture, allowing renewable energy production and aquatic farming to occur simultaneously on the same water body. The floating solar panels reduce water evaporation and moderate water temperature while generating electricity. A specialized form, known as fishvoltaics, integrates fish culture with floating solar installations, thereby enhancing the efficient utilization of reservoirs, ponds, and other aquatic resources.

Zoovoltavics

Zoovoltavics is an emerging approach that integrates renewable energy production with wildlife conservation. Rather than focusing on agricultural production, these systems are designed to maintain or restore habitats for wild animals within or around solar farms. By promoting biodiversity alongside clean energy generation, zoovoltavics support ecological sustainability while minimizing conflicts between renewable energy development and wildlife conservation.



BENEFITS OF AGRIVOLTAICS

- Agrivoltaic systems provide several environmental, agricultural, and socio-economic benefits.
- Agrivoltaics enables the simultaneous production of agricultural commodities and solar electricity on the same land, thereby improving overall land-use efficiency.
- The integration of photovoltaic systems with agriculture reduces dependence on fossil fuels and lowers greenhouse gas emissions, contributing to climate change mitigation and environmental sustainability.
- The partial shade created by solar panels moderates field temperatures, protects crops from excessive solar radiation and heat stress, and improves resilience against climate variability and extreme weather events.
- Reduced solar exposure decreases soil water evaporation, thereby improving soil moisture conservation and enhancing water-use efficiency, particularly in water-limited environments.
- Solar panels act as protective barriers against wind and heavy rainfall, reducing soil erosion, preserving soil structure, and maintaining long-term soil fertility.
- Agrivoltaic systems diversify farmers' income through simultaneous agricultural production and electricity generation, improving farm profitability and economic resilience.
- The decentralized generation of renewable electricity supports rural electrification, reduces transmission losses, and enhances energy access in remote agricultural regions.

COMPARISON OF AGRIVOLTAICS

Agrivoltaics Type	Advantages	Disadvantages
Crops	• Effective water use • Protection from hail and weather resilience • Improved microclimate and enhanced crop yield	• Excessive shading on some crops • Uneven water distribution and risk of soil erosion • Reduced soil porosity
Animals	• Thermal comfort for livestock • Improved animal welfare • Higher lamb production • Increased farm revenue	• Cable damage by animals • Wind-induced panel instability
Greenhouse	• Passive energy efficiency • Reduced evapotranspiration and lower water loss • Controlled greenhouse microclimate	• Reduced light availability • Higher greenhouse temperature • Need for additional ventilation
Different applications	• Shade for park visitors • Solar-powered charging stations • Improved thermal comfort	• Limits sports activities • Potential grass damage.

CONCLUSION

Agrivoltaics has emerged as a promising and sustainable land-use strategy that effectively integrates agricultural production with renewable energy generation. By combining photovoltaic systems with crop cultivation, livestock rearing, aquaculture, or biodiversity conservation, agrivoltaic systems maximize land-use efficiency while addressing the growing global demand for food and clean energy. The modified microclimate created beneath solar panels can improve soil moisture conservation, reduce crop heat stress, enhance water-use efficiency, and increase the resilience of agricultural systems to climate variability. Beyond environmental

benefits, agrivoltaics provides significant economic advantages by creating additional income opportunities for farmers through electricity generation while maintaining agricultural productivity. The technology also supports rural electrification, decentralized energy production, and sustainable resource management, making it particularly valuable for regions facing land constraints and increasing energy demands. Future studies should focus on region-specific system designs, long-term agronomic and economic assessments, integration with precision agriculture, and the development of policies that encourage large-scale adoption



HARYANA'S HORTICULTURE DEPARTMENT:

PIONEERING FARMER-CENTRIC GROWTH, INNOVATION AND AGRICULTURAL DIVERSIFICATION

Sushank

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INTRODUCTION

Haryana, a key contributor to India's food security through wheat and rice production, is increasingly embracing horticulture to address challenges such as groundwater depletion, rising input costs, climate variability and the need for higher farm incomes. The cultivation of fruits, vegetables, flowers, mushrooms, spices, medicinal plants and allied activities like beekeeping has created new opportunities for agricultural diversification and

profitability. Recognizing this potential, the Haryana Horticulture Department has implemented innovative schemes, financial assistance, technical support, capacity-building programmes and digital initiatives to promote high-value crops. These efforts have transformed horticulture into a major driver of sustainable agricultural growth and rural prosperity.



HARYANA'S GROWING HORTICULTURE SECTOR

Over the past two decades, Haryana has witnessed remarkable growth in horticultural activities. Farmers are increasingly cultivating fruits such as kinnow, guava, mango, ber, pomegranate, aonla and citrus crops, along with vegetables including tomato, onion,

potato, capsicum, cucumber, baby corn and several exotic vegetables. Protected cultivation, organic farming, mushroom production, floriculture and beekeeping have further diversified the sector. The state's emphasis on crop diversification has become particularly important in

addressing groundwater depletion caused by the rice-wheat cropping system. Horticultural crops not only generate higher income per unit area but also create opportunities for value addition, employment generation, export-oriented production and climate-resilient agriculture. The Haryana Horticulture Department has played a pivotal role in facilitating this transformation through policy support, infrastructure development, technological interventions and extensive extension services.



Empowering Farmers Through Comprehensive Horticulture Support Programmes

The Haryana Horticulture Department has emerged as a catalyst for agricultural diversification and income enhancement by implementing a wide spectrum of farmer-centric schemes covering production, infrastructure development, water conservation, post-harvest management, marketing, skill development and risk mitigation. Through strategic interventions under the Mission for Integrated Development of Horticulture (MIDH) and various state-sponsored initiatives, the department

has created a comprehensive ecosystem that supports farmers from planting to marketing.

Promoting Horticulture Diversification and High-Value Crop Cultivation

One of the department's foremost objectives is to encourage farmers to diversify from conventional cereal-based farming systems towards high-value horticultural crops. Financial assistance is provided for establishing orchards of mango, guava, citrus, pomegranate, ber, aonla, pear, peach, plum and other fruit crops. Subsidies are also available for high-density plantations, enabling farmers to increase productivity per unit area and achieve higher economic returns. The department actively promotes commercial vegetable cultivation through support for quality seeds, improved production technologies and scientific crop management practices. Floriculture has also received significant encouragement through assistance for marigold, gladiolus, rose and other ornamental flower crops.



HARYANA'S GROWING HORTICULTURE SECTOR

Recognizing the growing importance of climate-resilient agriculture, the department has invested heavily in protected cultivation technologies. Farmers receive substantial subsidies for naturally ventilated polyhouses, fan-and-pad polyhouses, shade-net houses, walk-in tunnels, anti-hail net structures, insect-proof net houses and plastic mulching systems. These interventions enable year-round production of vegetables, flowers and nursery plants while protecting crops from adverse weather conditions, pests and diseases. Protected cultivation has emerged as a transformative technology, allowing farmers to achieve significantly higher yields, superior produce quality and enhanced profitability.



► **Strengthening Water Conservation and Efficient Irrigation**

Water scarcity remains one of the major challenges confronting agriculture in Haryana. To address this issue, the department has implemented several water conservation initiatives. Financial assistance is provided for constructing community water storage tanks, farm

ponds, underground pipeline systems and micro-irrigation infrastructure including drip and sprinkler irrigation systems. These schemes promote efficient utilization of water resources, reduce conveyance losses, improve water-use efficiency and support sustainable agricultural practices.

► **Building Quality Planting Material Infrastructure**

The availability of quality planting material is fundamental to successful horticulture development. The department supports the establishment of fruit nurseries, vegetable nurseries, mother blocks and seedling production facilities to ensure farmers have access to healthy, disease-free and certified planting material. Digital services such as the online Fruit and Vegetable Plant Booking Portal have further streamlined access to quality planting material, making procurement transparent and farmer-friendly.

► **Encouraging Mushroom Cultivation and Beekeeping Enterprises**

To generate additional income opportunities for rural households, the department actively promotes mushroom cultivation and beekeeping. Farmers, women entrepreneurs and rural youth receive technical training, production guidance and financial support for establishing mushroom production, spawn and compost units. Similarly, scientific beekeeping is encouraged through subsidies on bee colonies, bee boxes, honey extractors and processing

equipment. Beyond honey production, beekeeping significantly enhances pollination and crop productivity.



➤ **Developing Post-Harvest and Cold Chain Infrastructure**

Post-harvest losses have historically reduced profitability in horticultural crops. To address this challenge, the department provides assistance for establishing pack houses, cold storages, ripening chambers, processing units, reefer transport systems and integrated cold-chain infrastructure. These facilities facilitate scientific grading, sorting, packaging, storage and transportation of produce, thereby reducing losses and enabling farmers to access distant markets with better price realization.

➤ **Advancing Horticulture Mechanization**

Mechanization has become an essential component of modern horticulture. Farmers are provided financial assistance for specialized horticultural machinery and equipment such as tractors, power tillers, orchard tools, sprayers, mulching equipment and other modern implements. The adoption of mechanization reduces labour requirements, improves operational efficiency and contributes to higher productivity.

➤ **Promoting Integrated Pest Management and Crop Health**

The department promotes environmentally sustainable crop protection practices through Integrated Pest Management (IPM) programmes. Farmers receive support for adopting pheromone traps, yellow sticky traps, bio-control agents and other eco-friendly technologies. Plant health diagnostic services and technical advisory support are also provided to help farmers effectively manage diseases and pest outbreaks.

➤ **Ensuring Better Market Access and Price Security**

Marketing remains a critical determinant of farm income. Haryana has pioneered innovative market-support interventions such as the Bhavantar Bharpai Yojana (BBY), which protects growers of notified horticultural crops from sharp price declines by compensating them whenever market prices fall below prescribed levels. The department also facilitates Farmer Producer Organizations (FPOs), collection centres, market linkages and value-chain integration to strengthen farmers' bargaining power and ensure remunerative returns.

➤ **Protecting Farmers Through Horticulture Insurance**

The Mukhyamantri Bagwani Bima Yojana (MBBY) represents a landmark initiative in horticultural risk management. Covering a wide range of horticultural crops, the scheme provides compensation against losses arising from adverse weather events, natural calamities and other notified risks. By offering affordable premium rates and direct benefit transfers, the scheme strengthens farmer confidence and encourages investment in high-value horticultural enterprises.

➤ **Building Human Capital Through Training and Capacity Development**

The department recognizes that technological advancement must be accompanied by knowledge dissemination. Through farmer training programmes, exposure visits, demonstrations, and specialized skill development initiatives, farmers, women and rural youth receive hands-on training in protected cultivation, nursery management, mushroom production, beekeeping, post-harvest management and value addition. These efforts bridge the gap between research and field-level adoption, accelerating innovation uptake and technology transfer.

➤ **Digital Transformation of Service Delivery**

The Haryana Horticulture Department has embraced digital governance to enhance transparency and accessibility. Farmers can access online subsidy applications, plant booking services, training portals, seed licensing systems and various departmental services through dedicated digital platforms. These initiatives have significantly reduced procedural delays and improved service delivery efficiency.

➤ **Leadership, Governance and Field-Level Excellence Driving Haryana's Horticultural Success**

Haryana's horticultural transformation is being guided by the visionary leadership of Sh. Shyam Singh Rana, Hon'ble Agriculture and Farmers Welfare Minister, Haryana; Sh. Vijayendra Kumar, IAS, Additional Chief Secretary; Sh. Arjun Singh Saini, Head of Department, Directorate of Horticulture; and Sh. Ranbir Singh, Director General,

Directorate of Horticulture. Their strategic direction, policy support and commitment to farmer welfare have accelerated horticultural growth and crop diversification across the state. Supporting them is a dedicated team of Joint Directors, Deputy Directors, District Horticulture Officers, Horticulture Development Officers and other staff who ensure effective implementation of government programmes.

➤ **Citizen-Centric Services for Farmer Welfare**

The Haryana Horticulture Department has adopted a citizen-centric approach through transparent and technology-driven governance. Major services available to farmers include:

- Online subsidy applications
- SARAL Haryana integration
- Meri Fasal Mera Byora registration
- RTI and RTS services
- Jan Samvad Portal
- CM Window grievance redressal
- Digital beneficiary verification
- Online licensing services for nurseries and seed businesses

These initiatives have significantly improved transparency, efficiency and accessibility of government services.





KISAN DRONES: A NEW ERA OF PRECISION CROP PROTECTION

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INTRODUCTION

Indian agriculture is undergoing a remarkable transformation with the adoption of digital technologies and precision farming practices. Among these innovations, Kisan Drones have emerged as one of the most promising tools for improving crop protection, enhancing productivity and reducing production costs. The Government of India has actively promoted drone technology

through the "Kisan Drone" initiative, encouraging farmers to adopt modern, efficient and environmentally sustainable methods of pesticide and nutrient application. Agricultural drones are now being increasingly used for crop health monitoring, pesticide spraying, fertilizer application and field mapping, offering farmers a faster and safer alternative to conventional spraying methods.



WHAT ARE KISAN DRONES?

Kisan Drones are Unmanned Aerial Vehicles (UAVs) specially designed for agricultural operations. Equipped with GPS, automated flight control systems, high-precision nozzles and spray tanks, these drones can accurately apply pesticides, herbicides, fungicides and liquid fertilizers over crop fields. Depending on the model, agricultural drones can carry 10–30 litres of spray

solution and cover 8–15 hectares per day, making them highly suitable for timely crop protection.

Unlike conventional knapsack sprayers, drones maintain a uniform spray pattern and operate at predetermined flight heights and speeds, ensuring even distribution of spray droplets across the crop canopy.

WHY ARE DRONES NEEDED IN CROP PROTECTION?

Modern agriculture faces several challenges, including labour shortages, rising wages, increasing pesticide costs and the need for timely pest management. Conventional pesticide application often requires large quantities of water and exposes farmers directly to harmful chemicals.

Drone technology addresses these challenges by offering rapid spraying of large areas, reduced dependence on skilled labour, lower water requirement and improved spray uniformity. According to Chen et al. (2021), UAV-based spraying improves operational efficiency while significantly reducing operator exposure to pesticides.



IMPLEMENTATION:

Faster pesticide application

A drone can spray several hectares within a few hours, allowing farmers to complete pesticide application during the optimum period before pest outbreaks become severe.

Water conservation

Conventional knapsack spraying

generally requires 300–500 litres of water per hectare, whereas drones can effectively spray crops using only 20–30 litres per hectare. This significantly reduces water consumption without compromising spray effectiveness.

Better spray coverage

The rotating propellers generate a

strong downward airflow that helps spray droplets penetrate deep into crop canopies. Research has shown that this rotor-induced airflow improves droplet deposition and canopy penetration, resulting in better pest management.

Reduced labour requirement

Finding agricultural labour during peak cropping seasons has become increasingly difficult. Drones reduce labour dependency and allow timely pesticide application even when labour availability is limited.

Improved operator safety

Manual spraying exposes farmers to pesticide vapours and direct skin contact, increasing health risks. Drone spraying eliminates direct exposure by allowing operators to control the equipment from a safe distance.

Reduced crop damage

Unlike tractor-mounted sprayers or manual movement within fields, drones spray from above the crop, avoiding trampling losses and protecting standing crops.

Applications of Kisan Drones

Agricultural drones are increasingly used for:

- Insecticide spraying
- Fungicide application
- Herbicide application
- Foliar nutrient spraying
- Micronutrient application
- Crop health monitoring using multispectral cameras
- Weed mapping
- Disease surveillance
- Crop damage assessment after floods or droughts
- Yield estimation



SUCCESS IN MAIZE PEST MANAGEMENT

Recent studies conducted on maize have demonstrated that drone-assisted spraying provides excellent control of major pests such as fall armyworm (*Spodoptera frugiperda*) and stem borer (*Chilo partellus*). Properly calibrated drones equipped with suitable nozzles and optimum spray volumes achieve better canopy penetration and more uniform insecticide deposition than conventional spraying methods.

Further research has shown that optimization of flight height, spray volume and operating speed plays a crucial role in maximizing insecticide deposition and improving pest control efficiency under field condition. These findings indicate that scientific optimization of

drone spraying parameters is essential for achieving effective pest management.



GOVERNMENT SUPPORT

Recognizing the potential of drones in agriculture, the Government of India has introduced several initiatives to encourage their adoption. The Ministry of Agriculture and Farmers Welfare has released Standard Operating Procedures (SOPs) for agricultural drone application and approved numerous insecticide formulations for drone spraying (Ministry of Agriculture and Farmers Welfare, 2022). Financial assistance, training programmes and custom hiring centres are also being promoted to make drone technology accessible to farmers.

CHALLENGES IN ADOPTION

Despite its advantages, certain constraints limit widespread adoption:

- High initial investment
- Need for trained drone pilots
- Battery charging infrastructure in remote villages
- Weather limitations, especially strong winds
- Need for crop-specific spraying protocols
- Limited awareness among farmers

Strengthening custom hiring services and providing regular training can overcome many of these challenges.

PRACTICES FOR DRONE SPRAYING

Farmers and drone operators should follow these recommendations:

- Spray during early morning or late evening when wind speed is low.
- Use only approved pesticides and recommended doses.
- Maintain the recommended flight height and speed.
- Calibrate the drone before every operation.
- Avoid spraying during rain or strong winds.
- Wear appropriate personal protective equipment while handling pesticides.
- Follow the Standard Operating Procedures issued by the Ministry of Agriculture and Farmers Welfare.

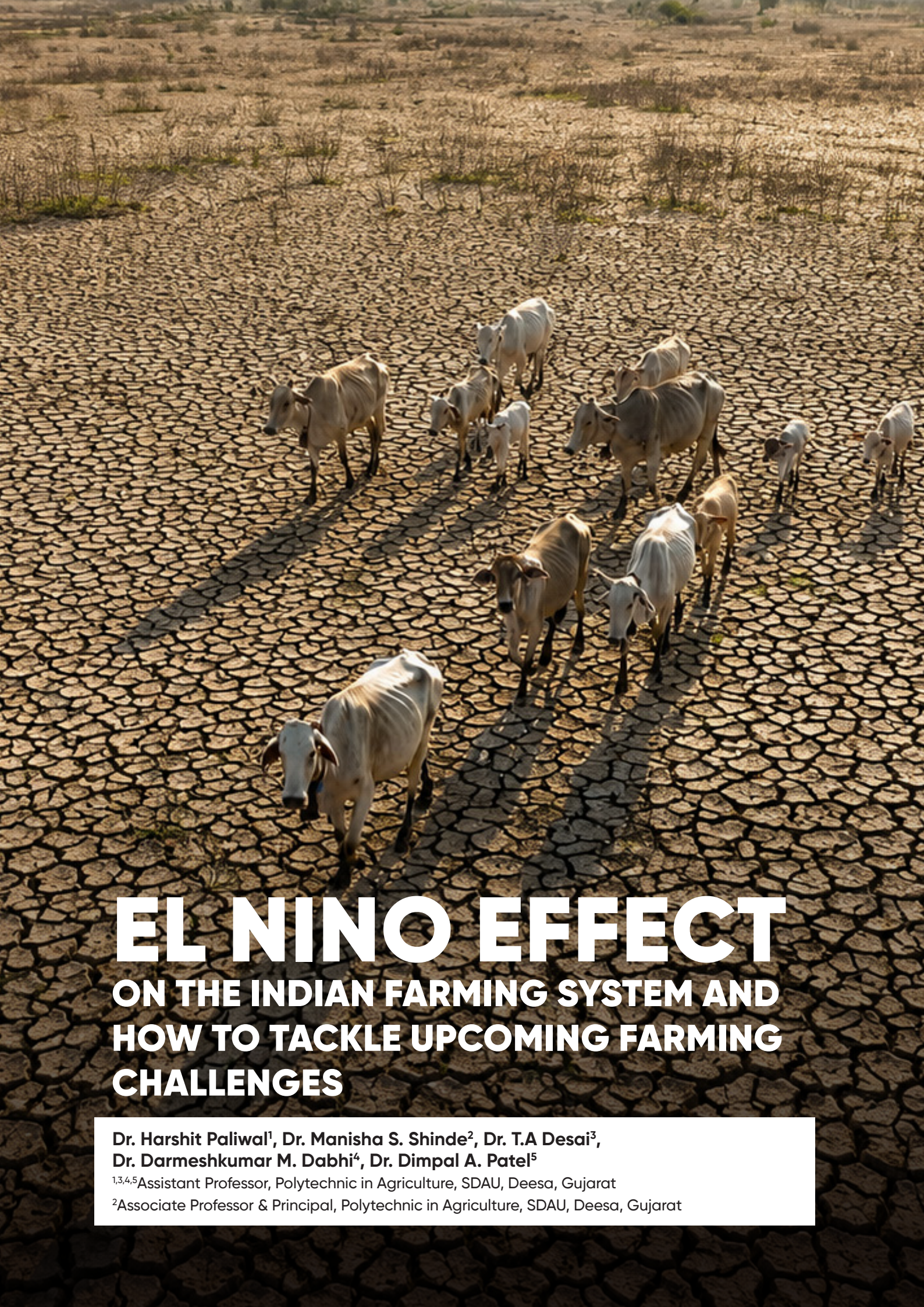
THE ROAD AHEAD

Agricultural drones are expected to play a major role in the future of Indian farming. Integration of drones with artificial intelligence, GPS navigation, remote sensing and Internet of Things (IoT) technologies will enable site-specific crop protection and real-time decision-making. Continuous research is being undertaken to improve spray deposition, nozzle design and application efficiency for different crops and pests. With increasing government support and technological advancements, drone-based crop protection is expected to become an integral part of precision agriculture in India.



CONCLUSION

Kisan Drones represent a significant advancement in precision crop protection. They offer farmers a practical solution to labour shortages, rising input costs and the need for efficient pesticide application. By ensuring timely spraying, reducing pesticide exposure, conserving water and improving spray coverage, drones contribute to higher productivity and more sustainable agriculture. As highlighted by the ICAR–Indian Institute of Maize Research (2023), adoption of modern precision technologies such as UAVs will play an important role in enhancing crop productivity while promoting environmentally responsible agriculture. With continued scientific validation, farmer awareness and government support, Kisan Drones have the potential to revolutionize crop protection and become an indispensable component of modern Indian farming.



EL NINO EFFECT

ON THE INDIAN FARMING SYSTEM AND HOW TO TACKLE UPCOMING FARMING CHALLENGES

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INTRODUCTION

Agriculture plays a vital role in India's economy, contributing to food security and providing livelihoods for millions of farming households. However, climate variability and extreme weather events increasingly threaten agricultural productivity. Among these, El Nino is one of the most influential global climate phenomena affecting the Indian monsoon. It often leads to below-normal rainfall, higher temperatures, water scarcity, and reduced crop yields,

particularly in rainfed regions. With the growing impacts of climate change, the frequency and intensity of weather-related risks have increased, making it essential to adopt climate-smart and resilient farming practices. Understanding the effects of El Nino and implementing appropriate adaptation strategies can help farmers minimize production losses and strengthen the sustainability of Indian agriculture.

WHAT IS EL NINO?

El Nino is a naturally occurring climate phenomenon characterized by the abnormal warming of sea surface temperatures in the central and eastern equatorial Pacific Ocean. It is one phase of the El Nino–Southern Oscillation (ENSO), a coupled ocean–atmosphere system that influences global weather and climate patterns. El Nino generally occurs at intervals of 2–7 years and typically lasts for 9–12 months, although some events may persist longer.

Under normal conditions, strong trade winds blow from east to west across the equatorial Pacific Ocean, pushing warm surface water toward Indonesia and Australia. This movement allows cold, nutrient-rich water to rise (upwelling) along the western coast of South America. During an El Nino event, these trade winds weaken or even reverse, causing warm ocean water to shift eastward

toward the central and eastern Pacific. As a result, sea surface temperatures increase in these regions, atmospheric circulation changes, and global weather patterns are disrupted.

El Nino has far-reaching impacts on temperature, rainfall, and extreme weather events across many parts of the world. In India, El Nino is commonly associated with a weaker southwest monsoon, which may lead to below-normal rainfall, prolonged dry spells, drought conditions, reduced water availability, and lower agricultural productivity. However, the intensity of its impact varies depending on the strength of the El Nino event and interactions with other climatic factors, such as the Indian Ocean Dipole (IOD). The effects of El Nino extend beyond agriculture. It can influence water resources, hydropower generation, fisheries, biodiversity, public health, and

food prices. Since Indian agriculture remains highly dependent on monsoon rainfall, understanding El Nino and its implications is essential for improving climate risk management, promoting climate-smart agriculture, and developing effective adaptation strategies that enhance farmers' resilience and ensure sustainable agricultural production.



HOW DOES EL NINO AFFECT INDIAN AGRICULTURE?

El Nino significantly influences the Indian agricultural system by altering monsoon rainfall patterns, increasing temperatures, and creating water stress. Since nearly half of India's net sown area is still dependent on rainfall, any disruption in the southwest monsoon directly affects crop production, livestock, and farmers' livelihoods. The major impacts of El Nino on Indian agriculture are discussed below.

1. Deficient Monsoon Rainfall

One of the most significant consequences of El Nino is the reduction in southwest monsoon rainfall. During El Nino years, many parts of India receive below-normal rainfall, particularly rainfed regions of central, western, and southern India. Delayed onset, prolonged dry spells, and early withdrawal of the monsoon reduce soil moisture, affecting seed germination,

crop establishment, and plant growth. Farmers often postpone sowing or reduce the cultivated area due to inadequate rainfall.

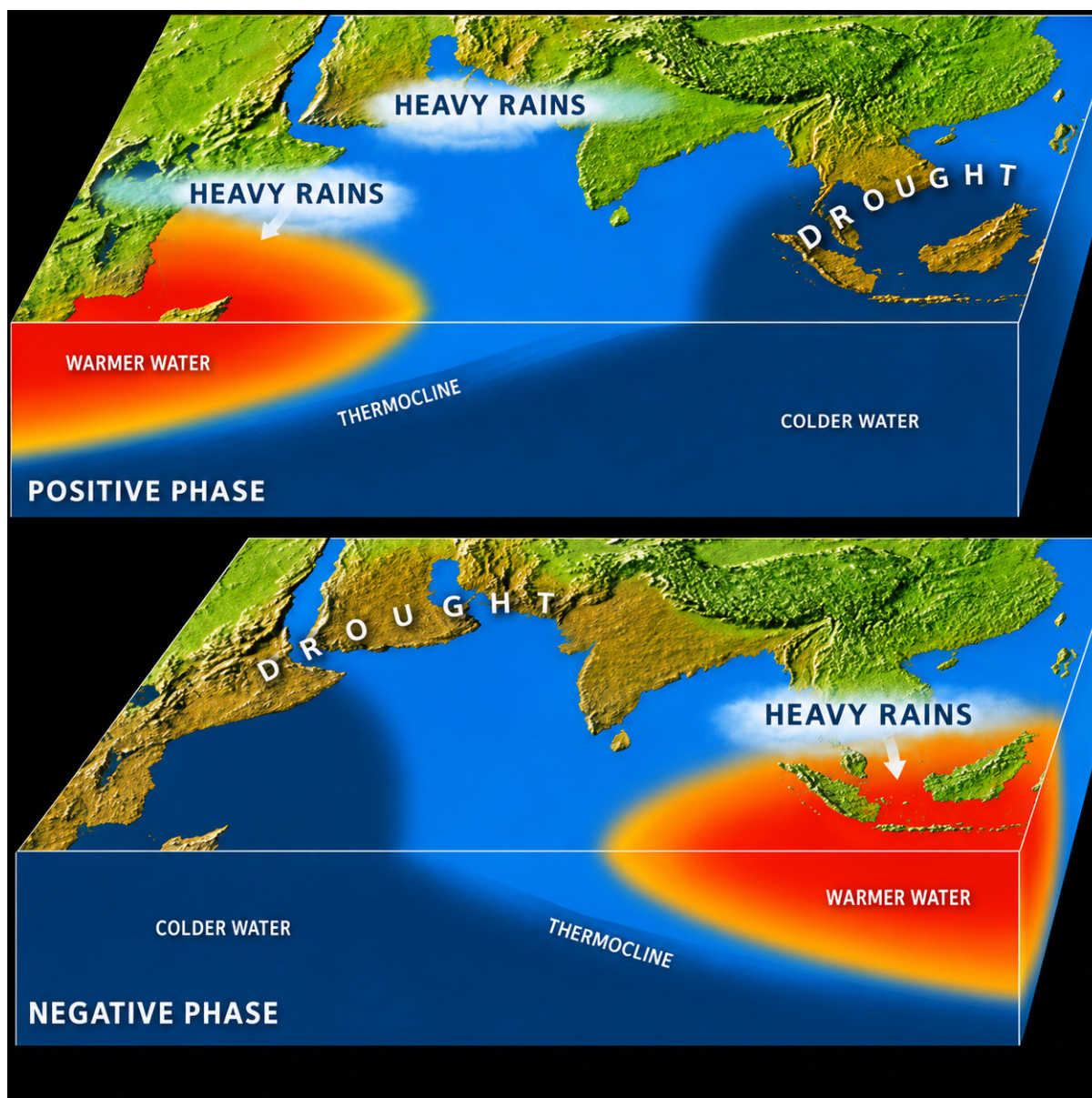
2. Reduced Crop Productivity

Insufficient rainfall and prolonged moisture stress negatively affect the growth and development of major crops. Crops such as rice, maize, soybean, pulses, cotton, and groundnut are highly vulnerable during critical growth stages, including germination, flowering, and grain filling. Water stress reduces photosynthesis, limits nutrient uptake, and shortens the crop growth period,

ultimately leading to lower yields and poor crop quality.

3. Water Scarcity

Poor monsoon rainfall decreases the availability of water in reservoirs, rivers, ponds, canals, and groundwater sources. Reduced groundwater recharge lowers the availability of irrigation water during both the Kharif and Rabi seasons. Farmers depending on tube wells face increased irrigation costs due to falling groundwater levels, while many rainfed farmers experience complete crop failure because of inadequate water availability.



4. Heat Stress

El Nino is generally associated with higher-than-normal temperatures across many parts of India. Excessive heat accelerates crop maturity, reducing the duration available for grain development and lowering grain weight. High temperatures also increase evapotranspiration, causing rapid loss of soil moisture and increasing irrigation requirements. Heat stress may reduce pollen viability, flowering success, fruit setting, and overall crop productivity.

5. Increased Pest and Disease Incidence

Changes in temperature, humidity, and rainfall patterns during El Nino create favourable conditions for the multiplication of insects, weeds, and plant pathogens. Farmers may experience higher incidences of stem borers, aphids, whiteflies, fall armyworm, fungal diseases, and viral infections depending on the crop and region. Increased pest and disease pressure raises production costs due to greater dependence on pesticides and crop protection measures.

6. Livestock Stress

Livestock production is also adversely affected during El Nino years. Reduced rainfall limits the availability of green fodder and drinking water, while high temperatures cause heat stress in animals. Dairy cattle and buffaloes often produce less milk, and reproductive efficiency may decline. Poor pasture growth and reduced fodder quality further affect the health and productivity of livestock, increasing the economic burden on farming households.

7. Economic Losses

The combined effects of reduced crop yields, water shortages, and livestock stress lead to substantial economic losses for farmers. Lower production decreases farm income and may increase indebtedness, particularly among small and marginal farmers. At the national level, reduced agricultural output can increase food prices, create market instability, affect agro-based industries, and pose challenges to food and nutritional security. Governments may also face higher expenditure on drought relief, crop insurance claims, and agricultural support programs.

MAJOR CROPS MOST VULNERABLE TO EL NINO

The impact of El Nino is most severe on crops that depend heavily on timely and adequate monsoon rainfall. Reduced precipitation, prolonged dry spells, high temperatures, and water scarcity during El Nino years adversely affect crop growth, productivity, and quality. Rainfed farming systems are particularly vulnerable because they rely almost entirely on natural rainfall. The major

crops affected are discussed below.

1. Rice

Rice is one of India's most important staple food crops and is highly dependent on monsoon rainfall, particularly in eastern and central India. Delayed monsoon onset and inadequate rainfall reduce transplanting, poor crop establishment, and lower tiller formation. Water stress during flowering and grain-filling stages

significantly decreases grain yield and quality. In severe drought years, farmers may be forced to shift to short-duration or drought-tolerant rice varieties.

2. Maize

Maize requires adequate soil moisture during germination, tasseling, silking, and grain-filling stages. El Nino-induced moisture stress reduces plant height, kernel formation, and grain weight. High temperatures during pollination can reduce fertilization, resulting in poor cob development and substantial yield losses.

3. Soybean

Soybean is mainly cultivated during the Kharif season and depends heavily on monsoon rainfall. Delayed sowing caused by insufficient rainfall reduces crop duration and vegetative growth. Moisture stress during flowering and pod formation leads to flower drop, poor seed filling, and lower oil content, ultimately reducing productivity.

4. Groundnut

Groundnut is highly sensitive to both drought and excessive heat. Water shortage during flowering, pegging, and pod development significantly reduces pod formation and seed development. Poor rainfall also lowers oil recovery and seed quality, directly affecting farmers' income.

5. Cotton

Cotton is relatively drought-tolerant compared to some other crops, but

prolonged dry spells during El Nino reduce boll formation, fibre quality, and lint yield. Heat stress and moisture deficiency also increase the incidence of pests such as whiteflies and pink bollworms, leading to higher crop protection costs.

6. Sugarcane

Sugarcane is a long-duration crop requiring a continuous supply of water throughout its growth period. During El Nino years, reduced irrigation water and high temperatures limit cane growth, decrease cane weight, and reduce sugar recovery. Water shortages may also delay planting and ratoon crop management.

7. Pulses

Major pulse crops such as pigeon pea, black gram, green gram, chickpea, and lentil are adversely affected by moisture stress during flowering and pod development. Drought conditions reduce pod formation, seed size, and grain yield. Since pulses contribute significantly to nutritional security, reduced production may increase market prices.

8. Oilseed Crops

Oilseed crops such as mustard, sesame, sunflower, safflower, and rapeseed are also vulnerable to irregular rainfall and high temperatures. Moisture stress reduces flowering, seed filling, and oil accumulation, leading to lower seed yield and poor oil quality. Production losses in oilseeds increase dependence on edible oil imports.

RAINFED REGIONS MOST VULNERABLE

Rainfed agricultural regions are the most severely affected during El Nino years because they rely almost entirely

on seasonal rainfall for crop production. These areas often have limited irrigation facilities and are highly exposed to

drought conditions.

The most vulnerable regions include:

- Central India: Madhya Pradesh, Chhattisgarh, and parts of Maharashtra.
- Western India: Rajasthan and Gujarat.
- Southern India: Karnataka, Telangana, Andhra Pradesh, and Tamil Nadu.
- Eastern Plateau and Dryland Regions: Parts of Odisha and Jharkhand.

In these regions, delayed monsoon onset, prolonged dry spells, and early monsoon withdrawal frequently result in poor crop establishment, reduced yields, livestock feed shortages, groundwater depletion, and economic losses for farming households. Small and marginal farmers are particularly vulnerable because they have limited financial resources, fewer irrigation facilities, and lower capacity to cope with climate-related risks.

STRATEGIES TO TACKLE EL NINO-INDUCED CHALLENGES

1. Climate-Smart Agriculture

Farmers should adopt climate-resilient farming practices that improve productivity while conserving natural resources.

2. Crop Diversification

Growing drought-tolerant cereals, pulses, oilseeds, and millets reduces production risks and ensures income stability.

3. Drought-Tolerant Varieties

Agricultural universities and ICAR institutes have developed drought-resistant crop varieties that perform better under moisture stress.

4. Efficient Water Management

- Drip irrigation
- Sprinkler irrigation
- Rainwater harvesting
- Farm ponds
- Mulching
- Laser land levelling

These technologies improve water-use efficiency.

5. Improved Soil Health

Application of organic manure, compost, green manure, biofertilizers, and crop

residue management enhances soil moisture retention.

6. Weather-Based Agro-Advisories

Farmers should regularly access weather forecasts and advisories through:

- IMD weather forecasts
- Kisan Suvidha App
- mKisan Portal
- Kisan Call Centre
- Krishi Vigyan Kendras (KVKs)
- WhatsApp advisory groups

Timely information helps farmers make informed decisions.

7. Integrated Pest Management (IPM)

Regular crop monitoring, biological control agents, resistant varieties, and need-based pesticide application reduce pest damage.

8. Crop Insurance

Enrol under the Pradhan Mantri Fasal Bima Yojana (PMFBY) provides financial protection against climatic losses.

9. Integrated Farming System (IFS)

Combining crops with dairy, poultry, fisheries, goat rearing, horticulture, and agroforestry diversifies income and minimizes climate risks.

10.Capacity Building

Regular farmer training, demonstrations, exposure visits, and digital literacy programmes improve climate resilience.

Government Initiatives Supporting Climate-Resilient Agriculture

Several initiatives are helping Indian agriculture adapt to climate variability:

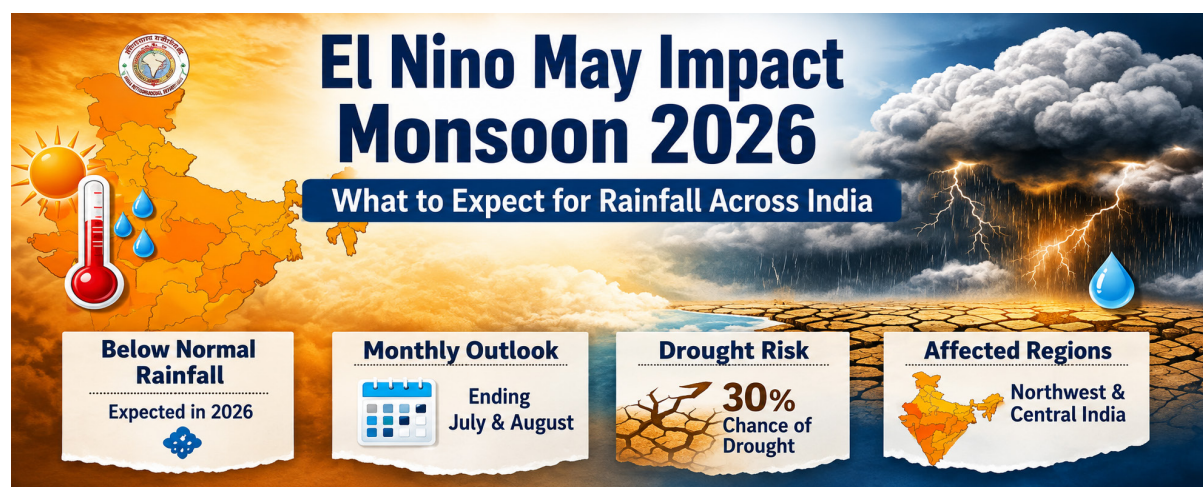
- National Mission for Sustainable Agriculture (NMSA)
- National Kharif Preparedness and District-Level Contingency Planning
- Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)
- Pradhan Mantri Fasal Bima Yojana (PMFBY)
- Soil Health Card Scheme
- National Innovations on Climate Resilient Agriculture (NICRA)
- Digital Agriculture Mission
- Krushi Vigyan Kendras (KVKs)

Future Challenges

In the coming decades, Indian agriculture may face:

- More frequent heat waves
- Erratic rainfall patterns
- Water scarcity
- Groundwater depletion
- Soil degradation
- Emerging pests and diseases
- Rising production costs
- Labour shortages
- Market uncertainty

Addressing these challenges will require scientific innovations, policy support, digital technologies, and strong extension services.



CONCLUSION

El Nino poses a significant challenge to Indian agriculture by influencing monsoon behaviour, water availability, and crop productivity. However, its adverse impacts can be minimized through climate-smart agriculture, efficient water management, crop diversification, weather-based advisory services, and integrated farming systems. Strengthening farmers' resilience through scientific knowledge, digital technologies, and supportive government policies will be essential for securing the future of Indian agriculture in an era of increasing climate uncertainty.

WHEAT BIOFORTIFICATION TO COMBAT FROM MALNUTRITION

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INTRODUCTION

Wheat is a major global crop, supplying ~20% of calories and 55% of carbohydrates. Hexaploid bread wheat accounts for ~95% of cultivation, with durum wheat comprising ~5%. In 2016, wheat covered 223.67 Mha and produced 735.3 Mt, with India contributing 108 Mt from 30 Mha. Nutritionally, wheat grain consists of bran (13–17%), endosperm (80–85%), and germ (2–3%), providing fiber, proteins, vitamins, minerals, and amino acids essential for health. Despite the productivity gains of the Green Revolution, intensive farming reduced nutritional quality, heightening concerns as the global population is projected to reach 9.8 billion by 2050. Deficiencies in zinc and iron are particularly critical, contributing to malnutrition and disease, with hidden hunger affecting over two billion people worldwide. In India, undernutrition remains severe, ranking 101st of 116 nations in the 2021 Global Hunger Index. The India Biofortification Program, launched in 2007 with HarvestPlus and DBT, aims to address these challenges. Biofortification offers a sustainable solution by enhancing Fe, Zn, Se, and Cu concentrations in wheat and other staples. This framework examines genetic variability, uptake mechanisms, and biofortification strategies—including conventional breeding, transgenesis, molecular breeding, metabolic engineering, and genome editing—while highlighting emerging challenges and opportunities for improving nutrition security.

Improvement in daily intake of micronutrients by biofortified wheat

Excessive dependence on conventional wheat products contributes to micronutrient malnutrition due to their low levels of iron (Fe), zinc (Zn), selenium (Se), and copper (Cu), alongside anti-nutritional factors that reduce bioavailability. The aleurone layer, rich in micronutrients, is typically removed during milling, diminishing nutritional quality. Retaining this layer could alleviate deficiencies, yet the broader challenge lies in enhancing both concentration and bioavailability of grain nutrients. Adult dietary requirements—10–15 mg Fe, 9–15 mg Zn, 0.055 mg Se, and 1.0–1.6 mg Cu per day—underscore the need for targeted nutritional improvement. Biofortification offers a sustainable strategy to enrich staple crops, with wheat being central given its global consumption in diverse foods such as bread, chapatti, pasta, and cereals. Developing and mainstreaming biofortified wheat represents a critical pathway to combat hidden hunger, improve public health, and provide nutritionally superior alternatives to conventional products.



BIOFORTIFICATION METHODS

The advanced and traditional methods of biofortification are discussed in this section. Figure 2 represents the graphical illustration of methods of biofortification.

Genetic engineering approaches for biofortification

Transgenic approaches, involving the insertion of novel genetic information into plant genomes, provide an effective strategy for biofortification. These methods enable targeted enhancement of micronutrients in crops that naturally lack sufficient levels. By modifying metabolic pathways, they increase nutrient concentrations, upregulate promoter compounds, and reduce anti-nutritional factors, thereby improving bioavailability. Gene characterization and functional identification are central to this process, alongside redistribution of nutrients to edible tissues and optimization of biochemical pathways for efficient accumulation. Although resource-intensive, transgenic techniques remain sustainable long-term solutions to micronutrient deficiencies. Their successful application across diverse crops—including sorghum, beans, oilseeds, maize, pulses, barley, fruits, vegetables, rice, and lupines—demonstrates their potential to strengthen global nutrition security through enriched staple foods.

Transgenic biofortification

Conventional breeding for biofortification is limited when genetic diversity is scarce, as breeding relies on existing variation. Genetic engineering addresses

this constraint by introducing novel genes, enabling targeted nutritional enhancement in crops such as rice and bananas. This approach integrates biotechnology with breeding principles to improve micronutrient concentration, transport, and absorption while reducing anti-nutritional factors. Microbial genes are pivotal: fluorescent *Pseudomonas* enhance iron uptake, while mycorrhizal fungi and rhizobacteria improve nutrient absorption. In wheat and rice, bacterial and fungal genes have modified phytate and lysine content, raising nutritional quality. Such interventions expand biofortification beyond natural diversity, allowing precise, cross-species gene transfers from bacteria, fungi, and other organisms. While traditional breeding remains effective for crops with sufficient variability, genetic engineering provides indispensable solutions for nutritionally critical species, positioning it as a cornerstone in combating hidden hunger and global malnutrition.



Genome editing

Genome editing enables precise modification, addition, or removal of DNA sequences across species, offering biofortification without foreign transgenes and addressing regulatory concerns. Techniques such as TALENs, meganucleases, ZFNs, and especially CRISPR/Cas9 valued for accuracy, adaptability, and affordability have been applied to enrich wheat with zinc and β -carotene and improve rice genotypes, though off-target effects remain a challenge. Refinements in nuclease specificity aim to mitigate these risks. Notable successes include Golden Rice, which increased β -carotene levels through overexpression of phytoene synthase and carotene desaturase, and cassava roots, which achieved a 37-fold rise in iron via the *Arabidopsis thaliana* vacuolar iron transporter VIT1. Genome editing thus expands biofortification beyond natural genetic limits, enabling targeted nutritional enhancement while preserving crop integrity. Its ability to avoid transgene introduction enhances public acceptance, positioning genome editing as a sustainable and powerful tool against hidden hunger and global malnutrition.

Conventional biofortification

Conventional breeding remains the most widely adopted and cost effective biofortification strategy, offering practical and reliable enhancement of crop nutrition compared to transgenic methods. It involves crossing nutrient rich genotypes with agronomically desirable varieties to produce lines combining improved nutritional quality with strong yield traits. Notable examples

include orange fleshed sweet potatoes enriched with provitamin A, quality protein maize, provitamin A cassava, iron biofortified beans, and zinc fortified wheat cultivars such as Akbar 2019 and Zincol. Statistically, conventional breeding has released more biofortified varieties than transgenic approaches, with cereals accounting for 58.1%, vegetables 19.8%, legumes 13.2%, and fruits 9%. Advances in genomic selection, marker assisted breeding, and QTL identification have further expanded its scope, exemplified by zinc biofortification in rice. Large scale initiatives such as HarvestPlus, BioCassava Plus, and the EU Health Grain Project have driven these achievements. Collectively, conventional breeding remains a cornerstone of biofortification, delivering scalable and sustainable solutions to combat hidden hunger.

Agronomic biofortification

Agronomic biofortification, or ferti fortification, enhances crop nutrition by supplying mineral fertilisers through soil or foliar application. It mobilises elements within plants, improving translocation to source and sink organs, and is particularly effective in cereals when combined with organic amendments. Foliar feeding delivers minerals in highly phytoavailable forms but is less effective under adverse weather. Microbe mediated approaches, such as inoculation with *Bacillus altitudinis* and *Talaromyces flavus*, have shown significant improvements in zinc accumulation, growth, and yield. While agronomic biofortification provides a rapid, short term solution, its reliance on repeated seasonal application limits sustainability. Integration with organic fertilisers, microbial inoculants, and advanced fertiliser technologies can

improve efficiency, but long term resilience requires combining agronomic methods with genetic and breeding based biofortification to strengthen food systems and global nutrition security.

Application Method	Crop	Nutrient	Level of Biofortification (%)	Nutrient Dose
Foliar application	Rice	Zinc	25	0.5%
	Rice	Iron	8	0.5%
	Rice	Selenium	300	0.005%
	Rice	Iodine	1754	0.05%
	Rice	Iodine	1450	0.05%
	Wheat	Zinc	21	0.5–1.0%
	Wheat	Zinc	63	25–50%
	Wheat	Iron	22	10 kg ha ⁻¹
	Wheat	Copper	47	2.80–10.30%
	Corn	Zinc	55	0.1–0.2%
	Eggplant	Iron	49	0.26%
	Eggplant	Manganese	47	0.27%
	Mungbean	Iron	87	0.26%
	Fodder	Selenium	6	0.01–0.1 mg
	Rice	Zinc	7	2–10 kg ha ⁻¹
	Wheat	Zinc	32	10–30 kg ha ⁻¹
	Chickpea	Zinc	6	0.5%
	Coriander	Zinc & Iron	423	0.5 & 0.3%
Soil-less cultivation	Rice	Iron	51	2–7 ppm
	Bean	Iron	35	40–80 ppm
	Lettuce	Iron	20–54	20–50 µM
Soil application	Wheat	Iron	25	1%
	Potato	Zinc	40	5–20 kg ha ⁻¹
	Barley	Copper	35	2–10 ppm
	Spinach	Iodine	30	10–100 µg kg ⁻¹

Application techniques and fortification levels achieved for numerous mineral micronutrients in different crops

CONCLUSIONS

Biofortification is a key strategy to combat micronutrient malnutrition, especially in regions lacking diverse diets. It enhances staple crops through three main approaches: conventional breeding, genetic engineering, and agronomic interventions. Conventional breeding has improved nutrient levels in crops like wheat, beans, and rice but is time intensive. Genetic engineering enables precise nutrient enrichment, though regulatory, financial, and public acceptance challenges limit adoption. Agronomic biofortification via soil and foliar fertilisation offers rapid solutions but requires repeated seasonal application, reducing sustainability. Effective programs demand collaboration among breeders, engineers, agronomists, and nutritionists, alongside policy support and public awareness. Integrating modern biotechnology with conventional breeding holds strong promise for addressing hidden hunger and advancing global nutrition security, paving the way for a healthier and more resilient future.





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