Agricultural Engineering TODAY

ISAE

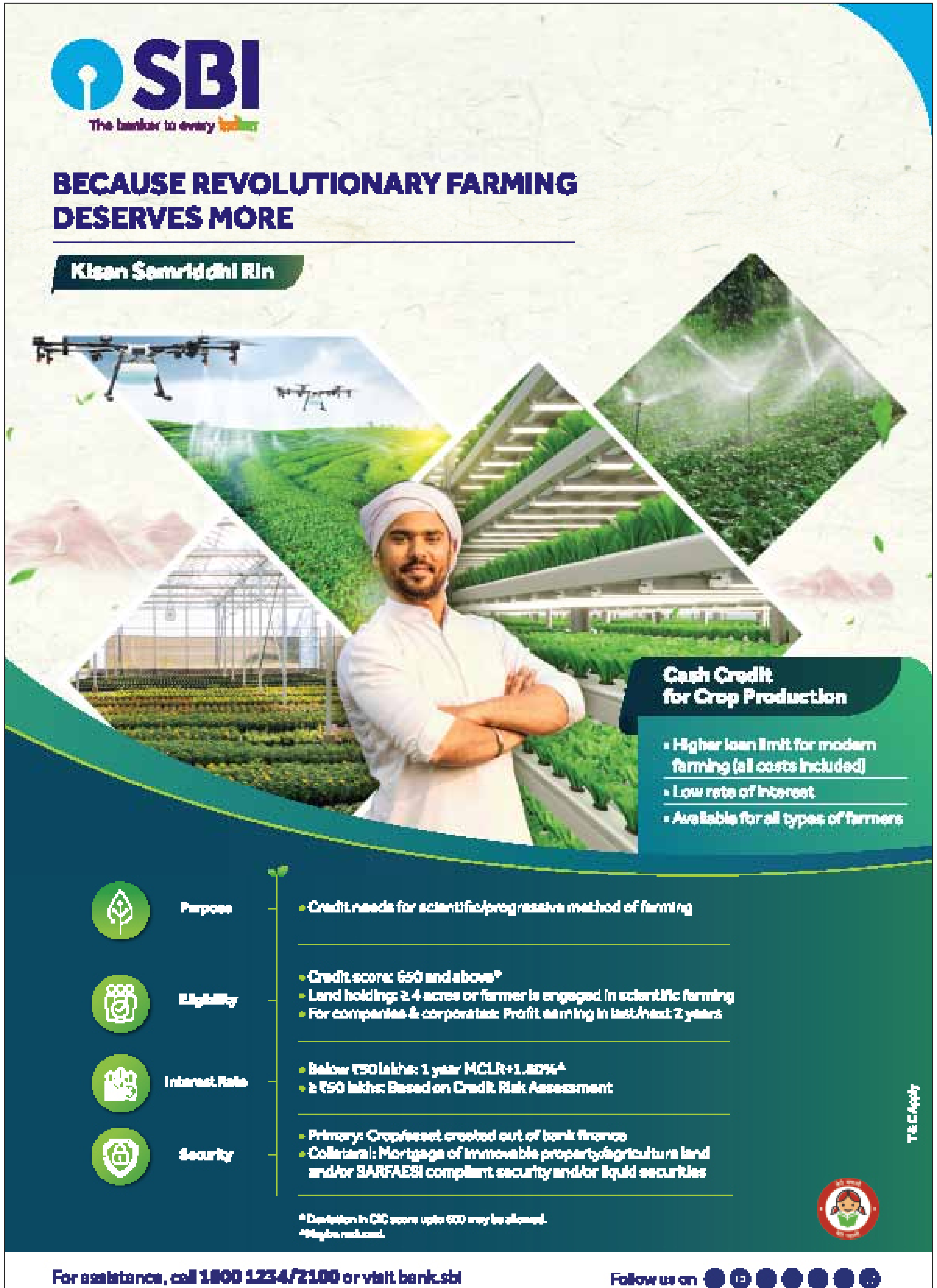
ISSN (Print): 0970-2962 | ISSN (Online): 2230-7265 | Vol. 50, No. 1 | January - March 2026

www.isae.in

Harnessing the Power of Technology

INDIAN SOCIETY OF AGRICULTURAL ENGINEERS

...Connecting Engineers in Agriculture



From the
Editor-in-Chief

Harnessing the Power of Technology

The global food system faces a daunting paradox: it must increase production by nearly 70% to feed the projected 2050 population while simultaneously reducing its environmental footprint. Harnessing Agricultural Technology (AgTech) is no longer a luxury; it is the primary mechanism for achieving this 'sustainable intensification'.

Precision Agriculture: The 'Less is More' Approach

At the heart of sustainable AgTech is Precision Agriculture. By utilizing GPS, IoT sensors, and satellite imagery, farmers can transition from uniform field management to site-specific care. Instead of blanket-spraying a whole farm, AI-driven sprayers identify and target individual weeds, reducing herbicide use by up to 90%.

• Soil Sensors: Monitor moisture and nutrient levels in real-time to prevent water wastage and fertilizer runoff.

• Variable Rate Technology (VRT): Automatically adjusts the amount of seed or fertilizer applied based on the specific needs of a soil patch.

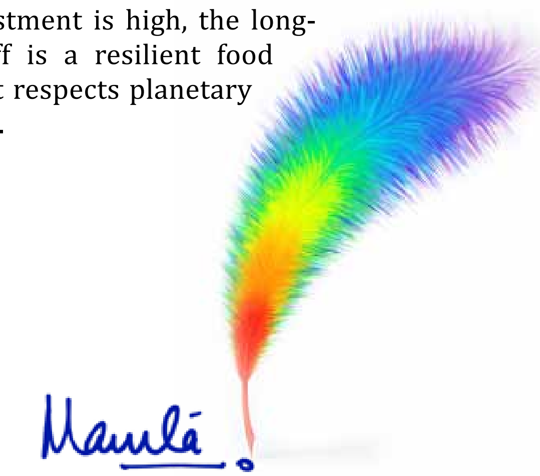
Controlled Environment Agriculture (CEA)

To protect biodiversity, we must stop expanding farmland into forests. Vertical farming and hydroponics allow us to grow 'up' instead of 'out'. These systems use 95% less water than traditional farming and eliminate the need for chemical pesticides by operating in sterile, indoor environments. This decoupled approach brings food production to urban centers, drastically cutting 'food miles' and CO2 emissions from transportation.

Biotechnology and Data

Beyond hardware, the "software" of plants is being upgraded. Advanced gene-editing (like CRISPR) creates drought-resistant and nitrogen-efficient crops. When paired with Big Data analytics, farmers can predict pest outbreaks or climate shifts before they happen, moving from reactive 'crisis management' to proactive stewardship.

The integration of these technologies creates a circular agricultural economy where waste is minimized, and soil health is restored. While the initial investment is high, the long-term payoff is a resilient food system that respects planetary boundaries.



Publication Enquiries

Agricultural Engineering Today is a publication of the Indian Society of Agricultural Engineers
(Tel.: 011-21520143; E-mail: isae1960@gmail.com; Website: www.isae.in)

All communications regarding this publication should be addressed to:

Editor-in-Chief (AET), Indian Society of Agricultural Engineers, G-4, A-Block (GF), National Societies Block, National Agricultural Science Centre (NASC) Complex, Dev Prakash Shastri Marg, Pusa Campus, New Delhi - 110012, India
E-mail: chiefeditoraet@isae.in

The opinions expressed by the authors are not necessarily those of Agricultural Engineering Today or ISAE.

Subscription Details

	Inland	Foreign
Annual subscription	Rs. 3000.00	US$ 550.00
Per copy	Rs. 900.00	US$ 200.00
Additional postage & handling charges		
Full year	Rs. 200.00	US$ 50.00
One copy	Rs. 75.00	US$ 25.00

For payment, cheque/draft including bank charges may be drawn in favour of "Indian Society of Agricultural Engineers" payable at New Delhi and sent to Secretary General, "INDIAN SOCIETY OF AGRICULTURAL ENGINEERS", G-4, A-Block (GF), National Societies Block, National Agricultural Science Centre (NASC) Complex, Dev Prakash Shastri Marg, Pusa Campus, New Delhi - 110012, India

Printed at New United Process, A-26, Naraina Industrial Area, Phase II, New Delhi - 110028, Mob: 9811426024

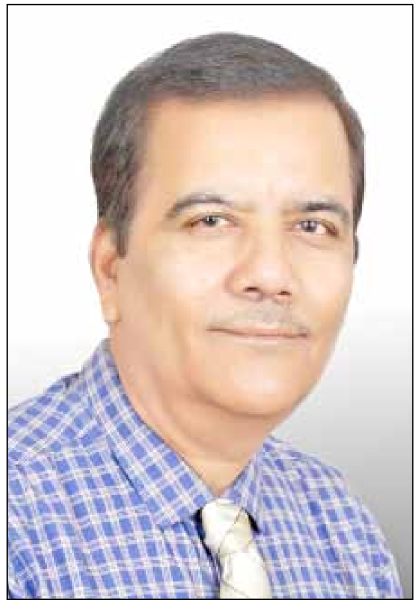
CONTENT

AGRICULTURAL ENGINEERING TODAY 50 (1)

Harnessing the Power of Agricultural Technologies for Sustainability

Dr. S. N. Jha
President, ISAE & DDG (Agricultural Engineering), ICAR

The global agricultural sector nowadays faces a dual challenge: feeding a population projected to reach nearly 10 billion by 2050 while drastically reducing its environmental footprint. Agriculture currently consumes approximately 70% of the world's freshwater and is responsible for roughly 30% of global energy consumption and 22–37% of greenhouse gas (GHG) emissions. India is now in centre stage and has in such scenario to play a pivotal role in fulfilling the gigantic task of keeping the world with full stomach. Harnessing modern agricultural technologies - ranging from precision farming and the Internet of Things (IoT) to advanced biotechnology - is no longer optional but a critical necessity for achieving long-term sustainability.



THE PILLARS OF SUSTAINABLE AGRICULTURAL TECHNOLOGY

Sustainable agriculture integrates three core dimensions: environmental health, economic profitability, and social equity. Reducing trend of farmers in using traditional technologies and climate change further complicate the situations. Modern technologies address these through several key innovations:

- **Precision Agriculture (PA):** Often called "smart farming," PA uses GPS, sensors, and data analytics to apply the right input (water, fertilizer, or pesticide) at the right time and at right place (Fig 1).
  - **Resource Efficiency:** Precision application can reduce fertilizer and pesticide use by 10–20% and water use efficiencies by 4–7%.
  - **Soil Health:** Targeted spraying and controlled machinery traffic reduce chemical runoff and soil compaction.
- **Internet of Things (IoT) and Real-Time Monitoring:** Interconnected sensors provide continuous data on soil moisture, pH, temperature, and nutrient levels, crop health, quality of harvests and their management.
  - This data-driven approach replaces traditional blanket treatments with site-specific management, allowing farmers to respond proactively to environmental threats like drought or pest infestations.

https://doi.org/10.52151/aet2026501.1890

Fig 1: Variable-Rate Technology for Precision Farming

- **Agricultural Biotechnology:** Bio-tech facilitates the development of drought-tolerant and heat-resistant varieties, vital for adapting to a warming planet. Techniques such as CRISPR gene editing and marker-assisted selection create crops that are inherently more resilient. Application of artificial intelligences, robotics in this fields will help in achieving accuracy and accelerate the varietal development process.
  - **Reduced Chemical Dependency:** Engineered pest-resistant crops (e.g., Bt Cotton) significantly lower the need for synthetic insecticides.

TECHNOLOGICAL INNOVATIONS IN ACTION

Beyond the field, technology is revolutionizing the entire supply chain and alternative production, processing and supply chain methods as below (Fig. 2):

- **Vertical Farming and Controlled Environment Agriculture (CEA):** By stacking crops in layers and using LED lighting, automated environment controlled agriculture, and vertical farms can produce food in urban centers with up to 95% less water and almost no pesticides.
- **Robotics and Automation:** Autonomous tractors and weeding robots reduce labour costs and eliminate manual exposure to hazardous chemicals. It provides more comforts to farmers and other stake holders from field preparations to storage, processing and supply chain management including marketing.
- **Blockchain for Traceability:** It creates immutable records of a product›s journey from farm to consumer, verifying sustainability claims and improving food safety response times.
- **Renewable Energy Integration:** Solar-powered irrigation and biomass energy reduce the carbon footprint of farm operations and India is progressing much better than many developing/developed countries.

ECONOMIC AND SOCIAL IMPACT

Technological adoption is a major driver of "Agricultural Value-Added" (AGRIVA), showing a strong positive correlation between mechanization/irrigation infrastructure and economic growth. For farmers, these tools offer:

- **Increased Profitability:** Studies suggest AI and precision agriculture

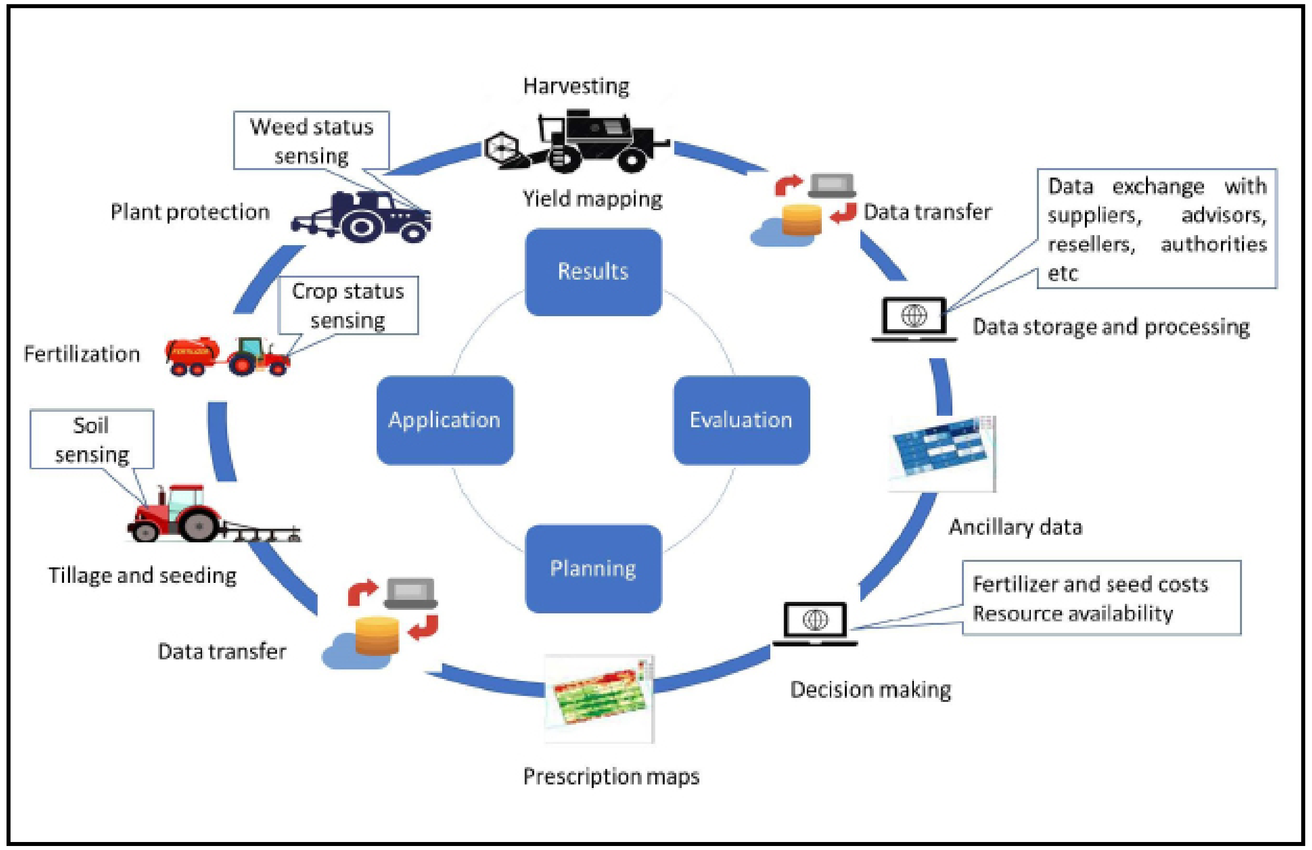


Fig 2: Technology for entire supply chain

could cut global operating costs by over 22% annually while increasing yields by roughly 4%.

- **Improved Quality of Life:** Automation reduces the physical burden of labour and the mental stress of managing unpredictable variables.
- **Empowering Smallholders:** Digital marketplaces enable small-scale farmers to bypass middlemen and access global buyers directly, ensuring fairer pricing.

CHALLENGES AND FUTURE PERSPECTIVES

Despite the potential, significant barriers remain to widespread adoption:

- **High Initial Costs:** Advanced machinery and sensor networks require substantial upfront investment, often out of reach for smallholder farmers without government subsidies or loan programs.
- **The Digital Divide:** Reliable internet connectivity and technical expertise are still lacking in many rural and developing regions. Deployment of trained Agricultural Engineers in sufficient numbers at village/panchayat, block and districts levels is better sooner than later.
- **Public Perception:** Perceptions of farmers and consumers are of paramount importance. Use of high-tech while requires urgently for sustainability, doubts surrounding such technologies, data privacy are slowing down the consumer acceptance of modern technologies.

The future of sustainable agriculture hinges on a holistic strategy that combines high-tech innovations with social responsibility. Transitioning from Agriculture 4.0 (precision) to Agriculture 5.0 (autonomous, AI-driven) will require collaboration between governments, tech firms, and the farming community to ensure that these powerful tools are accessible, equitable, and truly restorative for the planet.

Agricultural Technologies for Sustainability

Dr. T. Janakiram[1] and Dr. S. Vijay Rakesh Reddy[2]

1Former Vice-chancellor, Dr. YSRHU, A.P.; #180, SFS-208, 4th Main Road, 4th Stage, Yelahanka New Town, Bengaluru, Karnataka (ushajanaki2023@gmail.com).
2Senior Scientist, Division of PHT&AE, ICAR-IIHR, Hesaraghatta Lake Post, Bengaluru- 560 089, Karnataka (drrakesh.reddyiihr@gmail.com).

Agricultural technology is revolutionizing farming by boosting productivity while minimizing environmental harm, drawing from cutting-edge research in precision tools, biotech, and AI. Recent studies highlight how these innovations can cut resource waste and enhance sustainability amid climate challenges. Currently, the global agricultural sector is undergoing a profound paradigm shift. Faced with the dual pressure of feeding a projected population of 10 billion by 2050 and the accelerating impacts of climate change, the industry has moved beyond simple mechanization. Today, the focus is on intelligent, autonomous, and regenerative systems that treat the farm not just as a factory, but as a complex ecosystem.

KEY TECHNOLOGIES CONTRIBUTING FOR SUSTAINABILITY

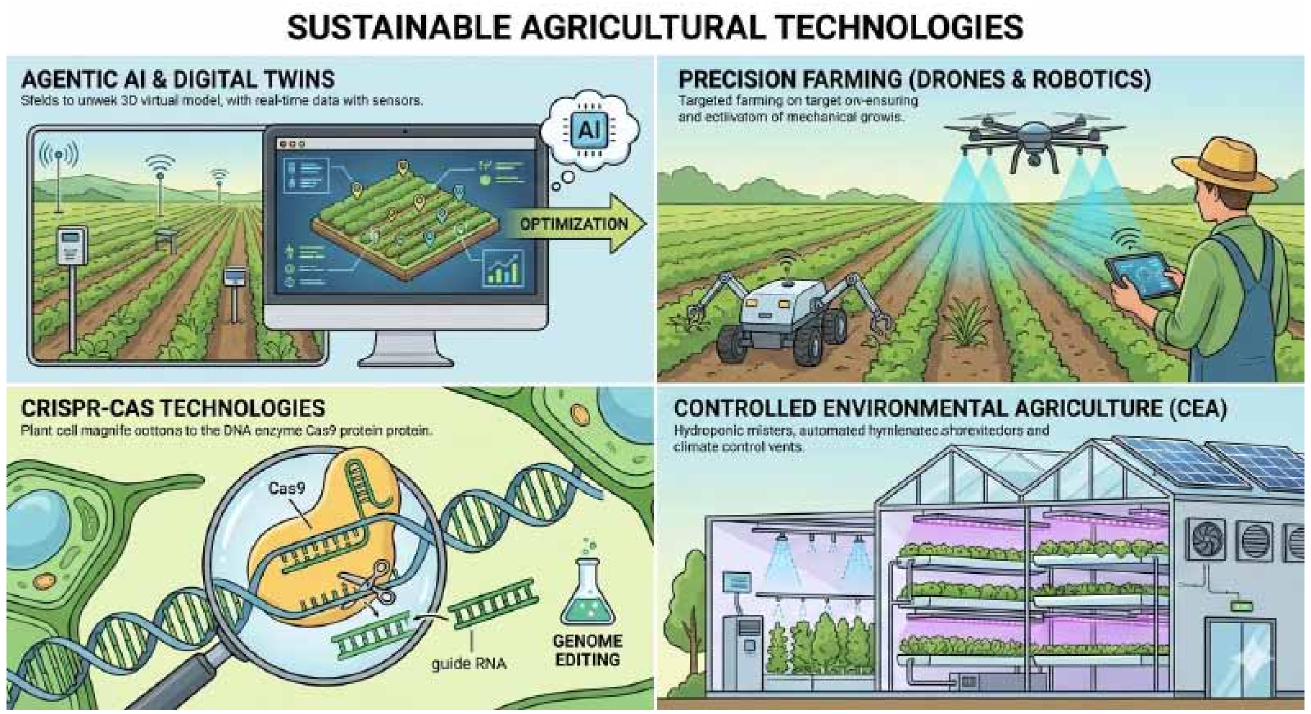
Modern agri-tech includes precision agriculture using GPS, drones, and IoT sensors, which boosts yields by 20-30% and reduces input waste like fertilizers by 40-60%. Biotechnology such as CRISPR-edited crops improves drought resistance and cuts pesticide use, as seen with Bt cotton reducing applications by 50% in India. Smart irrigation and AI analytics optimize water use by 40-60% and predict issues with over 90% accuracy.

1. The Rise of Agentic AI and Digital Twins

One of the most significant breakthroughs in 2025-2026 is the transition from predictive AI to Agentic AI. Unlike previous models that merely suggested actions, Agentic AI uses hierarchical frameworks where sub-agents independently manage irrigation, pest control, and fertilization, all aligned under a central "Digital Twin" of the farm.

Digital Twins are virtual replicas of physical farms that integrate real-time data from IoT sensors, satellite imagery, and weather APIs. They allow farmers to perform "what-if" analyses, simulating how a specific crop might respond to varied irrigation or nutrient levels before a single drop of water is spent. To support these AI models in remote areas with poor connectivity, xDTs (lightweight digital twins) are now deployed on edge devices like drones

https://doi.org/10.52151/aet2026501.1891



and autonomous sensors, enabling instant, offline decision-making.

2. **Precision Autonomy with Drones and Robotics**

Robotics has evolved from experimental prototypes to field-ready laborers. The automation of "delicate" tasks is a major focus for 2026, particularly in perennial crops and horticulture. Large-scale autonomous electric drones, such as the Guardian Agriculture SC1, are now replacing traditional crop-dusting planes. These drones carry up to 200 pounds of payload and use precision guidance to eliminate chemical drift, reducing pesticide use by up to 30%. Research into soft robotics and advanced computer vision has enabled machines to perform tasks like selective pruning and fruit harvesting without damaging the produce.

3. **Next-Generation Agricultural Biotechnology**

Biotechnology is moving toward "nature-positive" solutions that reduce reliance on synthetic chemicals. In 2025, the introduction of hypercompact CRISPR-Cas12j-8 nucleases significantly enhanced gene-editing efficiency in staple crops like rice and soybean. Furthermore, CRISPR-GPT, an AI system, now automates the design of gene-editing workflows. Synthetic biology is being used to engineer endophytic microbes. These microbes live inside plant tissues and produce phytohormones or insecticidal peptides on demand, acting as dynamic, "living" fertilizers that adapt to the crop's real-time needs.

4. **Regenerative Tech and Carbon Utilization**

Sustainability is increasingly being measured by Measurement, Reporting, and Verification (MRV) technologies. These tools track soil carbon sequestration with high precision, allowing farmers to monetize their sustainable practices through carbon credit markets. Beyond storage, technologies are advancing in carbon utilization. Biochar, produced from organic waste, locks carbon in the soil for centuries while enhancing fertility. IoT-based soil monitors now provide real-time data on microbial diversity and soil carbon, moving the focus from "yield at any cost" to "restoration as a service".

5. **Controlled Environment Agriculture (CEA)**

Vertical farming and hydroponics continue to expand, particularly in urbanized or water-stressed regions. By 2025, aeroponic systems have demonstrated the ability to use 90-95% less water than traditional field production. Despite their efficiency, vertical farms remain 4–10x more energy-intensive than traditional greenhouses. The integration of renewable energy and high-efficiency LEDs is critical for their long-term viability.

ENVIRONMENTAL BENEFITS

These technologies lower greenhouse gas emissions and preserve biodiversity through regenerative practices and renewable energy integration. Precision farming cuts herbicide/pesticide use by 9%, fossil fuels by 6%, and water usage by 4%, while improving soil quality. Nanotechnology and vertical farming further slash land and water needs by up to 95%, supporting circular economies.

ECONOMIC AND SOCIAL IMPACTS

Adoption enhances farmer incomes via cost savings and premium markets for sustainable produce, with precision tools yielding 4% higher production. In developing regions, IoT aids smallholders in organic transitions, measuring carbon reductions and boosting equity. Books like "Agricultural Sustainability through Nanotechnology" emphasize resource efficiency for global scalability.

CONCLUSION

The future of sustainable agriculture lies in the convergence of these technologies. By 2026, the most successful farming operations are those that integrate AI-driven insights, CRISPR-enhanced resilience, and regenerative soil management into a single, data-driven workflow.

For chilli farmers of Ariyandipuram in Tamil Nadu, Syngenta's hot experiment bears sweet fruit

Solar dryers deployed for chilli drying reducing 10 days work to 2 days

Susheel Kumar
Managing Director, Syngenta India

India red hot chillies need no further introduction. They have not just conquered the global spice market by their taste but also with the global export numbers, with India being the leading exporter. Over decades, farmers have relied upon the Sun God for drying this spice that gives it vibrant sheen, a color directly linked to their pungency and market value. However, what lies beneath this sight of red chillies laid out on open roads or courtyards is a persistent dependency, one that ties farmer incomes to the unpredictability of weather.

Drying chillies in open conditions exposes them to rain, wind, and contamination from dust or animals. In an economy where quality translates into price, such losses can be devastating. The traditional process, though deeply rooted in experience, demands constant labor, supervision, and patience, often stretching to ten days for a single drying cycle.

A SIMPLE, SUSTAINABLE INTERVENTION

At Syngenta India, our constant endeavor has been to bridge such

gaps, to modernize age-old practices with simple, scalable, and sustainable interventions. The **Solar Dryer Facility** established in Ariyandipuram, Tamil Nadu, in partnership with Hand in Hand India, embodies this philosophy.
The 180-square-feet solar drying yard was built at a cost of Rs.13 lakh (around $15,000) to serve members of the **Lower Vaigai Ilayangudi Farmer Producer Organization (FPO)**. The facility creates a controlled, solar-powered environment that accelerates the drying process while protecting produce from external elements.

It may look modest, resembling a greenhouse built of transparent panels and metal framing, yet its impact has been transformative. What once took up to ten days can now be achieved in just two to three. This fivefold increase in efficiency not only reduces labor and post-harvest losses but also allows farmers to bring their produce to market more quickly, maintaining the deep red color and pungency that buyers seek.

What makes this initiative particularly significant is not just the technology, but the model behind it. The solar dryer is owned and managed collectively by the Farmer Producer Organization. Members pay a nominal usage fee, which goes toward maintenance and upkeep, ensuring both ownership and sustainability.

https://doi.org/10.52151/aet2026501.1892

Such community-led models reinforce self-reliance and accountability while democratizing access to innovation. When smallholders take charge of technology, the benefits extend beyond individual gains to collective prosperity. Faster drying of the hot peppers means shorter turnaround times between harvest and sale. Better-quality produce fetches better prices. Reduced dependence on weather provides greater stability.

These improvements may seem incremental, but together they form a powerful foundation for **resilient agriculture**, one that empowers farmers to adapt to changing climatic conditions and fluctuating markets with confidence.

THE BROADER CONTEXT: CHILLI AS AN ECONOMIC CROP

India is one of the world's largest producers and exporters of chillies. Globally, the dry chilli market was valued at **$6.31 billion in 2024**, and it is expected to grow to **$7.82 billion by 2030**, driven by rising demand for high-quality, sustainably produced spices.

However, the post-harvest stage has historically been a weak link in this value chain. Inadequate drying, improper storage, and inconsistent processing have often limited farmers from realizing the full potential of their crop.

By introducing scientific drying systems like the solar facility in Ariyandipuram, we are not just improving the quality of a commodity, we are enhancing the efficiency of an entire ecosystem. Properly dried chillies retain their color, aroma, and integrity for longer periods. They weigh less, occupy less space, and are easier to transport and store. The result is a direct reduction in spoilage and wastage, issues that continue to plague smallholder agriculture across India.

SUSTAINABILITY IN ACTION

The Solar Dryer Facility is a microcosm of Syngenta's larger vision for sustainable agriculture, where technology, partnership, and farmer empowerment converge. Sustainability is not an abstract goal for us; it is a tangible outcome, measured in improved livelihoods, reduced resource waste, and strengthened rural communities.

By leveraging renewable energy and promoting community ownership, this initiative aligns with multiple global and national priorities — from **climate-smart farming** and **resource efficiency** to **inclusive growth** and **rural resilience**.

As India continues its transition toward sustainable agriculture, the lessons from Ariyandipuram hold broader relevance. The future of farming will depend on how effectively we can blend tradition with innovation, respecting local knowledge while equipping farmers with modern tools.

Solar-powered infrastructure represents a critical step in that direction. It reduces carbon footprint, conserves energy, and delivers tangible economic benefits. Scaling such models across crops and regions could redefine how India manages its post-harvest systems, making them cleaner, faster, and more profitable.

At Syngenta India, we see this as part of a larger movement: enabling farmers to thrive not in spite of climate change, but because they are better prepared for it.

A NEW CHAPTER IN RURAL PROSPERITY

The story of the solar chilli dryer is, at its core, a story of empowerment. It reflects how targeted innovation, when rooted in sustainability, can unlock new opportunities for growth.

When farmers gain control over processes that once relied entirely on nature's mercy, they gain confidence. When their produce commands a fairer price, they gain dignity. And when communities come together to sustain a shared resource, they gain resilience.

The Ariyandipuram project may have begun as an experiment in post-harvest management, but it has evolved into something far greater, a model for how sustainable innovation can transform rural India.

As we look ahead, our focus will remain on replicating such success stories, ensuring that every farmer, regardless of scale or geography, has access to the knowledge and technologies that can secure their future.

Because when agriculture becomes more efficient, equitable, and environmentally conscious, it is not just the farmers who prosper, it is the nation as a whole.

AgriCon INDIA

HORTICONNECT INDIA

MESSE MÜNCHEN

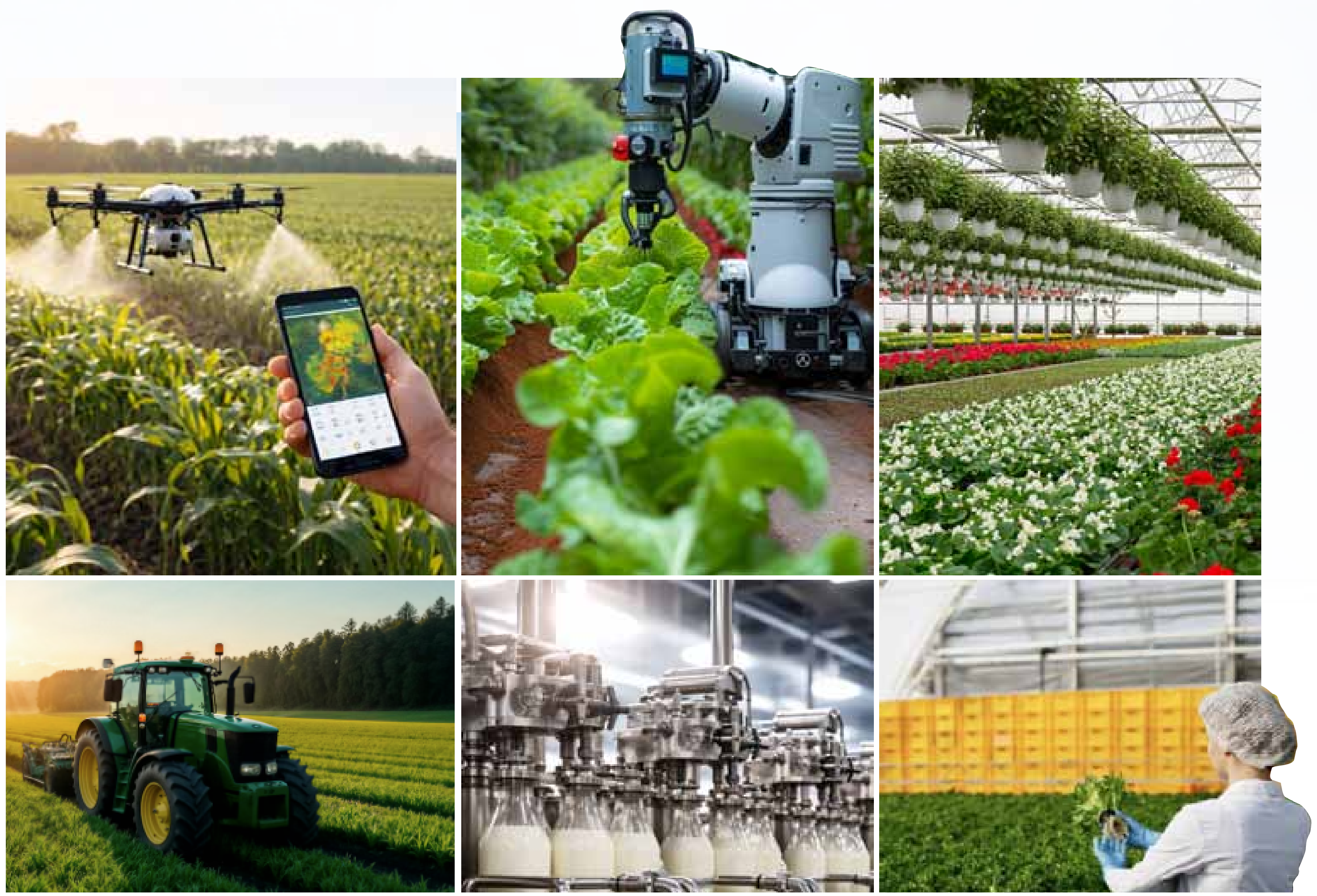
1 - 2 - 3 October 2026 | BIEC Bengaluru, Karnataka | India

AN INITIATIVE BY MESSE MUENCHEN INDIA PVT. LTD. AND HORTICONNECT GLOBAL PVT. LTD.

Catalysing Tomorrow's Agriculture & Horticulture Today

ONE ROOF.
TWO BUYER WORLDS.
YOUR 2027 PIPELINE SECURED.

30,000+	300+	50,000+
sq.m of Innovation	Global Exhibitors	Targeted Buyers



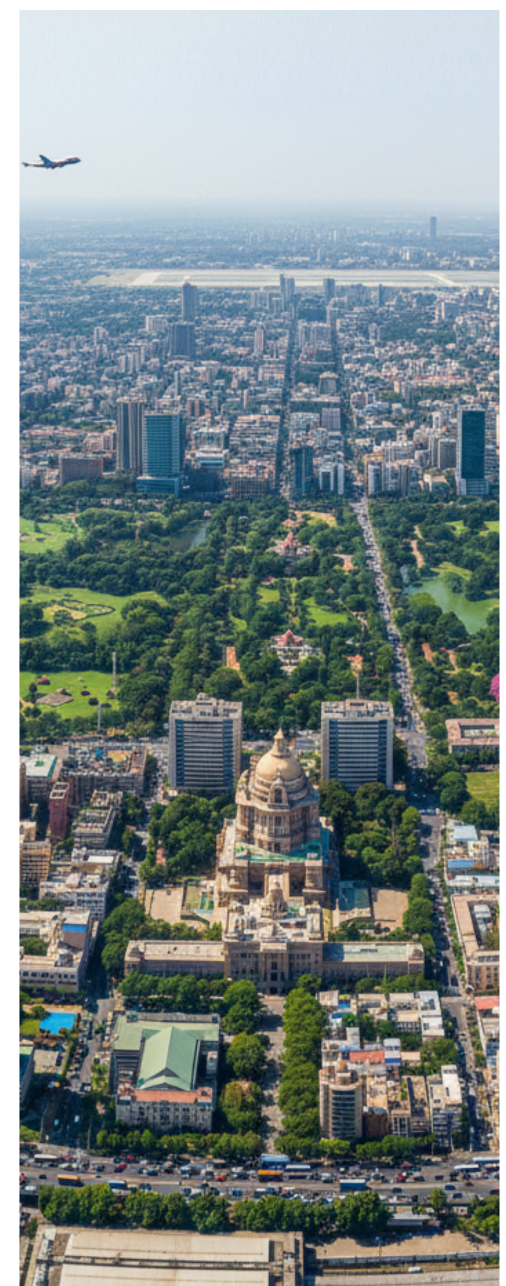
Association Partners

Contact:
Mr. Bhola Mandal
Tel: +91 22 4255 4726
M: +91 9930700292
E: bhola.mandal@mm-india.in

www.agriconindia.in

TO BOOK SPACE

WHY BENGALURU



Bangalore's strong agri base, leading technology ecosystem, strong connectivity and a quality venue with access to quality visitors makes it an ideal location for AgriCon India

Karnataka - A Strong Agricultural Base : Agriculture and its allied activities contributes 15% to state GDP and is one of the largest Agri producing states in India

High adoption of modern farming and higher mechanisation level compared to other regions

Strong Technology & Innovation Ecosystem : Bangalore is India's tech capital, making it ideal for showcasing Agricon, precision farming, drones, IoT, automation, farm software and startups

Attracts high-quality decision-makers, innovators and investors

Quality venues & strong connectivity : Has one of India's largest exhibition venues (BIEC with >83 thsd sqm) to host large shows

Has strong air, rail, road and metro links keeping the city well connected for people and business

Visitor Catchment Beyond Karnataka : Bangalore is the regional distribution hub of Southern India & easily accessible from neighbouring states (Tamil Nadu, Andhra Pradesh, Telangana, Kerala) and overseas destinations

States have high-income, technology-driven farmers, making visitor quality strong

Headquarters and base for multiple domestic & multinational companies having key decision-makers concentrated in the city

Small and niche focus segments are successful with focused shows like (Krishi Mela, HortiConnect India & Agricon India) providing overall coverage of agriculture sector

OEMs, component suppliers

- Live demonstration of new age technologies & business models for implementation
- Showcasing success stories / case studies of new products / technologies
- Technology discussions with international players (B2B meetings)
- Meetings with local / international component suppliers for localization

Food processing companies, export traders, institutional buyers

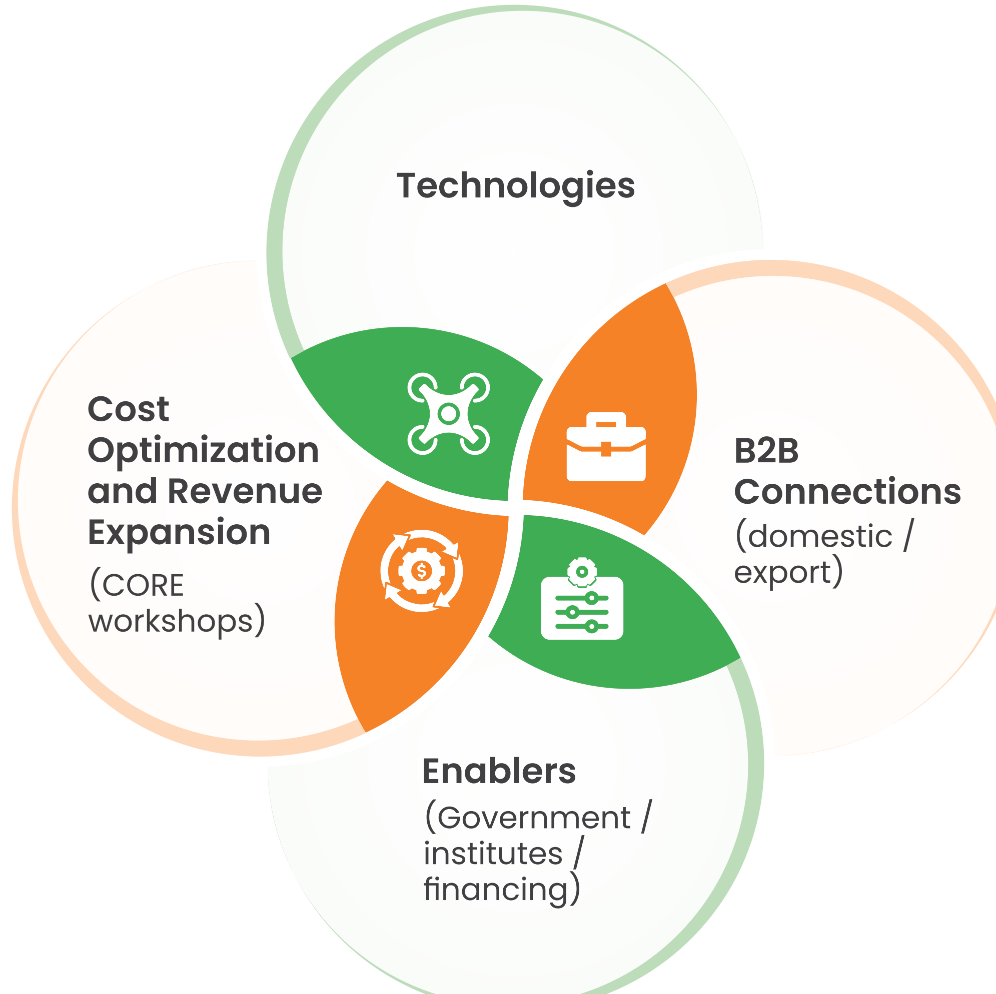
- B2B meetings with potential buyers
- FPO meetings with institutional / corporate buyers (food processing / exporters / international importers)
- OEMs meeting with institutional buyers, CHCs, FPOs

Why AgriCon + HortiConnect Together?

Horticulture & agriculture are two sides of the same coin. HortiConnect brings India's leading horticulture platform. **AgriCon India** adds Messe Muenchen's global exhibition expertise. Together, they create the ONLY unified platform where growers, technology providers, and policy makers connect across BOTH sectors under one roof.

Vision

AgriCon HortiConnect will serve as "A platform to showcase national-level success stories of key farmers, new-age technologies, and states excelling in Agri practices."



Key Achievements & Testimonials Exhibitor Success (HortiConnect 2025)

Leads :	Avg Rating :	Visitor Stats:	Repeat Exhibitors:
150+	**4.3/5**	**50K+**	**80%+**
Qualified leads in 3 days	Avg Rating	Visitors	Planning ROI

Testimonial

Exceeded expectations.
150+ quality leads. The event was well organized

S. SOMASHEKHAR RAO
Maharashtra Bio Fertilizers.

FPOs, progressive farmers, influencers

- Display of highest quality farm produces & land holdings (open for contract farming)
- National level success stories of key farmers adopting precision farming, dual cropping, doubling of income, etc.
- Core workshops on new cash crops, export potential, precision farming, new age technologies, cost optimization, generating additional revenue, etc.

Central and state government, KVKs, research institutes

- Showcasing successful state agri-practices, policies, & technology needs(G2G meetings)
- Initiating B2G dialogues by OEMs to display / discuss new technology products, to align future subsidy / incentives / mechanization policies at central & state governments
- Display of ongoing projects / initiatives, presentation of innovations & success stories

Aligning Biofuel Ambitions with Farmer Interests: Urgent Policy Recalibration

Krishan Bir Chaudhary

President, Bharatiya Krishak Samaj
Member, High Level Committee on MSP & Agricultural issues (GOI)

With India's ambitious **Ethanol Blending Programme (EBP)** targeting **20% ethanol blending by 2025-26**, the country has witnessed substantial growth in ethanol production capacity, which is now exceeds domestic demand. Thanks to Strong policy push from Government of India and equally excellent response from our farmers enabling this achievement of 20 percent EDB before time. This is the time to protect interests of the farmers by making Ethanol Policy more responsive to the changed scenario..

At present, India has surplus ethanol production capacity of **930 crore liters after meeting the ~20% ethanol blending target in petrol. As of Oct 2025, the ethanol production capacity was 1953 crore liters, while the** ethanol procured for **~20%** **b**lending was **1023 crore litres.**

Due to surplus production of Ethanol, many **ethanol Distilleries are not utilized to their maximum capacity**. At presents, 499 ethanol distilleries are operating in India, with majority of them running under capacity. Some are running at less than 40% capacity. This under capacity is resulting in

less procurement of raw materials from farmers which is causing glut in the marketplace. For example, a year ago open-market maize prices were around INR 2500 per quintal, which were higher than the MSP of INR 2400 declared by Government of India; they have since fallen to INR 1500 per quintal which is much below the MSP, placing maize farmers under significant financial stress.

Sugarcane farmers are in trouble because of underutilization of ethanol distilleries. In 2018, GoI made ethanol an important revenue-generating by-product of the sugar industry. Since then, the FRP of Sugarcane increased by **39%** from 255 Rs./Qntl to 355 Rs/Qntl. This increased the income of 5 crore Sugarcane farmers in the country. At present, Sugarcane accounts for 30% of ethanol consumption of India. Unsold ethanol inventories at distilleries are delaying the payment of sugar cane farmers, again resulting in distress to the farming community.

Likewise, India produces more rice than its annual domestic demand, and the surplus is increasingly being used for ethanol production. This development was positively impacting grain farmers' incomes by reducing their dependence on traditional markets and also helping them to have handsome returns. However, the underutilization of distillery capacity is causing steep declines in grain prices and restricting the utilization of other grains as ethanol feedstock.

This achievement of Indian farmers in terms of surplus production of raw material for ethanol blending program is helping India to be food and fuel secured and must be supported by the strong policy push that create scope for off take of the raw material from the farmers and help them to remain on the path of the prosperity. Bhartiya Krushak Samaj is suggesting following policy measures.

Leveraging exports and development of newer markets. Exporting surplus ethanol can stabilize prices and ensure timely farmer payments. The target markets could be Southeast Asia, Europe, and Africa (growing demand for biofuels) & the countries with which India is negotiating FTAs. The Estimated Export Potential in this newer market could be about 930 crore liters ethanol annually.

Increase Ethanol Blending in Petrol. Government should remove hurdles from the path of achieving ethanol blending in petrol to 27 percent. Bureau of Indian Standards (BIS) has been instructed to come up with norms for the **E27** fuel on a priority basis. This needs to be expedited on earliest. A policy needs to be mandated for new vehicle registration compatible with E20 & higher fuels.

Promoting Ethanol in Aviation & Industrial Sectors & Diesel. To promote ethanol adoption across aviation, industrial sectors, and diesel, efforts should focus on expediting research into ethanol–diesel blending, advancing the development of Sustainable Aviation Fuel (SAF) derived from ethanol, and encouraging its broader use within the chemical and pharmaceutical industries.

Establish an Ethanol Price Stabilization Fund that incorporates a buffer stock mechanism to absorb surplus production and stabilize prices, while ensuring a minimum support price (MSP) for ethanol to safeguard farmers' incomes.

Payment mechanisms should be strengthened by implementing direct payment systems that ensure farmers are paid within 14 days of cane delivery and impose penalties on sugar mills for any delays in disbursing payments.

Ethanol Derivatives Market needs to be developed to promote production of ethyl acetate, ethylene, and bioplastics from ethanol. This will create new revenue streams for farmers and processors.

These policy measures will enable stabilization of the Ethanol market in India with strong production base of the raw material and relieve the value chain partners from stress which they are passing through currently.

ETHANOL: NEW EDGE BUSINESS OPPORTUNITY FOR FARMERS

Ethanol production has provided substantial economic, social, and environmental gains for the farmer community in India, with marked increases in income, job creation, crop diversification, and support for rural prosperity.

Ethanol production has created a reliable new market for crops like sugarcane, maize, and surplus grains, which stabilises farm gate prices and increases incomes for participating farmers. Data from recent years shows sugarcane and maize farmers have seen a 15–18 per cent increase in annual earnings due to higher ethanol procurement rates, with maize farmers in Bihar, for instance, earning Rs 2,500–3,000 per hectare more than those in states lacking ethanol production.

The sector has facilitated payments exceeding Rs 1.04 lakh crore to farmers, greatly strengthening rural incomes and financial sustainability, especially in sugar belt regions like Uttar Pradesh and Maharashtra.

JOB GENERATION AND RURAL ECONOMY GROWTH

Expansion of ethanol production facilities and infrastructure has generated significant employment in rural areas, with every crore litre of ethanol produced resulting in nearly 290 direct and 1,280 indirect jobs along the agricultural value chain.

New distillery and logistics jobs have been created across states, supporting the broader rural bioeconomy and reducing dependence on government subsidies.

CROP DIVERSIFICATION AND PRICE STABILITY

The ethanol program promotes crop diversification by incentivizing cultivation of alternate feedstocks (e.g., maize, sweet sorghum, biomass), which helps farmers manage risks and achieve more stable incomes. Absorption of surplus and damaged food grains prevents gluts, stabilizing prices, supporting food security policy goals, and reducing wastage.

ENVIRONMENTAL AND SOCIAL IMPACT

Ethanol production and blending in fuel have considerably reduced greenhouse gas emissions—avoiding roughly 700 lakh tonnes of CO_2 equivalents and supporting India's climate commitments.

2G ethanol production offers significant economic and environmental benefits to farmers by converting agricultural waste into a valuable commodity. This creates new revenue streams, addresses the issue of crop stubble burning, and stimulates the rural economy.

FINANCIAL BENEFITS

Farmers gain additional income by selling agricultural residues, such as rice and wheat straw, sugarcane bagasse, and corn stalks, to biofuel plants. This "waste-to-wealth" approach turns a former disposal problem into a profitable opportunity.

https://doi.org/10.52151/aet2026501.1893

Agricultural Engineering Today | 50 (1)

By selling their leftover biomass, farmers can offset or eliminate the costs associated with burning or otherwise disposing of agricultural waste.
Utilising all parts of the crop allows farmers to increase their overall productivity and maximize returns from their land.

Government procurement policies, Minimum Support Prices (MSPs), price guarantees, and blending targets (e.g., the 20 per cent ethanol blending milestone) have ensured market access and fair returns for farmers.

Special schemes such as interest subventions, infrastructure investment, and feedstock diversification support further growth in rural economies and farm incomes.

Ethanol procurement has significantly increased farmer incomes in India, with direct impact measured in thousands of crores of rupees and substantial per-hectare profit gains for sugarcane and maize farmers.

OVERALL DIRECT INCOME BOOST

Payments to farmers from ethanol procurement reached over Rs.1,11,703 crore in sugar season 2023–24 alone, with around Rs 40,000 crore expected to be paid directly to farmers in the current year as India approaches 20 per cent ethanol blending.

Since the start of the Ethanol Blended Petrol (EBP) Programme, the cumulative earnings for farmers from ethanol supply have surpassed Rs 1,21,000 crore, illustrating a dramatic increase in rural cash flows and timely payments, especially to sugarcane growers.

Grain-based ethanol procurement, particularly from surplus maize and rice, is projected to generate an additional Rs 35,000 crore per year in direct payments to grain farmers, as 165 lakh metric tonnes of surplus grain are used annually for ethanol production.
Sugarcane farmers in key states like Uttar Pradesh and Maharashtra have experienced a 15–18 per cent increase in annual earnings, with net profits for sugarcane cultivation rising to approximately Rs 40,000 per hectare when ethanol demand is strong (compared to less for non-ethanol-linked markets).

Maize farmers in states supplying ethanol distilleries have gained an extra Rs 2,500–3,000 per hectare in income relative to those in regions without ethanol procurement. The government's move to pay separate GST and transport charges for ethanol supply ensures that farmers receive higher effective earnings, in addition to support prices and timely procurement.

FUTURE AHEAD

If ethanol blending reaches 20 per cent, Indian farmers are projected to earn approximately Rs 40,000– Rs 45,000 crore per year in direct payments from ethanol procurement, marking an unprecedented windfall for the agricultural community according to the report of PIB.

These payments result in direct increases in farm household income, leading to enhanced spending capacity, improved rural prosperity, and reduced dependence on government support or subsidies.

Diversification toward grain-based ethanol (especially maize and surplus rice) ensures the payout is distributed across sugarcane belts and newly participating regions, broadening rural impact.

REVENUE BREAKDOWN BY CROP TYPE

Sugarcane: Represents the largest component, typically accounting for around 70–75 per cent of ethanol feedstock due to long-standing linkage with the sugar industry. With a total projected farmer revenue at Rs 40,000–Rs 45,000 crore annually, this means sugarcane farmers are likely to receive Rs 28,000– Rs 34,000 crore per year.

Maize: As the government promotes grain-based ethanol alongside sugarcane, maize's contribution is rising. Recent projections suggest maize could account for about 15–18% of total ethanol production, translating to Rs.6,000–Rs.8,000 crore in annual farmer revenue at full 20 per cent blending.

Surplus Food Grains (Rice/Wheat/ Broken Rice): Surplus and damaged grains redirected from government stockpiles and FCI procurement for ethanol could provide 7–10 per cent of the feedstock, supporting Rs 3,000– Rs 4,500 crore per year in farm revenue.

Most farmer revenue at the 20 per cent ethanol blending milestone will go to sugarcane growers, but income for maize and surplus grain farmers is set to increase sharply as feedstock diversification accelerates. This trend will boost incomes across more regions and crop types as the ethanol value chain expands.

Agricultural Technologies for Sustainability: Reflections for India's Small and Marginal Farmers

Pawan Kumar
Chief General Manager, Patanjali Organic Research Institute

After more than thirty-five years of working closely with farmers across India, I gradually realised that sustainability is not a fashionable term for them. For a small or marginal farmer cultivating less than one hectare, sustainability means three simple questions:

- Will my soil remain productive year after year?
- Will my cost of cultivation stay under control?
- What will I do when the weather fails or markets collapse?

Agricultural technology can help answer these questions, but only when it supports farmers' thinking and experience rather than replacing them. India's agriculture today is under pressure from many sides. Climate change has made rainfall uncertain, groundwater levels are falling, soils losing organic matter and the cost of cultivation continues to rise. More than 85% of Indian farmers are small and marginal, with limited capital and very little margin for error. Technology that ignores this reality will most likely increase distress instead of reducing it.

TECHNOLOGY TO REDUCE RISK AND CONTROL COSTS

For small farmers, technology must first reduce risk and save money. Tools such as soil moisture sensors, weather-based advisories and micro-irrigation systems have shown their value when used appropriately. In dry regions of Maharashtra, Bundelkhand and parts of Rajasthan, sensor-assisted drip irrigation has helped farmers reduce water use by 25 to 40% while maintaining stable yields of vegetables, pulses and oilseeds. The greatest benefit of technology comes when farmers learn what not to do. Knowing when not to irrigate, not to spray pesticides and not to apply fertilisers saves money and protects soil life. When such advice is delivered in the local languages it can become practical and useful.

USING AI TO LEARN FASTER AND SUPPORT DECISIONS

Artificial intelligence is gradually becoming part of agricultural technology, often without farmers even realising it. When used responsibly, AI helps farmers and extension workers learn faster and make better decisions. For farmers, AI-based tools can analyse large amounts of information such as weather patterns, soil data, crop performance and pest outbreaks and identify trends that would otherwise take many years to understand. Farmers can now use simple mobile applications to identify crop diseases or nutrient deficiencies from photographs, understand likely weather risks, or get an idea of market price trends. For extension workers, AI supports decision-making at scale. One extension officer often serves hundreds of farmers across multiple villages. Digital tools can help track crop stages, rainfall variations and pest alerts so that attention can be focused where it is needed most. Recognizing this potential, the Government of India has launched the Digital Agriculture Mission, which aims to build a strong digital foundation for Indian agriculture. This includes farmer databases, soil maps and decision support systems that can guide farmers and extension agencies in a timely and location-specific manner.

https://doi.org/10.52151/aet2026501.1894

Agricultural Engineering Today | 50 (1)

DRONES, REMOTE SENSING AND COLLECTIVE USE

Drones and satellite imagery are often seen as technologies meant only for large farms. In reality, when deployed through SHGs, Farmer Producer Organisations (FPOs), cooperatives or Custom Hiring Centres, even small farmers can benefit. Drone-based surveys help identify pest attacks, water stress and nutrient deficiencies early. This allows farmers to take targeted action instead of spraying entire fields. In many regions, drone application of bio-inputs has reduced chemical use, labour costs and health risks for farm workers.

TECHNOLOGY FOR PESTICIDE MONITORING AND SAFETY

One of the most important roles of agricultural technology is pesticide monitoring and restraint. Indiscriminate use of chemicals has harmed farm families' health, destroyed beneficial insects, polluted soil and water and affected India's export credibility. Digital spray records, pest surveillance systems and field monitoring tools help track what is sprayed, where and how often. When this information is combined with pest population monitoring using traps and field observations, farmers spray only when pest levels cross damaging limits. Residue testing kits and simple traceability systems are also helping farmers understand the link between safer produce and better market acceptance.

FASTER LEARNING AND BETTER MARKETS

Mobile phones have become the most powerful extension tool in Indian agriculture. Weather alerts, pest warnings and crop advisories when delivered at the right time and in simple language can help farmers avoid losses. Voice-based advisories are especially useful for farmers who are less comfortable with reading. However, technology alone cannot solve market problems. Despite platforms such as e-NAM improving price transparency, small farmers still struggle with grading, storage, transport and delayed payments.

NATURAL FARMING AND BIO-INPUT RESOURCE CENTRES

Sustainability for small farmers is closely linked to self-reliance. The National Mission on Natural Farming (NMNF) recognized this by promoting farming systems that rebuild soil health and reduce dependence on external inputs. A key element of this mission is the establishment of Bio-Input Resource Centres at village or cluster level. These centres help farmers produce Jeevamrit, Beejamrit and botanical extracts using locally available materials. Over time, learning from field results helps farmers refine practices suited to their soils and crops. Technology supports this learning without replacing traditional knowledge.

RISKS OF TECHNOLOGY AND AI

While agricultural technology and AI offer many benefits, they also carry risks that cannot be ignored. Data ownership is a major concern. Many platforms collect farm-level data without clearly explaining how it will be used or who controls it. AI-based recommendations depend on data quality. Poor or incomplete data can lead to wrong advice. Subscription-based models may quietly increase costs, replacing chemical dependence with digital dependence. There is also a real risk of exclusion of farmers without smartphones, internet access or digital literacy. The key issue is not the technology itself but who controls it. When drones and digital tools are managed by farmer institutions, they promote sustainability. When they are directly linked to input sales, they often encourage excessive use and higher costs.

TECHNOLOGY WITH VALUES

After decades of working with farmers who face uncertainty every season, I believe technology can become empowering or harmful depending on who controls it and whose interests it serves. The future of Indian agriculture lies in farmer-controlled, locally adapted and ethically guided technologies. When agricultural technology and AI help farmers learn faster, support better decisions and strengthen extension systems without taking control away from farmers sustainability becomes real and moves from policy documents into farmers' fields and part of their daily lives.

What Precision Agriculture Really Looks Like on Indian Farms

Ezhilan Nanmaran
Head of Product and Strategic Partnerships, ideaForge Technology Ltd.

Indian agriculture has always been complex and non-uniform, a reality farmers have long navigated through experience rather than data. Soil properties can shift within a few meters, crops often grow unevenly even when planted together, and water availability can differ across the same plot. Because of this inherent variability, farming decisions have historically depended as much on keen observation and judgment as on the inputs themselves.

Today, the core challenge of agricultural complexity remains, but what is rapidly changing is our ability to observe these variations clearly and respond with unparalleled precision. Drone-based technologies are driving this practical shift—not as a replacement for traditional knowledge or a far-off promise of automation, but as powerful tools that help researchers and farmers gain a granular understanding of what is truly happening within their fields.

Real-world success stories, such as work conducted by the Indian Council of Agricultural Research (ICAR) in rice-growing areas and by apple researchers in Kashmir, show that precision agriculture is steadily

moving from academic theory into established, on-farm practice.

BRINGING PRECISION TO THE PLOT: THE DRONE ADVANTAGE

For decades, remote sensing in agriculture was synonymous with satellite imagery, which remains valuable for tracking regional trends. However, most critical farming decisions are made not at the district or state level, but plot by plot, and *within* the field itself. This is where drones offer a visible difference. Flying at low altitudes, they capture high-resolution imagery and can be deployed at specific, critical growth stages. This flexibility allows conditions to be assessed exactly when decisions are needed, rather than being bound by fixed satellite imaging schedules.

In field studies, drones have been crucial for observing crop stress caused by pests and diseases, as well as stress resulting from nutrient imbalances, water scarcity, and heat. They also support the continuous monitoring of crop growth and phenological stages—tasks that previously demanded labor-intensive, repeated field visits.

FROM AIR TO ACTION: GENERATING AND UTILIZING FIELD DATA

Across these studies, Unmanned Aerial Vehicle (UAV) platforms are integrated with multispectral sensors that capture reflectance across visible and near-infrared wavelengths. This imagery is used to derive vegetation indices such, as NDVI, NDRE, GNDVI, MSAVI, and SAVI. While these indices do not replace on-the-ground observation, they provide a consistent, quantitative way to indicate crop vigour, stress levels, and nutrient status.

https://doi.org/10.52151/aet2026501.1895

Equally important is the consistency of data collection. Automated flight planning and mapping software allow researchers to reliably cover entire plots and repeat flights precisely over time. For agricultural data used in seasonal comparisons or sophisticated modeling, consistency in data capture is as vital as the sensor quality itself.

MAPPING SOIL HEALTH WITH DRONE-BASED SENSORS

One significant application demonstrated by ICAR researchers focuses on Soil Organic Carbon (SOC), a key metric for long-term soil health and fertility. Conventionally, estimating SOC is a slow, labor-intensive process requiring repeated soil sampling and laboratory analysis.

By deploying drone-mounted multispectral sensors, researchers have generated plot-level soil organic carbon prediction maps. Across the fields studied, these maps revealed strong correlations between SOC and various vegetation indices, including NDRE, IPVI, GNDVI, MSAVI, and SAVI. This approach, while still requiring ground validation, offers a far more efficient method for understanding how soil health varies within a field, allowing for better, site-specific soil management over time.

FORECASTING HARVEST: PRECISION RICE YIELD ESTIMATION

Yield estimation is a critical task in rice cultivation for farmers, insurers, and policymakers alike. ICAR researchers leveraged UAV multispectral imagery captured during the panicle initiation stage to develop high-precision, plot-level yield prediction models.

The data was rigorously analyzed using multiple machine learning approaches, including Random Forest, Support Vector Machine (SVM), and Artificial Neural Network models. The SVM approach ultimately delivered the highest predictive accuracy. The scale of this work is its key value: plot-level yield estimates are significantly more relevant for applications like crop insurance and risk assessment than broad regional averages.

OPTIMIZING NUTRIENTS: PRECISE NITROGEN MANAGEMENT

Managing nitrogen, one of the most challenging aspects of crop production, is also being revolutionized. In rice systems, UAV multispectral data collected during the maximum tillering stage was used alongside machine learning models to estimate nitrogen content. These findings enable nutrient management practices that are better aligned with the actual demand of the crop within specific parts of the field, reducing waste and improving efficiency.

ORCHARD-LEVEL PRECISION: APPLICATIONS IN KASHMIRI APPLES

Apple researchers in Kashmir have successfully adapted similar drone-based techniques for orchard systems, where decisions on crop load and input application directly impact fruit quality. One application focused on estimating blossom density using UAV-based photogrammetry, an area where manual assessment is often subjective and inaccurate.

Excess blossoms lead to smaller, less marketable fruits, and drone imagery offers an objective way to assess canopy structure and blossom density. Furthermore, researchers have used drones to estimate canopy volume by comparing manual measurements with 2D and 3D LiDAR-based approaches, which supports more precise spray application. Multispectral imagery is also being used to assess nutritional stress during peak demand periods, such as July and August.

THE PATH AHEAD FOR PRECISION FARMING IN INDIA

Drone-based remote sensing is powerful, but it is not a cure-all. Challenges persist, including the affordability of sensors, the readiness of analytics infrastructure, and the ongoing need for continued validation of models. Critically, ensuring that small and marginal farmers can access and utilize these technologies will determine their ultimate success.

Nevertheless, ongoing work confirms that drones are effectively bridging the gap between traditional farming knowledge and data-driven insight. By making the natural variability within fields both visible and measurable, precision agriculture can support decisions that are not just *advanced*, but fundamentally more efficient, informed, and sustainable. For Indian farmers, the real value is not the technology itself, but the better, more profitable decisions grounded in what is actually happening within their own fields.

Artificial Intelligence (AI), Biotechnology and Automation in Agriculture

Deepak Pareek
Founder, HnyB Tech Incubations

As the global population marches toward 10 billion by 2050, the pressure on our food systems has reached a critical inflection point. We are tasked with producing more food on less land while grappling with the volatility of a changing climate.

In this complex landscape, **technology** emerge as the centrepiece of a new agricultural paradigm: **Regenerative Agriculture.**

When driven by the trifecta of **Artificial Intelligence (AI), Biotechnology, and Automation**, ancient crops like pulses become a cornerstone of a food-secure future that restores the planet rather than depleting it.

THE BIOLOGICAL ENGINE OF REGENERATION

Regenerative agriculture seeks to improve soil health, increase biodiversity, and capture carbon. Pulses are the natural engines of this movement because they possess the unique ability to “fix” atmospheric nitrogen into the soil.

Through a symbiotic relationship with *Rhizobium* bacteria, pulses convert nitrogen from the air into a form plant can use. This eliminates the need for synthetic nitrogen fertilizers, which are energy-intensive to produce and major contributors to nitrous oxide emissions, a greenhouse gas significantly more potent than carbon dioxide.

AI-DRIVEN ECOSYSTEM MANAGEMENT

In a regenerative system, the farm is viewed as a complex ecosystem. AI is the tool that allows us to manage that complexity at scale.

- **Predictive Crop Sequencing:** AI algorithms analyze decades of weather data, soil microbiology reports, and market trends to design optimal crop rotations. Instead of monocropping, AI might suggest a “Pulse-Cereal-Cover Crop” sequence that maximizes soil carbon sequestration and breaks pest cycles naturally.
- **Real-time Soil Health Monitoring:** AI-powered platforms process data from ground-based sensors to track the “Carbon-to-Nitrogen” (C:N) ratio in real-time. This allows farmers to understand exactly how much organic matter the pulse crop is contributing back to the earth, turning the farm into a verified carbon sink.

BIOTECH: ENHANCING THE SYMBIOTIC RELATIONSHIP

Modern Biotechnology is moving beyond simple genetic modification toward **Microbiome Engineering**. This “BioTech 2.0” focuses on the relationship between the seed and the soil.

- **Enhanced Inoculants:** Scientists are using BioTech to develop “super-strains” of nitrogen-fixing

https://doi.org/10.52151/aet2026501.1896

bacteria tailored to specific soil types. When applied to pulse seeds, these inoculants maximize the plant’s regenerative potential even in degraded soils.
- **Climate-Adaptive Traits:** Through CRISPR and advanced breeding, researchers are developing pulses with deeper root systems. These “carbon-deep” varieties not only survive extreme droughts but also deposit carbon much deeper into the soil profile, where it is less likely to be released back into the atmosphere.

AUTOMATION: THE PRECISION OF REGENERATIVE CARE

Regenerative farming often requires more labour-intensive practices, such as “no-till” seeding and complex cover cropping. **Automation** solves the labour gap while increasing precision.

- **Autonomous No-Till Drills:** Robotic planters can now sow pulse seeds directly into the residue of a previous crop without turning the soil. This prevents soil erosion and keeps the underground fungal networks (mycorrhizae) intact, which is vital for nutrient cycling.
- **Targeted Weeding Robots:** Instead of blanket herbicide applications that kill beneficial soil life, AI-driven robots like “See-and-Spray” platforms use computer vision to identify and laser-neutralize weeds. This protects the pulse crop while maintaining the microbial integrity of the surrounding soil.

CLOSING THE LOOP: THE CIRCULAR ECONOMY

The synergy of pulses and AgTech creates a circularity that defines sustainability. A digital farm management tool can calculate the exact “nitrogen credit” a lentil crop leaves behind, allowing the subsequent wheat crop to be grown with 40% less fertilizer.

The Regenerative Impact: Integrating pulses into a digitally managed, automated regenerative system can reduce a farm’s net carbon footprint to zero—or even make it carbon-negative—while restoring the biological vitality of the land.

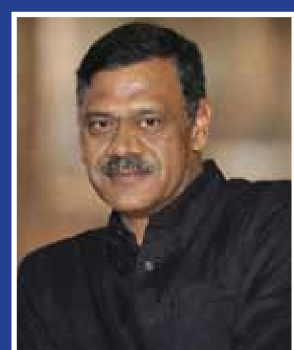
CHALLENGES AND THE PATH FORWARD

The transition to an AI-and-BioTech-driven pulse industry is not without hurdles. The high cost of autonomous machinery and the “digital divide” in rural areas remain significant barriers. However, as “Agriculture-as-a-Service” (AaaS) models grow, even smallholder farmers are beginning to access these high-tech tools through cooperatives and mobile-first platforms.

CONCLUSION: A DIGITAL-GREEN REVOLUTION

We are moving away from the “Green Revolution” of the 20th century, which relied on chemical inputs, toward a **“Digital-Regenerative Revolution”** rooted in ecological intelligence. By harnessing AI, BioTech, and Automation to optimize pulse production, we aren’t just growing food; we are healing the soil. The humble pulse, empowered by the silicon chip and genetic insight, is the most powerful tool we have to feed the world while cooling the planet.

Growing More with Less - How Agricultural Technology Shaping Sustainable Farming




Anurag Saxena and Preety Rajkumari
ICAR-National Dairy Research Institute, Karnal, Haryana

Feeding humanity has always been a story of ingenuity. From the first stone tools to the Green Revolution, agriculture has evolved alongside human civilization. Today, however, farming stands at a crossroads. Climate change, soil degradation, water scarcity, biodiversity loss, and a growing global population are placing unprecedented pressure on food systems. The challenge is not only to produce more food, but to do so sustainably protecting ecosystems while ensuring farmer livelihoods.

Agricultural technology (AgTech) is quietly rewriting the future of farming. By blending biology, engineering, data science, and renewable energy, modern AgTech offers powerful tools to grow more with less and to do it responsibly.

FROM TRADITIONAL FIELDS TO SMART FARMS

For centuries, farmers relied on experience, intuition, and seasonal rhythms. While these remain invaluable, they are no longer sufficient in an era of erratic rainfall, rising temperatures, and shrinking resources. Sustainable agriculture today requires precision, adaptability, and real-time decision-making.

Smart farming technologies enable farmers to treat fields not as uniform plots but as living mosaics—each patch of soil, plant, or animal managed according to its specific needs. This shift reduces waste, cuts emissions, and improves resilience to climate shocks.

PRECISION AGRICULTURE: RIGHT INPUT, RIGHT PLACE, RIGHT TIME

At the heart of sustainable AgTech lies precision agriculture. Using GPS mapping, soil sensors, satellite imagery, and data analytics, farmers can apply water, fertilizers, and pesticides only where and when they are needed.

Instead of blanket spraying an entire field, precision tools identify nutrient-deficient zones or pest hotspots. This targeted approach delivers multiple sustainability benefits:

- Reduced chemical runoff, protecting rivers and groundwater
- Lower production costs, improving farm profitability
- Healthier soils, preserving long-term productivity
- In water-stressed regions, precision irrigation can cut water use by 30–50%, a critical gain as freshwater becomes increasingly scarce.

ARTIFICIAL INTELLIGENCE: FARMING WITH FORESIGHT

Artificial Intelligence (AI) is transforming agriculture from reactive to predictive. By analyzing weather patterns, soil data, crop growth stages, and historical yields, AI systems can forecast outcomes and recommend actions long before problems appear. AI-powered decision-support platforms can:

- Predict pest outbreaks before they spread
- Optimize planting dates based on climate trends
- Estimate yields and market risks in advance

Such foresight helps farmers adapt to climate uncertainty while reducing losses and unnecessary interventions. Sustainability, in this sense, becomes data-driven resilience.

DRONES AND ROBOTICS: EYES AND HANDS OF THE MODERN FARM

Once the stuff of science fiction, drones and robots are now practical tools in sustainable agriculture. Drones scan fields using multispectral cameras, detecting crop stress, disease, or nutrient deficiencies invisible to the human eye. Robots, meanwhile, can perform precision weeding removing unwanted plants mechanically rather than chemically.

In livestock systems, wearable sensors monitor animal health, movement, and feeding behaviour, improving welfare while reducing disease-related losses. These technologies not only save labour but also minimize environmental footprints by reducing fuel use and chemical dependency.

SOIL HEALTH TECHNOLOGIES: REBUILDING THE LIVING FOUNDATION

Healthy soil is the cornerstone of sustainable agriculture. Yet decades of intensive farming have depleted organic matter and microbial diversity in many regions. AgTech is helping reverse this trend.

Soil sensors measure moisture, temperature, salinity, and nutrient levels in real time. Digital soil maps guide conservation practices such as cover cropping, reduced tillage, and organic amendments. By restoring soil carbon, these technologies contribute to climate change mitigation, turning farms into carbon sinks rather than sources.

RENEWABLE ENERGY ON FARMS: POWERING SUSTAINABILITY

Energy use is a hidden cost of modern agriculture. Diesel pumps, cold storage, and mechanization contribute significantly to greenhouse gas emissions. Renewable energy technologies offer cleaner alternatives.

- Solar-powered irrigation systems replace diesel pumps
- Biogas plants convert animal waste into energy and organic fertilizer
- Wind and solar microgrids power cold storage and processing units

These solutions not only cut emissions but also enhance energy independence for rural communities.

DIGITAL PLATFORMS AND THE FARMER'S SMARTPHONE

One of the most democratizing aspects of AgTech is the smartphone. Mobile apps now deliver weather alerts, pest advisories, soil recommendations, and real-time market prices directly to farmers' hands.

Digital extension services bridge gaps between research institutions and farmers, accelerating the adoption of sustainable practices. Organizations such as Food and Agriculture Organization emphasize that digital tools are essential for inclusive, climate-smart agriculture, especially for smallholders who form the backbone of global food production.

CHALLENGES: TECHNOLOGY IS NOT A SILVER BULLET

Despite its promise, AgTech is not without challenges. High initial costs, limited digital literacy, data privacy concerns, and unequal access can widen gaps between large and small farmers if not addressed thoughtfully.

Sustainability requires more than technology alone, it demands supportive policies, capacity building, and locally adapted solutions. Tools must complement traditional knowledge rather than replace it.

A SUSTAINABLE HARVEST FOR THE FUTURE

Agricultural technology is not about replacing farmers with machines. It is about empowering farmers with knowledge, precision, and resilience. When thoughtfully deployed, AgTech aligns productivity with environmental stewardship producing food while conserving water, restoring soils, reducing emissions, and protecting biodiversity. As humanity faces the twin challenges of feeding billions and safeguarding the planet, sustainable agriculture powered by smart technology offers a hopeful path forward. The fields of the future will not only grow crops; they will grow solutions.

https://doi.org/10.52151/aet2026501.1897

Modernising Indian Agriculture for Environmental Sustainability


Dr. BV Ramana Rao[1] and Dr. Surender Singh[2]

[1]Founder Project Coordinator, AICRP on Agricultural Meteorology, ICAR-CRIDA, Hyderabad, India
[2]Sr Professor/Principal Scientist (Rtd) Agricultural Meteorology, CCS Agricultural University, Hisar

Indian agriculture stands at a defining crossroads. The nation's hard-won achievement of food self-sufficiency has come with an unspoken price; rapidly depleting groundwater, declining soil health and growing exposure to an increasingly volatile climate. As India looks ahead, this paradox can no longer be ignored. The shift from resource-intensive practices to a technology-enabled, sustainable agricultural model is not a matter of choice; it is an imperative. By 2047, when India must nourish over 1.6 billion citizens, the future of food security will depend on how wisely natural resources are managed today. Through the integration of cutting-edge agri-technologies, India has the opportunity to transform its farms into engines of efficiency, resilience, and long-term sustainability securing both livelihoods and landscapes for generations to come.

RESILIENT SEEDS AND CLIMATE ADAPTATION

The first pillar of this transformation lies in developing crop varieties capable of withstanding weather-related stresses. Traditional breeding is being accelerated by genomic sequencing to create climate-smart crops. In the Indian context, this means rice varieties that can survive being submerged under flood waters for two weeks or wheat that remains productive despite the "terminal heat" of a premature summer. Such varieties act as a biological insurance policy for the farmer, ensuring that unseasonal heat waves or delayed monsoons do not result in total financial ruin.

RESTORING THE EARTH: SOIL ENRICHMENT

Sustainable agriculture is rooted in soil health. For decades, indiscriminate use of chemical fertilizers has led to soil degradation in once-fertile tracts of the Indo-Gangetic plains. Modern soil enrichment technology focuses on precision and biological restoration. Efficient fertilizer use represents a significant step forward; a single well-managed application can replace dozens of indiscriminate doses of conventional granular urea, substantially reducing excess application and the chemical runoff that contaminates groundwater. Furthermore, digital Soil Health Cards integrated with Geographic Information Systems (GIS) allow farmers to practice site-specific nutrient management, applying only the minerals a particular patch lacks, thereby restoring the natural microbial balance.

PRECISION WATER MANAGEMENT

Water management is perhaps the most critical challenge for Indian Ag-Tech, as agriculture consumes nearly 80% of the country's fresh water. Beyond simple drip lines, the integration of the Internet of Things (IoT) allows for a "smart" irrigation ecosystem.

Sensors embedded in the soil measure real-time moisture levels and transmit data to a central cloud, triggering irrigation only when necessary. This prevents the dual evils of water wastage and soil salinization, ensuring every drop contributes directly to growth.

CROP DIVERSIFICATION AND NUTRITION

Sustainability requires shifting away from the rice-wheat monoculture that has dominated since the Green Revolution. Crop diversification, guided by satellite imagery and big data, helps farmers transition to oilseeds, pulses, and millets naturally suited to arid conditions. This is linked to the cultivation of healthy, nutrition-rich crops. Rather than focusing solely on caloric output, the emphasis is moving toward crops with higher protein and mineral content. Millets, rebranded as "Shree Anna," are a prime example. These "super-crops" require minimal water and no pesticides while addressing the nation's nutritional needs.

INTELLIGENCE AGAINST YIELD REDUCERS

The unpredictability of pests, diseases, and extreme weather often catches farmers off guard. Early warning systems powered by Artificial Intelligence (AI) are now bridging this gap. By analyzing decades of historical weather data alongside real-time satellite feeds, these systems predict pest outbreaks or localized hailstorms days in advance. Farmers receive alerts via mobile applications, allowing for preventative biological treatments. This shift from "crisis management" to "risk mitigation" saves billions in potential annual crop losses.

MECHANIZATION FOR THE SMALLHOLDER

Mechanization in India faces the challenge of fragmented landholdings; large machinery is often impractical for a farmer with only two acres. The solution is the "uberization" of machinery through Custom Hiring Centers (CHCs). These platforms provide smallholders access to high-tech equipment like Laser Land Levelers, ensuring uniform water distribution and drones for precision spraying. Drones are transformative, covering large areas in minutes using significantly less water and fewer chemicals, while protecting farmers from direct toxin exposure.

STRENGTHENING THE POST-HARVEST LINK

The final frontier is reducing waste through cost-effective infrastructure. In India, significant produce rots due to a lack of cold chain logistics. Modern Ag-Tech addresses this with decentralized, solar-powered cold storage units managed by village cooperatives. Coupled with AI- driven grading machines, these technologies allow farmers to sort produce by quality on-site. By extending shelf-life and enabling primary processing at the farm gate, we reduce the carbon footprint of transport and ensure farmers capture a higher share of market value.

HUMAN RESOURCE DEVELOPMENT

The journey toward a sustainable agricultural future in India is a marathon, not a sprint. It requires the seamless integration of ancient wisdom with modern silicon. As these eight technological pillars become more accessible, the Indian farm will transform from a site of struggle into a sophisticated, sustainable enterprise that feeds the world while respecting the planet. Ultimately, to succeed in this new era, India needs scientists and extension workers capable of not just looking at soil and crops but can also read the sky.

In conclusion, the transformation of Indian agriculture demands a coherent, long-term framework that places sustainability, technology adoption, and farmer empowerment at its core. Public investment must prioritize climate-resilient research, digital infrastructure, and decentralized innovation systems that reach small and marginal farmers. Policies should incentivize precision use of water and nutrients, promote diversified cropping systems, strengthen agri-startups and scale Custom Hiring Centers and post-harvest infrastructure through public–private partnerships. Equally critical is the development of human capital, scientists, extension workers, and agri-entrepreneurs capable of translating complex data into actionable field-level decisions. As India advances toward 2047, agricultural policy must move beyond yield-centric targets to embrace resilience, resource efficiency and nutritional security, ensuring that technological progress translates into equitable growth, environmental stewardship, and enduring food security for the nation.

https://doi.org/10.52151/aet2026501.1898

Leveraging Agri-Tech for India's Agriculture

Dr V Vijayan
Founder & CEO BizAble RI, India

As the global population rises and environmental pressures intensify, sustainable farming practices supported by technology have become essential for ensuring food security and ecological balance. Agricultural Technology or AgTech plays a vital role in promoting sustainable farming by optimizing resources and reducing environmental impact. It is transforming the way we grow and manage crops and distribute food.

In 2026, the intersection of agriculture and technology has moved beyond "innovation" and into "integration". As the global population nears 8.3 billion, AgTech is no longer just about increasing yields, it is about building a climate-resilient stack that balances food security with the preservation of natural resources.

Agriculture lies at the heart of humanity's survival and at the center of many environmental challenges. Feeding a growing global population while protecting ecosystems, conserving water and reducing emissions is no small task. This is where AgTech becomes a game changer, offering tools that make farming more productive and sustainable.

Key innovations like precision agriculture, data analytics and AI enable informed decisions that boost efficiency while minimizing waste. IoT-based systems automate irrigation smartly based on soil moisture data, conserving water and preventing over-irrigation. Renewable energy supports sustainability by lowering the energy costs. Biotech gene-editing tools like CRISPR create climate-resilient crops, such as drought-tolerant rice or nitrogen-fixing cereals, reducing fertilizer needs and boosting yields up to 50%. Automated machineries and robotics streamline the agriculture operations towards sustainability. Emerging technologies like blockchain ensure supply chain traceability, building trust in sustainable products. These innovations support regenerative practices like cover cropping, improving soil health and carbon sequestration.

PRECISION AGRICULTURE: DOING MORE WITH LESS TO ZERO-WASTE

Precision agriculture uses data-driven tools such as GPS mapping, IoT sensors, drones and AI to monitor soil health, crop growth and weather conditions in real-time. This allows variable-rate application of water, fertilizers and pesticides, what is needed-where is needed-when is needed, cutting their usage by 20-60% and preventing chemical runoff into water bodies. Farmers gain early disease detection and yield forecasts, enhancing resilience to climate variability. Farmers also reduce waste, lower costs and minimize environmental impact. Precision Agriculture analyzes and applies data to ensure that every seed, drop of water and gram of fertilizer is used with maximum efficiency. By 2026, this has evolved from simple GPS guidance to AI-driven prescriptive farming.

SMART IRRIGATION SYSTEMS & WATER CONSERVATION

Water scarcity is one of the biggest challenges in agriculture globally. Smart irrigation systems use real-time data and automation to optimize water use, ensuring crops receive the right amount of water and maintain moisture without overuse. Technologies such as soil moisture sensors, automated drip irrigation and AI-driven weather forecasting help farmers optimize irrigation schedules. This not only conserves water 40-50%, but also improves crop yields to a greater extent.

https://doi.org/10.52151/aet2026501.1899

RENEWABLE ENERGY INTEGRATION

Solar-powered machinery, wind energy and bioenergy solutions are helping farms reduce their dependence on fossil fuels. Integrating renewable energy into agricultural operations supports sustainability while lowering long-term energy costs.

BIOTECHNOLOGY AND SUSTAINABLE CROPS

Advances in biotechnology, including CRISPR gene editing and improved breeding techniques, thrive and have led to the development of such "climate-smart" crops as drought-tolerant, heat-resilient, salt-tolerant, pest-resistant, disease-resistant and nutrient-efficient crops. These innovations help farmers maintain and increase productivity even under challenging environmental conditions, reducing the need for chemical inputs and supporting both food security and environmental health.

DIGITAL PLATFORMS, AI & DATA ANALYTICS

Artificial intelligence and digital farm management platforms turn massive amounts of data into actionable insights. Farmers can predict pest outbreaks, plan planting and maintenance, optimize resources and forecast harvesting and yields more accurately. This data-driven decision-making reduces risk, improves planning and supports long-term sustainability. Predictive models can forecast weather patterns, detect diseases early and optimize supply chains, leading to more resilient agricultural systems.

ROBOTICS AND AUTOMATION

Autonomous tractors, robotic weeders and smart harvesters are reshaping labor-intensive tasks. Some robotic weeders eliminate the need for herbicides entirely, controlling weeds mechanically or with targeted micro-sprays. In AI weed control, "see-and-spray" robots use computer vision to identify weeds and apply a targeted micro-dose of herbicide only to the weed, leaving the crop untouched. This reduces chemical herbicide use by as much as 90% while improving soil health and biodiversity.

VERTICAL AND URBAN FARMING

Vertical farming and hydroponic systems allow food production in urban areas using minimal land and water. These methods reduce transportation emissions and bring fresh produce closer to consumers, contributing to sustainable urban living.

CLIMATE RESILIENCE AND CARBON FARMING

Sustainability in 2026 is deeply tied to carbon sequestration. Agriculture is shifting from a carbon source to a carbon sink. Satellite-based remote sensing now provides real-time verification of soil carbon levels. This allows farmers to participate in "Carbon Credit" programs, getting paid for adopting regenerative practices like no-till farming and cover cropping.

BIOLOGICALS OVER CHEMICALS

Biological fertilizers and biostimulants (made from microbes and plant extracts) are becoming mainstream. These improve soil health and microbial diversity while reducing reliance on synthetic nitrogen, a major source of greenhouse gas emissions.

AUTOMATION AND LABOR SUSTAINABILITY

Sustainability also includes the human element. Automation is addressing global labor shortages and improving the safety of farm work. Driverless tractors can operate 24/7 with optimized pathing, which reduces soil compaction (preserving soil structure) and lowers fuel consumption. AI-powered robots can now handle delicate fruits and vegetables, reducing the physical strain on human workers and minimizing harvest waste through precise ripeness detection.

THE BIGGER PICTURE

Agricultural Technologies are not just about higher yields, they are about creating farming systems that are economically viable, environmentally responsible and socially inclusive. Harnessing the AgTech is creating a sustainable future. By combining innovation with environmental stewardship, AgTech lowers costs through reduced inputs and higher yields while cutting carbon emissions and promoting biodiversity. When combined with supportive policies, farmer training and equitable access, AgTech can help agriculture transition from a major environmental pressure point to a key solution for sustainability.

In short, AgTech gives farmers the tools to farm smarter, not harder and empowers them to produce more food with fewer resources to meet the increasing global food demands, while protecting the planet for future generations

Nutritional and Pharmacological Properties of Stinging Nettle *(Urtica dioica)* of the Himalayas

Sandhya Dhyani[1] and Simran Kaur Arora[2*]

[1]Ph. D. Research Scholar, [2*]Corresponding Author: Assistant Professor
Department of Foods and Nutrition, College of Home Science, College of Agriculture, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar
Email: sim_n@rediffmail.com

India, a biodiversity hotspot, hosts rich flora and fauna, with forests as key reservoirs of wild edible plants vital for nutrition, livelihoods, and cultural identity. As food insecurity rises, underutilized crops like wild plants gain importance. The *Urticaceae* family, especially *Urtica dioica* (stinging nettle), is notable for its wide distribution and medicinal, nutritional value. Known by various names across India, famous as *Bichhu Ghaas* especially in Uttarakhand, this wild herb has traditional significance due to its wild, and easily available nature. Stinging nettle is a versatile yet underutilized plant, valued as a nutritious pot herb. Its leaves, roots, seeds, and stems are used in cooking, herbal teas, and nutrient-rich livestock fodder. Traditionally, it is used to treat health problems as an ethnomedicine across the world. Commercially, nettle provides chlorophyll for natural colorants, sustainable fibers for textiles, and therapeutic extracts for cosmetics. Ecologically, it enhances soil health, aids phytoremediation by absorbing heavy metals, stabilizes soils, and supports beneficial insects, promoting biodiversity and reducing pesticide use in sustainable agriculture.

NUTRITIONAL PROPERTIES

The fresh leaves of the stinging nettle plant are rich in various amino acids as well as the essential fatty acids such as palmitic acid, linoleic acid and alpha-linolenic acid. It contains 89% moisture, 3.7% protein, 6.4% fibre, 0.6% fat (with 2.7% MUFA and 61.8% PUFA), 4935 IU % vitamin A, 278 mg % calcium, 1.1 mg % ascorbic acid, on wet basis (Adhikari et. al., 2016). According to Kregiel et. al. (2018), the leaf powder contains 33.77% crude protein, 3.5% crude fat and 9.08% crude fibre. Minerals such as potassium (917.2 mg/100g), calcium (113.2 mg/100g), magnesium, iron, and zinc are abundant, with potassium content higher than Chenopodium and Amaranthus. It is also a rich source of B-complex vitamins. Stinging nettle is a low-calorie functional food, with leaves containing more protein than stems or roots. In comparison to cereals and tubers, it has lower carbohydrate content, thus has a low glycemic index, making it suitable for diabetic diets. However, the high fiber content along the antinutritional factors such as phytates (4.4 to 6.5 mg/100gm) and oxalates (2000 to 3800 mg/100gm) may affect the bioavailability of protein and certain

https://doi.org/10.52151/aet2026501.1900

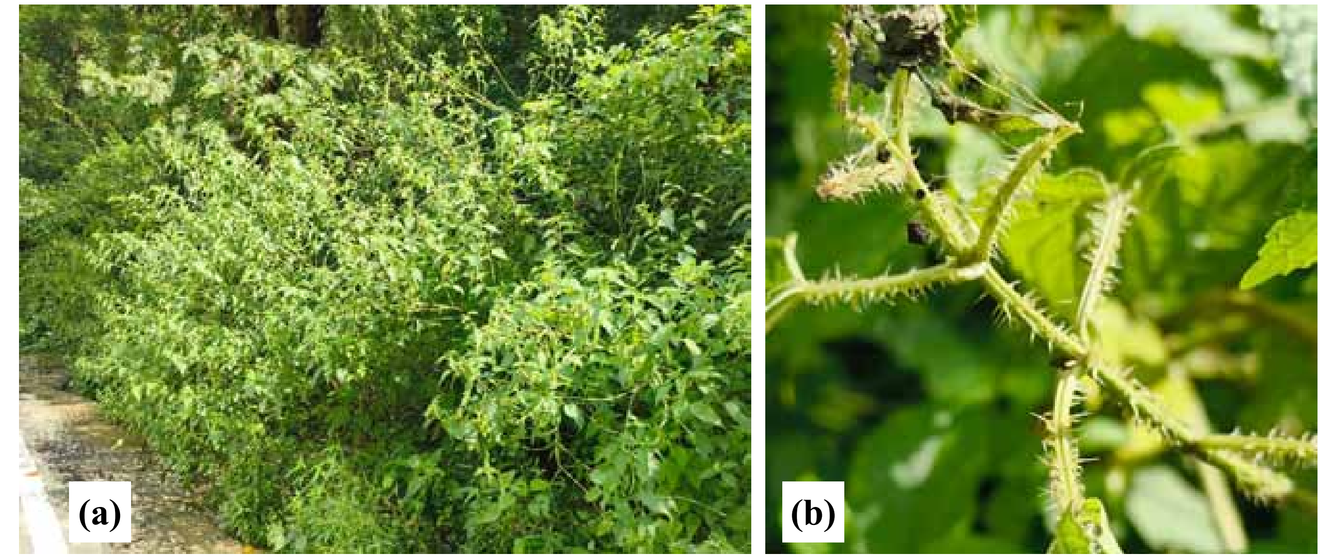
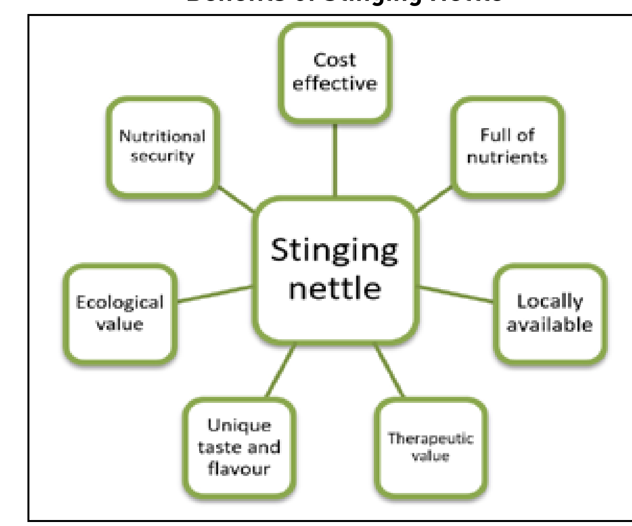


Fig 1. The Stinging Nettle (a) Plant with (b) Stinging Hairs

minerals (Arora, 2023). Proper processing treatments such as blanching or fermentation may minimize these risks, making nettle a safe and valuable dietary plant.

Benefits of Stinging Nettle



PHARMACOLOGICAL PROPERTIES

Stinging nettle contains diverse phytochemicals with strong pharmacological properties, varying across plant parts. Aerial parts are rich in flavonoids, organic acids, carotenoids, chlorophyll, minerals, and trace elements; roots contain acidic polysaccharides, flavonoids, phytosterols, lignans, and coumarins; while fruits and seeds are abundant in fixed oils, carotenoids, and polysaccharides. Its ethyl acetate extract includes alkaloids, saponins, tannins, steroids, terpenoids, glycosides, and phenols, with quercetin being the most active flavonoid. These compounds exhibit potent antioxidant effects by scavenging free radicals and provide anti-inflammatory, antiviral, antibacterial, anticancer, analgesic, hepatoprotective, anti-allergic, immunomodulatory, and antifungal activities (Pant & Sundriyal, 2016).

Traditionally, nettle preparations such as dried powders, infusions, decoctions, fresh extracts, and juices are used to treat conditions including arthritis, infections, gout, diabetes, hypertension, menstrual disorders, respiratory ailments, skin issues, and circulatory problems (Sharafetdinov et al., 2017). Fresh shoots are applied topically to relieve pain and improve circulation in musculoskeletal disorders. Root powders and juices serve as remedies for chickenpox, diarrhoea, dropsy, deworming, and early-stage benign prostatic hyperplasia.

CONCLUSION

Stinging nettle is an underutilized but a valuable crop with growing significance across globe. Its economic appeal lies in its wide range of applications across the food, pharmaceutical, cosmetic, and textile sectors. It can present new livelihood opportunities, especially for small-scale and rural farmers. Advances in processing technologies and extraction methods have enhanced the efficiency of isolating bioactive compounds, which have potential for use in functional foods and therapeutic applications. Altogether, stinging nettle is emerging not only as a multipurpose crop with economic and environmental value but also as a key player in the shift toward more sustainable, inclusive, and resource-efficient agricultural and industrial systems.

Agricultural Technologies for Small and Marginal Farmers

Dr. Ashutosh Pal
Agri-Expert
Mahashakti Foundation, Bhubaneswar, Odisha

EXECUTIVE SUMMARY

In Makuakateni village of Kankadahad block, Dhenkanal district, Odisha, a transformative agricultural initiative is demonstrating how technology, community participation and sustainability can converge to strengthen rural livelihoods. Implemented by Mahashakti Foundation with support from HDFC Bank under the Parivartan Programme, the project covers 22 acres involving 30 small and marginal farmers. Through a cluster-based, technology-enabled approach, the intervention has improved productivity, reduced input costs, conserved water and enhanced climate resilience in alignment closely with SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

INTRODUCTION

Indian agriculture is undergoing a critical transition as small and marginal farmers confront erratic rainfall, frequent droughts, declining soil fertility, imbalanced nutrient use, high pest and disease incidence,

low adoption of modern tools, low awareness of government schemes & digital platforms and reduced farm profitability. They struggle to adopt modern technologies due to fragmented landholdings, high capital costs and limited institutional support. In this context, the convergence of agricultural technology with collective action and community governance offers a promising pathway toward sustainability.

The project was implemented in Makuakateni village by Mahashakti Foundation with the support of HDFC Bank under its Parivartan Programme to address these challenges through a holistic, cluster-based farming model among 30 farmers covering 22 acres of land to enable economies of scale through efficient use of shared resources, collective crop planning and peer learning resulting in enhanced operational efficiency and reduced costs. The cluster approach also laid the foundation for aggregation, value addition and improved market access, to reduce crop failure risk and ensure income diversification under moisture stress conditions. The intervention blended modern agri-technologies with traditional knowledge systems, emphasizing efficient resource use, ecological balance and farmer empowerment resulting in a sustainable and resilient livelihood system. The initiative also aligns with national priorities on climate-smart agriculture and global sustainability frameworks.

PROJECT OBJECTIVES

The key objectives of the project were to promote climate-resilient and sustainable agriculture, improve water, soil, and nutrient use efficiency, reduce dependency on chemical inputs through IPM and INM practices, strengthen community institutions such as SHGs, Producer Groups, and Water User Groups, enhance farm productivity, profitability and resilience and align grassroots agricultural development with SDGs.

TECHNOLOGY INTERVENTIONS FOR SUSTAINABLE AGRICULTURE

- Integrated Pest Management (IPM) practices reduced chemical pesticide use through pest surveillance, bio-pesticides, botanical formulations and need-based advisories, lowering input costs and improving ecological balance.
- Integrated Nutrient Management (INM) strategies focused on restoring soil health through application of balanced bio-fertilizers and soil testing supported by sensor-based assessments.
- Manual farming tools, multi-row and power sprayers (for uniform application of bio-pesticides) and power sprayers reduced drudgery, addressed labour shortages, and improved precision in farm operations.
- Soil sensors, moisture meters, multi-parameter nutrient meters, and Brix refractometers enabled real-time monitoring of soil and crop health, leading to data-driven decision-making and better crop quality.
- A hi-tech nursery with a capacity of 30,000 seedlings supplied disease-free saplings, improving survival rates and creating local entrepreneurship opportunities. HDPE vermicompost and azolla tanks supported circular and regenerative farming practices.
- To combat the erratic nature of rainfall, a Check Dam was constructed over Mahapatia Nala measuring 10m x 2m, boasting a staggering storage capacity of 9.6 million liters. To ensure the longevity of this asset, a Water User Group (WUG) was formed to manage distribution and maintenance, fostering community ownership and sustainability. This helps in Groundwater recharge, Protective irrigation during dry spells and Improved cropping intensity.
- Installation of drip irrigation systems and rain pipes improved water use efficiency
- Solar pumps provided reliable and clean energy to power Drip Irrigation and Rain Pipe systems, delivering water directly to the root zones.
- Solar fencing is a sustainable, non-lethal solution to protect high-value crops from cattle and wild animal intrusion protected crops from stray animals and wildlife
- These interventions significantly reduced water wastage and energy costs.
- The project promoted drought-resistant crop varieties, including Jhain Moong, along with climate-resilient vegetables for better performance under moisture stress, reduction of crop failure risk and ensuring diversified income sources for farmers
- An Aggregation Centre facilitated collective storage and marketing

CAPACITY BUILDING AND KNOWLEDGE ECOSYSTEMS

The Farmer Field School (FFS) model served as a living classroom for hands-on learning in crop stages, IPM, and INM, streamlining SHGs/Producer Groups and farmers received training on crop planning, market access, digital tools and government schemes, strengthening local institutions and governance.

IMPACT AND OUTCOMES

The integration of technology and community governance generated significant outcomes. Crop yields increased by 20–30%, while input costs declined by 30–40%, resulting in an average income increase of 25–35% per farmer per season. Water savings of 40–50% were achieved through drip irrigation and rain pipes. The check dam ensured irrigation security during dry spells, enhanced groundwater recharge, and increased cropping intensity, institutional strengthening through WUGs and Producer Groups improved resource management and long-term sustainability. Overall, 30 small and marginal farmers across 22 acres benefited directly from the intervention.

CONCLUSION

The Makuakateni cluster intervention illustrates that technology-driven, community-managed agriculture can be a powerful engine for sustainability. By integrating precision tools, renewable energy, water conservation, bio-inputs, and strong institutions, the project has created a scalable and replicable model for climate-resilient agriculture. This initiative proves that when corporate CSR support converges with grassroots expertise, farmers transition from climate vulnerability to climate leadership- this model provides a scalable pathway for ensuring long-term environmental and economic sustainability for smallholder farmers.

https://doi.org/10.52151/aet2026501.1901

Agricultural Engineering Today | 50 (1)

Soil, Skills, and Self-Reliance: How Vermicompost Training is Transforming Rural Women's Lives

Kapil Verma

Program Coordinator, CEASI- Centres of Excellence for Agriculture Skills in India
Kanpur, Uttar Pradesh

INTRODUCTION

As the winter sun rises over Village Kakoopur Halbal in Shivrajpur Block of Kanpur Nagar, Uttar Pradesh, a quiet transformation is taking place in courtyards and farm corners. Under simple shade structures, rows of vermibeds rest — alive with millions of earthworms silently working. For many, these are just compost units. But for the rural women who manage them, they are symbols of income, identity, and independence.

In a region where women have long contributed to agriculture without recognition or earnings of their own, a six-day Vermicompost Producers Training Programme (5 days training + 1 day assessment) has sparked a shift. Supported by the Agriculture Skill Council of India (ASCI) and Centers of Excellence for Agriculture Skills, with funding from PepsiCo, the programme combined sustainability with livelihood creation — placing women at its center.

Out of 30 participants, 25 were women (83.3%) and 5 were men (16.7%),

turning the training into a powerful example of women-led agricultural entrepreneurship.

THE TWIN CHALLENGE: SOIL DEGRADATION AND GENDER INEQUALITY

The training addressed the dual issues of declining soil health and limited income opportunities for rural women. Vermicomposting restores soil fertility while creating a low-investment, home-based enterprise that women can manage alongside household responsibilities.

TRAINING STRUCTURE AND LEARNING APPROACH

The six-day programme included five days of intensive practical training and one day of assessment. Participants learned soil health management, earthworm biology, vermibed preparation, raw material management, moisture and aeration control, harvesting techniques, packaging, and marketing strategies. Hands-on learning played a key role. Participants built vermibeds, layered materials, and observed compost formation. Initial hesitation turned into confidence as they saw waste transform into valuable organic manure.

FROM SKILL TO ENTERPRISE

Vermicompost production requires minimal infrastructure and uses materials available in rural households. A single vermibed can produce compost in cycles of 45–60 days. This creates opportunities for regular income, reduced fertilizer expenditure, and potential expansion into small-scale enterprises.

https://doi.org/10.52151/aet2026501.1902

ECONOMIC IMPACT

- Additional household income
- Reduced expenditure on chemical fertilizers
- Opportunity to sell compost to local farmers and nurseries

AGRICULTURAL IMPACT

- Improved soil structure and microbial activity
- Enhanced nutrient availability
- Support to organic and natural farming practices

ENVIRONMENTAL IMPACT

- Recycling of farm and household organic waste
- Reduced burning of crop residues
- Lower dependence on synthetic inputs

SOCIAL TRANSFORMATION

Perhaps the most meaningful change is social. Women who once worked silently in fields are now recognized as producers and entrepreneurs. Household discussions now include production planning, pricing, and marketing decisions. The vermibed has become more than a compost unit — it symbolizes confidence, knowledge, and economic identity.

Support for Enterprise Initiation

To ensure continuity beyond training, participants received certificates after assessment and vermibeds for immediate use. This direct asset support helped them start production at home without delay.

Economic, Agricultural, and Environmental Benefits

Economically, vermicomposting reduces fertilizer costs and creates additional income opportunities. Agriculturally, it improves soil structure, microbial life, and nutrient availability. Environmentally, it promotes recycling of organic waste and reduces chemical dependency.

Social Transformation and Women Empowerment

Socially, the impact has been transformative. Women are stepping into the role of producers and entrepreneurs, participating in household decision-making and community discussions on agriculture.

CONCLUSION

The experience from Village Kakoopur Halbal demonstrates that skill development, environmental sustainability, and women empowerment can grow together. Soil, skills, and self-reliance form the foundation of resilient rural development.

When women nurture soil, they nurture the future of agriculture itself.

Sustainability-driven Agricultural Technology for Jharkhand

Dr. Ajai Singh

Professor, Department of Civil Engineering & Dean School of Engineering and Technology, Central University of Jharkhand, Ranchi, India, Email: ajai.singh@cuj.ac.in

Despite relatively good annual rainfall of 1200-1400mm in Jharkhand, the dependence on monsoon distribution and dry spells makes the agricultural sector vulnerable and uncertain. Jharkhand has a geographical area of about 79.70 lakh ha, of which about 38 lakh ha is cultivable and nearly 25–26 lakh ha is net sown area. The state's major crops include paddy, wheat, maize, pulses, oilseeds and horticultural crops, with rice occupying a dominant share of cropped area (e.g., rice area about 1763 thousand ha and production about 5322 thousand MT, as reported in the state profile), indicating that improving water productivity and input efficiency in rice-based systems can yield major sustainability gains. The majority of agricultural area are under rainfed with low irrigation coverage, and therefore, harnessing the power of agricultural technology is essential for achieving long-term sustainability in Jharkhand because the state's farming system is predominantly rainfed, resource-constrained, and highly exposed to climate variability. Key sustainability constraints typical of Jharkhand such as sloping lands with hard rock areas, severe soil erosion, water scarcity, acidic soils, low soil fertility, low input use, and open grazing in rabi season, which together depress productivity and accelerate land degradation. Lowering of soil erosion, preserving moisture, improving climate resilience, and enhancing resource-use efficiency for small and marginal farmers are issues which can be addressed by adopting appropriate agricultural technology to achieve agricultural sustainability in Jharkhand.

The agriculture sector contributed about 23% of the state's GDP in 2023–2024, which supports investments in agri-tech to bring inclusive growth, rural employment, and a reduction in poverty levels. Therefore, boosting sustainability through technology is also economically sensible since it improves farm income and counter the vulnerability. Jharkhand's first sustainability pillar is precision water and irrigation technologies. Even in the absence of canal or big surface systems, micro-irrigation (drip and sprinkler), solar pumping with intelligent scheduling, and sensor-based

https://doi.org/10.52151/aet2026501.1903

irrigation advising can significantly improve water consumption efficiency and extend effective irrigation. The goal of improving farm-level water consumption efficiency through micro-irrigation systems like drip and sprinkler is explicitly defined in the Government of India's Per Drop More Crop (PDMC) operational guidelines. Because Jharkhand's irrigation coverage is low, PDMC-type interventions, when combined with watershed and minor irrigation improvements, can reduce overdependence on monsoon rains and improve drought tolerance, particularly in upland and undulating plateau settings.

The second sustainability pillar is climate-smart advisory technology, which uses agro-meteorological forecasts, district/block advisories, and digital dissemination platforms (SMS/WhatsApp/IVRS) to guide farmers on sowing dates, irrigation scheduling, nutrient timing, and pest alerts. Jharkhand experiences strong rainfall variability in space and time, and technology-backed advisories reduce the risk of sowing failure and crop loss by enabling decisions based on rainfall probability and dry-spell forecasts. The climate-resilient crop planning tools such as district contingency plans prepared by institutions like ICAR-CRIDA provide evidence-backed adaptation pathways that can be integrated into digital advisory services for local stakeholders. The third sustainability pillar is soil health improvement, because soil constraints are a major limitation in Jharkhand. Since acidic soils, erosion and low fertility are widely reported constraints, digitized soil health mapping, soil health card linked decision support systems, and variable/need-based input application (especially liming advisory and balanced nutrients) can improve long-term soil productivity while reducing excessive fertilizer use and input wastage. The integration of remote sensing and GIS into soil and water conservation planning can improve targeting efficiency of watershed interventions, ensure that drought/erosion hotspots are prioritized first, and enable monitoring of outcomes (vegetation cover, moisture stress, cropping intensity) without costly field-only methods.

Institutional and value-chain digitization, which improves access to capital, inputs, and markets, is the fourth pillar that supports sustainability. Primary agricultural credit society/cooperatives, digital finance, and transparent input/output chains are examples of farmer service delivery systems that have been digitized to lower transaction costs and increase the resilience of rural livelihoods, particularly for smallholder and tribal farmers. A comprehensive sustainability ecosystem is created when such digital platforms are combined with irrigation assets, watershed structures, and advisory services. Farmers can access affordable technology, receive practical advice, and obtain steady market and financial support. Therefore, a sustainability-driven agri-tech strategy for Jharkhand should be built on better water management techniques, early warning systems, soil health reporting and value chains. These will directly address the state's current problems, such as low irrigation coverage, rainfall dependence, soil degradation and economic vulnerability.

Technological Applications in Aquaculture

Dr Pratap Mukhopadhyay
Principal Scientist (Retired), ICAR-CIFA, Bhubaneswar, India

Aquaculture in India which evolved from a state homestead activity in early 1960s has now become reasonably major enterprise across the country in both inland and coastal states thereby adding to the food basket, employment generation as well as economy of different regions. The aquaculture practices including integrated farming, inland saline aquaculture, ornamental fish culture, prawn farming are highly compatible and flexible with regard to scale of operation, both in size and investment.

FISH BREEDING AND REPRODUCTION

Earlier in the absence of precise knowledge on aspects of fish breeding and reproduction fish seed- the primary input in aquaculture used to be collected from riverine sources during monsoon months and then stocking those painstakingly collected seeds in culture ponds for farming. This was then followed by gradual epoch making technology development . The use of pituitary hormones in carp breeding in captivity was established in 1957. It was on 10th July,1957 *Cirrhinus reba* was induced to breed by administration of aqueous carp pituitary extract (female fish receiving pituitary extract in two split doses at 6 hours interval while male species received the single dose at the time of second dose to female) at Cuttack Research Centre of ICAR-CIFRI, Barrackpore. This confined water induced breeding (The various carp species mature in confined/still water but fail to breed spontaneously there and that was the reason why the required quantity of seed had to be collected from nature and then to stock in ponds/tanks for culture) may be considered as the first viable technology used in aquaculture. Since then this was subjected to several modifications for increasing the efficiency. Development of several ready to use synthetic inducing agents like LHRH-a ,HCG, GnRH plus domperidone etc as alternative to pituitary hormone made the technology of induced breeding easier and farmer-friendly The technology of multiple carp breeding in the same season has been able to demonstrate 2-3 fold higher spawn recovery from a single female through 3-4 times breeding within an interval of 45-50 days between each breeding The technological evolution of hatchery designed operation from initial earthen ponds/pits to double walled hapa and subsequently to glass jar and circular eco-hatchery provided scope to produce and handle large quantities of egg obtained during hatching. Now there are several thousand hatcheries in operation in the country both in public and private sector. FRP hatchery- a portable small size hatchery facilitates to undertake fish breeding programme even in the hilly regions.

Another important technology has

https://doi.org/10.52151/aet2026501.1904

been the cryopreservation sperms (-196 degree Celsius) from healthy male species enabled fertilization of mature and viable eggs during the off season as well as during the season in case the maturity of male and female species did not synchronise. This cryopreservation has been facilitating preservation of sperms from genetically superior male fishes for fertilization of matured eggs allowing production of healthy spawn. quality fish seed could ensure significant improvement in aquaculture production paving the way for a vibrant commercial enterprise.

The next major breakthrough resulted in the development of a high yielding production technology popularly called composite fish culture. This is a polyculture involving a combination of three indigenous major carps-catla, rohu and mrigal along with three exotic carps silver carp, grass carp and common carp. This technology made use of natural food organisms available in three different ecological niches of a pond that could be enhanced further by fertilization/ manuring and supplemented through exogenously prepared compounded feed. Over the past decade there has been a transition from traditional extensive culture system with a production level of about 2 tonne / ha/year to semi -intensive production level of 5-6 tonne/ha/year and then towards intensive systems (production level of 10-15 tonne/ha/year. This was achieved by increasing stocking densities from 5000 to 10000 pieces / ha .As the stocking density exceeds the natural carrying capacity of ponds, a shift from dependence of natural food to a supply of nutritionally complete exogenous feed became vital Advances in the optimization of supply various macro and micronutrients, through nutrient and energy requirement study

of the cultured species ,data related to appropriate protein: ,energy ratio led to a production of 17 tonne /ha/year in intensive carp culture. In a similar manner certain important catfish ,perch, murrels, featherback ,loaches, prawns have also been brought under controlled culture systems and so also cold water species like trouts. Researches on fish nutrition have demonstrated that expression of related genes can be modified with different feeding components.From nutrigenomics point of view nutrients are feding signals which are detected by cerllular system of sensors and which influence the expression of genes and proteins in consequence

NUTRITION AND FEEDING

Since fishes including carps have a general tendency to utilize significant proportion of dietary protein to meet their energy demands, recent research promotes the concepts that considerable protein economy can be achieved without adverse effects on growth by increasing dietary non-protein energy supply leading to better protein utilization for growth with consequent decreased emission of catabolic end products such as ammonia into the ambient environment. Deficiency of non-protein energy sources results in catabolism of protein to generate energy while excess energy can suppress appetite, reduce growth and increase lipid deposition. To optimize protein utilization in fish, the concept of protein-energy interaction has received adequate attention and it is now known that significant dietary protein sparing can be achieved by increasing the dietary digestible energy levels through incorporation of lipid and carbohydrate constituents. Given that the nature of rapid transition from extensive to semi-intensive and intensive feed based culture systems, knowledge on the metabolic utilization of nutrients is recognized as fundamental for questions related to sustainability.

Indian major carps have very long intestine to facilitate utilisation of various plant derived feedstuff naturally rich in carbohydrates and they have very high intestinal amylase activity also. Some difficulties seem to arise with high levels of dietary starch as exemplified by high plasma glucose concentration and prolonged post-prandial hyperglycaemia. These phenomena were initially thought to be due to impairment of glucose phosphorylation capacity which is catalysed by a group of enzymes commonly called hexokinases. Until recently glucokinase was considered absent in fish but data now available confirmed existence of this enzyme in carp hepatopancreas as well as its regulation by dietary carbohydrate supply. Gluconeogenesis from dietary amino acids or from body protein degradation is also considered high in fish. Persistent gluconeogenesis is another possible mechanism by which high post-prandial hyperglycaemia is maintained in fish. Whether changes with dietary carbohydrate level, hepatic glucose 6 phosphatase activity and its gene expression get affected, however, yet to be established in Indian major carps.

Carps generally can adapt to high carbohydrate diet by increasing hepatic glycolysis and lipogenesis with concomitant decrease in gluconeogenesis and amino acid degradation. One of the major concerns is to achieve an understanding of the nutritional regulation of carbohydrate metabolism in fish since improvement in its utilisation will have practical implications in aquaculture.

IMPROVEMENT IN NUTRIENT UTILISATION FROM PLANT DERIVED FEEDSTUFFS

High levels of non-starch polysaccharides (NSP) such as cellulose, xylans and mannans found in cell wall materials reduce the nutritive value of many plant derived feed resources. The potential of bacterial cellulase pre-treatment of supplementary feed has been tested with success in carp feeding. The application and benefits of phytase in fish species is well documented now. There are a range of factors that can affect nutrient and energy utilization from feed ingredients. The anti-nutritional factors (ANFs) have the potential to cause problem in this context by interfering with digestion, palatability or even cellular function. There are simple means which can be applied to eliminate these depending on the mode of action of these factors. The common detoxification methods to overcome most of the anti nutritional factors are inactivation by heat and/or soaking in warm water. However, these physical processes are not conclusive in removing the deleterious effects of the wide variety of anti nutrients. Water-soluble nutrients may leach out, or heat may destroy some of the nutrients lowering the quality of feedstuffs. Suitable processing can increase the nutritive value of these ingredients. Phytic acid is the major phosphorus (P) storage compound in most plant feedstuffs. Again phytate forms compounds with a large number of minerals (K, Mg, Ca, Zn, Fe and Cu) and also forms complexes with proteins and basic amino acids like lysine and arginine, thereby reduces bioavailability of minerals and decrease digestibility of proteins in fish

Technologies like CIFABROOD (Trademark) - a broodstock feed that helps in providing better egg quality and thus contributes to higher survival, growth and healthy fish production.

Genetic improvement of cultivable carps: Genetic improvement of Rohu through selective breeding for growth and feed utilization efficiency demonstrated an impressive 17% genetic gain per generation over 6th generation of selection. The improved Rohu (Jayanti) is now one of the most favoured species in the country. The improved Rohu has been taken up in several states of the country including Odisha, West Bengal and Andhra Pradesh. The field testing were successfully done prior to dissemination at different agro-climatic regions for example Rahara in West Bengal, Jalandhar in Punjab, Vijaywada in Andhra Pradesh. In a similar manner, improved catla and improved scampi (Macrobrachium rosenburgii) have been developed and disseminated throughout the country.

Fish health management: Several disease diagnostic kits like Dot-ELISA kit for farm diagnosis of ulcers, septicemia with different bacterial soluble antigens, positive and negative serum raised in rabbit; spot agglutination kit for on-farm diagnosis of Aeromonus, Edwardsiella, Vibrio, Pseudomonus and Flavobacterium species in particular Value addition in terms of product and improvement of traitsare now achievable ICAR_CIFA has a variety of technological offeringto augment the fish production.Improved rohu (Jayanti) a genetically improved strain of rohu which gives18 %

additional growth in a year. Similarly, catla (Improved) named Amrit catla and scampi (macrobrachium rosenbergii) thus indicating key strategies for vertical expansion through genetic improvement of cultured stock Selective breeding programme benefit immensely particularly after the emergence of massive parallel sequencing technology along with remarkable advances in computational technology and artificial intelligence

There have been several other farmer friendly simple technologies like periphyton based fish farming system proved quite promising in terms of growth, survival and total yield with periphyton. The submerged substrates on which periphyton developed in the aquatic system improved water quality in particular. The substrates were bamboo sticks, PVC pipe, ceramic tiles etc. It has been noticed that periphyton based system increased aquaculture production and also developed resistance towards infection through augmentation of immune response. Again multiple stocking and multiple harvesting model was developed for resource poor farmers wherein multiple stocking and multiple harvesting model resulted in augmentation in productivity of small ponds by many folds. Just by managing the ponds for 3-4 months through such stocking and harvesting model the farmers starts earning which is reinvested for procurement of required inputs for medium and minor carp rearing. This technology indicated that, with meagre resources the farmer can continue fish culture and earn at regular intervals continuously.

Recently two water use efficient technologies, one recirculatory aquaculture system (RAS), biofloc technology (BFT) and aquaponics have been developed and are getting widespread acceptance. RAS is essentially a technology for farming fish by reusing the water in the production. The production is based use of mechanical and biological filters. Here the water exchange is almost non-existent. The biofilters continuously reduce ammonia built up. The main benefit is the ability to reduce the need for clean fresh water while still maintaining an ambient of fairly good water quality for fish. BFT is mainly based on the principal of metabolically waste recycling in particular nitrogenous into microbial biomass that can be utilized insitu by the cultured fish. Heterotrophic microbiota is stimulated to grow by stimulating the C/N ratio in water through the modification of carbohydrate sources in feed or by the addition of an external C source in water so that the bacteria can assimilate the waste ammonia for new biomass production. BFT significantly reduces the quantity of water use in aquaculture.

Demonstration of a host of culture technologies depending upon the availability and provision of varied types and levels of inputs has made aquaculture practice more acceptable and remunerative. Though localized Though localized, the non-conventional culture sytems like wastewatefed aquaculture, integrated farming system,cage and pen culture have shown their potential as ecofriendly and alternaive farming options in several states in the country.

Shortage of water and land will likely to impact backyard ponds and small waterbodies from the present scene and would therefore necessitate large scale useof pens and cages in tanks, wetlands and reservoir. Seasonal and wtersheds thaso far, it is imperative that these are suitably used to have not been used for aquaculture that might disappear in the foreseeable future.

Agriculture's Digital Shift: Lessons from the Field

Mr. Swapnil(Neil) Jadhav
Founder & CEO, MapMyCrop

India's agriculture sector stands at a curious inflection point. While there is a surge of digital innovation ranging from satellite-based crop monitoring to AI-driven advisory tools, the bulk of Indian farming is stubbornly anachronistic. This gap between promise and penetration offers an important lesson: technology alone will not transform Indian agriculture unless it is integrated, validated on the ground, and designed for the smallholder, at the last mile.

The numbers tell a revealing story. India's agritech market is set to grow from $9 billion in 2025 to $28 billion by 2030, a robust 25% CAGR, according to Inc42. Yet the broader agriculture sector expected to expand from $452 billion to $563 billion over the same period will see agritech's share rise only from 2% to about 5%. This suggests that while innovation is accelerating, adoption is tardy.

Fragmentation is the core constraint. Nearly 86% of India's farmers are small and marginal, and an ASSOCHAM report of November 2025 notes that most agritech solutions fail to reach them. "India must shift from fragmented agricultural innovations to systemic integration through state-level testing platforms and unified data frameworks to reach the vast majority of farmers still untouched by technology," the report mentions. Technologies are often developed in silos with separate apps for advisory, credit, insurance, or market linkage leaving farmers to navigate a fragmented digital ecosystem with limited literacy and connectivity. This is where policy has begun to play an enabling role.

DIGITAL AGRICULTURE MISSION

Recognising the need for integration, the government approved the Digital Agriculture Mission in 2024 with an outlay of Rs 2,817 crore to build digital public infrastructure (DPI) for agriculture. The mission aims to create foundational layers such as AgriStack, a Krishi Decision Support System, and soil profile mapping, according to the Press Information Bureau.

A central element is the creation of unique Farmer IDs, with a target of covering 11 crore farmers by 2026–27. Parallelly, the Digital Crop Survey covering over 23.9 crore land parcels during the Rabi 2024–25 season has begun generating real-time, plot-level data on crops and landholdings. This data collection is critical: without reliable, interoperable datasets, satellite- and AI-driven crop intelligence platforms cannot scale sustainably across regions.

https://doi.org/10.52151/aet2026501.1905

STATES AS LABORATORIES OF INTEGRATION

While the central government provides the architecture, state governments are where digital agriculture meets the field. Under the National e-Governance Plan in Agriculture (NeGPA), states receive funding to deploy emerging technologies such as AI/ML, IoT, and blockchain. Several applications of AI and IoT have been deployed on the ground across agriculture, including precision farming, agricultural drones, livestock and climate monitoring, smart greenhouses, and AI-enabled satellite and computer vision for crop and field analysis.

Several states offer instructive examples. Uttar Pradesh is positioning State Agricultural Universities as agri-incubators to accelerate technology validation and farmer adoption. Madhya Pradesh's UNNATI (AgriGIS) project combines satellite imagery, drone data, and mobile-based ground verification to improve crop assessment and procurement decisions. Maharashtra has rolled out a comprehensive agri-tech policy that formally integrates artificial and digital intelligence across the entire farming value chain moving beyond pilots to state-wide deployment. Karnataka's C-CAMP K-tech Agri Centre of Excellence, supported by state funding, is helping startups conduct field trials and access scientific networks. The common thread across these initiatives is integration linking data, institutions, and last-mile delivery rather than treating technology as a standalone fix.

LESSONS FROM THE FIELD

What does this mean for farmers on the ground?

First, digital tools work best when paired with physical interventions. The centrally sponsored Per Drop More Crop (PDMC) scheme illustrates this well. Micro-irrigation systems supported by digital planning tools have helped save 40–50% water, reduced fertilizer use through fertigation, and improved crop productivity by 20–30%, according to government evaluations.

Second, technology adoption depends on human capability. The Modi government has rolled out multiple skill development initiatives to upskill farmers, rural youth, and agricultural workers, focusing on scientific farming, mechanisation, and entrepreneurship. Programmes such as Skill Training of Rural Youth (STRY) provide short-term training in modern agricultural practices, while Krishi Vigyan Kendras act as local knowledge hubs for technology transfer. The Agriculture Technology Management Agency (ATMA) strengthens district-level extension services, ensuring timely access to best practices. Under the horticulture mission's HRD component, training and exposure visits build farmer confidence in new methods. Complementing these efforts, Rashtriya Krishi Vikas Yojana gives states flexibility to design region-specific agricultural interventions.

Third, AI is emerging as an invisible enabler rather than a headline feature. An AI-powered chatbot, unveiled in June 2025, built using Google Gemini and trained on AgriStack data, answers farmers' queries in multiple languages. At the field level satellite- based crop intelligence platforms are using AI to fuse high resolution imagery, weather data, rainfall patterns, and crop growth models to detect water stress, pest pressure and nutrient deficiences early, converting these signals into simple, plot level advisories delivered through mobile and conversational interfaces. Other pilots use AI for crop identification, survey authentication, and backend optimisation quietly improving efficiency without burdening farmers with complexity.

INTEGRATION IS THE REAL TAKEAWAY

Agri-tech will not scale through isolated apps or short-term pilots. It requires interoperable data, policy-backed digital public infrastructure, state-level execution, and farmer-centric delivery models. The key lesson from the field is clear: integration not innovation alone is what converts digital promise into agricultural productivity. When we get this right, agri-tech will evolve from a niche sector into a genuine growth engine for a workforce that still employs nearly two-thirds of the country.

How Technology is Helping Create Stronger Connections Between Farms and Supply Chains

Vinay Nair
Founder & CEO, Khetibuddy Agritech

Over the past several years, I have spent time with farmers, agribusiness leaders, exporters, and food brands both in India and overseas. One pattern is clear: farms and supply chains are deeply dependent on each other, yet historically they have operated with limited visibility into each other's realities. Farmers focus on production. Buyers focus on procurement. Processors focus on quality. Brands focus on consumers. But very often, the data connecting these stakeholders is either delayed, incomplete, or inconsistent.

This gap creates inefficiency, mistrust, and financial risk. Today, technology is beginning to close that gap and in doing so, it is fundamentally strengthening the relationship between farms and supply chains.

FROM UNCERTAINTY TO VISIBILITY

In traditional systems, information typically flows after harvest. Yield estimates are confirmed late. Quality issues are discovered at procurement centers. Compliance documentation is assembled manually. If a pest

outbreak affects yield, the buyer may know only when volumes fall short. **This reactive model increases cost for everyone.**

Digital platforms, remote sensing, mobile-based field data capture, and IoT integrations are changing that. Crop health can now be monitored through satellite imagery. Farm activities such as input application, irrigation, and harvest dates can be logged in real time. Soil and weather data can be integrated into predictive models. When this information is shared across the supply chain, decisions improve.

Procurement teams can forecast more accurately. Processors can anticipate quality variation. Exporters can verify compliance before shipment. The sustainability teams can monitor environmental factors directly from the source. The farm is no longer a "black box." It is now a transparent and measurable part of the supply chain.

At KhetiBuddy, this realization helped shape our strategy for building our software platform, Verdnt, which is designed exclusively for large farms and agri-businesses. The strategy is simple: to provide a shared data framework that connects farm-level operations to the supply chain requirements that follow.

PREDICTABILITY REDUCES RISK

Unpredictability is one of the biggest sources of pain in the agricultural industry Weather patterns, pest attacks, nutrient deficiencies, and farm-level issues can all impact production and quality. For supply chains, this means broken commitments, price instability, and failed deliveries.

https://doi.org/10.52151/aet2026501.1906

Precision agriculture technology is working to fix this.

Crop monitoring through satellite imaging can identify stress early on. AI-powered alerts can suggest corrective measures. Digital crop planners synchronize farm activities with procurement schedules. Weather forecast alerts can prevent unnecessary damage.

When supply chains are aware of these factors prior to harvest, they can better plan for them.
Technology does not eliminate agricultural risk but it converts unknown risks into manageable ones.
Traceability Is No Longer Optional
Consumers and governments are calling for more transparency.

Export markets are increasingly demanding traceability at the farm level. ESG goals require quantifiable data. Customers want to know not only what is being produced, but also how it is being produced.
Manual systems cannot meet these expectations at scale.

Digital traceability systems allow geo-tagged farm records, package of practices, harvest tracking, and batch-level mapping across the supply chain. When properly integrated, they create an auditable record that strengthens trust between farmers and buyers.
This shift benefits both sides.

Farmers who maintain clean, compliant records gain stronger market access. Buyers reduce compliance risk and improve brand credibility.

In many ways, traceability is becoming the new baseline for serious agribusinesses.

SUSTAINABILITY AS A SHARED RESPONSIBILITY

Perhaps the most significant shift is happening in sustainability measurement. Large food and agriculture companies have committed to reducing their carbon footprint. But emissions do not originate in corporate offices they originate in fields.

Fertilizer usage, irrigation practices, soil carbon levels, and crop residue management all influence environmental impact. To manage Scope 3 emissions effectively, supply chains need accurate farm-level data.

Digital Monitoring, Reporting, and Verification (DMRV) solutions are now making it possible to estimate carbon and monitor sustainability based on farm data, satellite imagery, and scientific models. This opens up new possibilities.

Farmers practicing regenerative agriculture can now potentially qualify for carbon-based rewards. Businesses can now report measurable environmental success rather than vague objectives. Profitability and sustainability can now be integrated in supply chains.

At KhetiBuddy, we believe that sustainability should not be a project by itself but should be an essential part of the supply chain data platform. Platforms such as Verdnt seek to integrate operational, traceability, and sustainability data into a single system because a fragmented system cannot produce measurable results.

ADOPTION IS THE REAL TEST

But the biggest challenge still remains in adoption.

Technology has to be useful. It has to fit with the way field teams work. It has to provide clear economic value not just digital reporting.

When farmers notice better yields, faster payments, better market access, or lower risk, adoption follows naturally. When agribusinesses notice better forecasting, lower rejection rates, and better compliance positioning, integration becomes a priority.

Technology is most useful when it makes coordination easier—not harder.

THE ROAD AHEAD

The agricultural sector is on the cusp of a new era in which data-driven collaboration will set the pace for competitiveness.

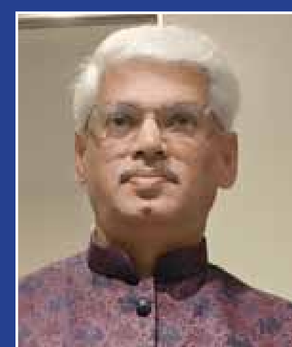
Farms will increasingly be digitally enabled production units. Supply chains will be intelligent networks, not separate stages. Sustainability will shift from a goal to a measurable reality.

Technology is not undermining human relationships in agriculture. It is enhancing them by creating transparency, predictability, and shared accountability.

Better links between farms and supply chains are more than just efficiency gains. They are resilience gains.

And in today's agricultural world, resilience is everything.

Rethinking GM Crops: Balancing Promise, Risk, and Sustainability



Dr Chittaranjan Kole & Dr. Manikanda Boopathi

A recent perspective article published in the international scientific journal *The Plant Genome*, titled "*Benefits, concerns, and sustainable alternatives to genetically modified crops from a global and Indian perspective*," examines the growing debate around genetically modified crops (GMCs). The study is authored by a team of 20 scientists from prominent research institutions in India and the United States. The authors include experts from ICAR institutes, public universities, private universities, an autonomous college, an institute and a non-profit society from India, and HudsonAlpha Institute for Biotechnology, Texas Tech University and the USDA-ARS from the United States. Their combined expertise in plant biotechnology, genetics, breeding, genomics, agronomy and information technology provides a strong scientific foundation for the article's balanced analysis of genetically modified crops. Most importantly, this article was conceptualized and led by Prof. Chittaranjan Kole, regarded as the "Father of Plant Biotechnology in India" and coordinated by Prof. N. Manikanda Boopathi, an eminent agricultural biotechnologist.

Genetically modified crops (GMCs) are plants in which alien genes have been inserted to help farmers grow food more easily and reliably. Today, they are widely discussed because of their possible role in improving food supply, protecting the environment, and using new technology in farming. Over the years, studies and real farm experience in many countries have shown that some GMCs can be useful. It helps farmers control harmful insects, diseases and weeds, delay ripening, and use fewer chemical pesticides. This means farmers are exposed to fewer toxic sprays and can earn better profits.

New types of GMCs are now being developed to handle problems like drought, salty soil, and extreme weather, which are becoming more common due to climate change. Some GMCs are also being designed to contain extra vitamins or minerals. These crops could help fight "hidden hunger," where people eat enough food but still lack important nutrients.

However, GMCs also raise serious concerns. One major worry is their effect on the environment. When the same GM crops are grown over very large areas, insects and weeds can slowly adapt and become resistant. This can make the crops less effective and force

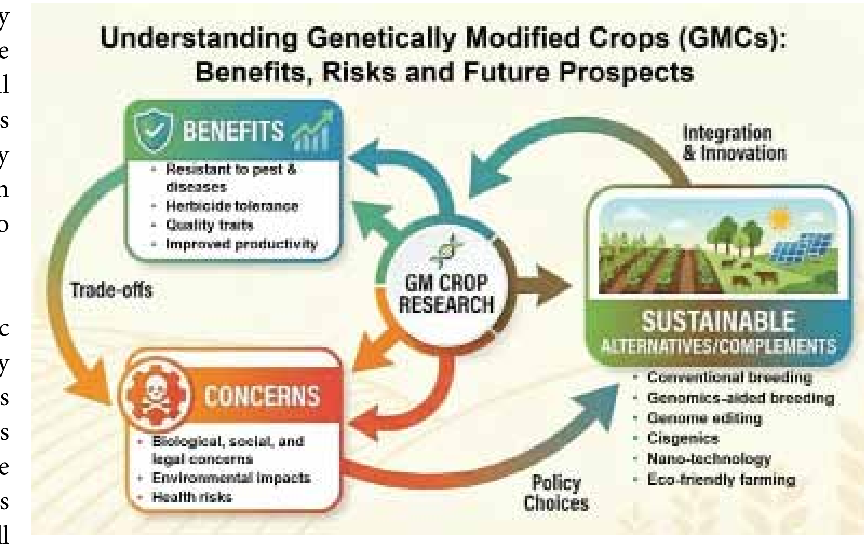
https://doi.org/10.52151/aet2026501.1907

farmers to use more chemicals or buy new seeds. There are also fears that these crops may harm helpful insects, soil organisms, or disturb natural ecosystems over time. These effects are hard to study quickly because they need long-term observation, which many countries do not properly support.

There are also social and economic issues. Many GM seeds are owned by large multinational companies. Critics worry that when only a few companies control most seeds, farmers may lose their freedom to save or share seeds and may have to pay higher prices. Small farmers can become dependent on these companies and may suffer if prices rise or supplies are disrupted. Weak safety rules, unclear responsibility in case of damage, and lack of transparency have also increased public distrust. In many places, people hear only extreme opinions for or against GM foods, without clear and balanced information.

This mix of benefits and concerns explains why GMCs are used unevenly around the world. Most GM farming involves only a few crops (soybean, maize, cotton, and canola) and is concentrated in a small number of countries. India is a good example of cautious use. Apart from Bt cotton, very few GM crops are allowed, even though Indian scientists have developed useful varieties. Long court cases, unclear policies, and strong public disagreements have slowed approvals. At the same time, India faces big challenges: feeding a large population, dealing with climate change, and improving nutrition. Because of this, it is hard to fully reject GMCs or accept them without question.

As a result, many experts suggest a rational middle path. Instead of banning all GM crops or approving all of them, each crop should be judged separately.



Important questions should be asked before and after developing a GM crop: Does this crop yield more? Does this crop solve a real farming or nutrition problem? Are the risks acceptable in the local environment? Who benefits, and who might be harmed? Farmers and local communities should be included in these decisions, not just scientists and officials.

It is also important to remember that GMCs are not the only solution. Traditional plant breeding has improved crops for many years and continues to do so. New tools like molecular breeding, genomics-aided breeding, nanotechnology, cisgenics, and gene editing can make small, precise changes without adding genes from other species. Along with this, eco-friendly farming methods (such as improving soil health, growing different crops, using fewer chemicals, and managing pests carefully) can increase yields and protect nature. Better farm practices like timely planting and precise use of inputs also help.

For governments, the main task is to combine all these approaches into a clear and fair food policy. Strong and transparent safety rules are essential. Comprehensive review and survey are essential before initiating research. Crops should be carefully tested before approval, and their effects should be monitored over time. Rules should clearly explain who is responsible if something goes wrong. Public research and open access to technology can reduce the power of big companies. Just as important is honest communication. People need simple explanations about what GM crops are, how they differ from traditional crops, and what risks and benefits they may bring. Admitting uncertainties and involving farmers early can build trust.

In the end, the debate about GM crops is not only about science. It is also about who controls food, how farming should develop, and what kind of future society wants. By recognising both the benefits and the risks of GMCs, and by using them alongside other farming methods, countries like India can choose a balanced path that feeds people while protecting the environment.

Sweat Behind the Fiber: Uncovering Labour Burdens in India's Cotton Economy, Automation and Robotics Opportunities

Chetan M. Badgujar[1], Mrutyunjay Padhiary[2], and Lori Duncan[1]

[1]Biosystem Engineering, The University of Tennessee, Knoxville, USA, 37996.

[2]Department of Agricultural Engineering, Assam University, Silchar, India,788011.

INTRODUCTION:

Cotton, being a major cash crop, is often referred to as "*white gold*" in India. It clothes a nation, drives a $222 billion textile industry, and sustains the livelihoods of over 6 million farmers. India stands as a global powerhouse in cotton production, cultivating 12.4 million hectares in 2023-24, making it the world's largest cotton acreage holder and the second-largest producer by volume (Table 1). Yet, for all its global significance, the story of cotton often overlooks the

https://doi.org/10.52151/aet2026501.1908

Table 1: Comparative overview of the top five cotton-producing countries in the world for the years 2023-2024.

Country	Area (Thousand ha)	Production (Million metric tons)	Avg. Yield (kg/ha)	Harvesting Mechanization Level
China	2872	5.60	1950	Medium (~75-80%)
India	12469	5.50	441	Low (~2-4%)
Brazil	1930	3.56	1845	High (90-100%)
USA	2859	2.63	921	High (100%
Pakistan	2370	1.35	570	Low (~2-4%)

Figure 1: Two examples of cotton harvesters developed for Indian conditions.

harsh reality of those who harvest it. Almost all cotton in India is still hand-picked. Each white boll passes through the hands of human pickers, who work long hours under the scorching sun. The task involves repetitive bending, plucking, storing, and carrying heavy loads, making harvesting physically exhausting and socially and economically burdensome. This article sheds light on the hidden sweat behind India's cotton harvesting, exploring the labour challenges, mechanized solutions, and how emerging automation and robotics could redefine cotton's future.

COTTON HARVESTING IN INDIA: A MANUAL MARATHON

Unlike in the USA, Brazil, and China, where mechanical harvesters dominate the landscape, India's cotton is almost entirely picked by hand. This reliance on manual labour stems from a combination of factors, including small and fragmented landholdings, varied planting patterns, high machinery costs, and cotton varieties that are not always suited to mechanical pickers. These challenges leave farmers with little choice but to rely on human labour.

An experienced adult can pick only 15-20 kg of seed cotton per day, and it is estimated that cotton harvesting requires ~500 man-hours per hectare. To put this in perspective, harvesting India's 12.4 million hectares of cotton in 2024 (at a rate of 500 man-hours/hectare) would require approximately 6 billion man-hours. This stands in stark contrast to the USA, where 100% of cotton is harvested by machines across millions of hectares, underscoring the vast difference in mechanization and the heavy burden placed on India's farmworkers.

The faces behind this arduous labour are predominantly women, children, and migrant families. These workers often work under informal or casual arrangements where daily earnings frequently fall in the lower range of approximately Rs.200–Rs.300, although formal minimum wage rates in several states are higher. Women and children often face wage disparities, earning less than men for the same tasks. The physical toll on workers is severe, leading to chronic musculoskeletal strain from constant bending and repetitive motions, respiratory issues from inhaling dust and fibres, and exhaustion from long hours under the sun. Beyond the immediate physical burdens, relying on manual labour perpetuates a cycle of poverty that often affects children's access to education and hinders socio-economic mobility within these communities. Unlike industrial workers, manual cotton harvesters frequently lack access to basic health protections, leaving them vulnerable to chronic conditions and long-term health decline.

WHY DOES MECHANIZATION LAG IN INDIA?

If cotton harvesting is so backbreaking, why hasn't India shifted toward machines? Several interrelated factors explain the persistence of hand-picking. First, India's average farm size is less than two hectares, which makes large U.S.-style harvesters impractical on fragmented plots. Second, Indian cotton varieties often mature unevenly, requiring multiple rounds of picking that machines struggle to perform efficiently. Third, even scaled-down harvesters remain prohibitively expensive for most smallholders, a challenge exacerbated by the limited availability or accessibility of government subsidies and supportive financial mechanisms. Historically, policy frameworks have struggled to effectively promote mechanization among small and fragmented landholdings. Future policy considerations could involve targeted subsidies, credit facilities, and awareness campaigns to incentivize the adoption of suitable technologies. Finally, cotton harvesting supports millions of rural jobs; any sudden shift to mechanization risks displacing vulnerable groups, making it both politically and socially sensitive. While a new, adapted harvester system is being developed for Indian conditions (Figure 1), its widespread adoption remains a challenge.

Figure 2: Example of ongoing research effort on robotic harvester in USA and India.

AUTOMATION AND ROBOTICS: A NEW DAWN FOR HARVESTING?

As India seeks to modernize its agricultural sector, cotton harvesting emerges as a prime candidate for automation innovation. However, solutions for cotton must be uniquely tailored to India's farm structures and production realities. This necessitates the development of robotic systems capable of selective picking, which is crucial for India's cotton varieties that mature unevenly. Recently, agricultural robotics has received considerable attention in crop production, and cotton may benefit from this trend in the long run. Experimental robotic arms equipped with computer vision are being tested to identify and pluck open bolls selectively, an approach especially suited to India's unevenly maturing cotton. Although these technologies are still in the early stages, they hold promise to transform harvesting into a more precise and less labor-intensive process. At present, however, most robotic pickers or arms remain in the research and development phase, with a long journey ahead before becoming field-deployable systems.

A robotic arm-type picker is very common in research and development since it mimics human hand-picking action. A robotic cotton arm works by combining sensors, computer vision, and precise mechanical movement to automate harvesting. Cameras and sensors first scan the plants to detect and locate ripe cotton bolls. This visual data is then processed by algorithms, which decide which boll to pick and the optimal path to reach it without damaging the plant. The robotic arm extends, and its end-effector, often a suction device or soft gripper, plucks the cotton. The harvested fiber is transferred into a collection bin, while the system continuously updates through sensor feedback to maintain accuracy. This selective and automated approach shows potential to solve the labor challenges.

Several promising pilot projects in India are showcasing the potential for localized solutions. Prototypes developed by institutions like the Indian Institute of Technology, and startups such as GRoboMac (http://www.grobomac.com/), are undergoing testing in diverse field conditions (Figure 2). These trials are evaluating key performance metrics such as picking efficiency, crop damage rates,

and adaptability to varying plant architectures. Early results, while encouraging, also highlight areas for improvement, particularly concerning speed, cost-effectiveness, and robustness for widespread deployment across small farms.

Despite these promising prototypes, no robotic cotton harvester has been successfully commercialized to date. Key components like robot navigation, boll detection, types of end effector, and precise arm manipulation and control continue to be the primary focus of research. In the USA, institutions like the University of Georgia and Clemson University are also actively researching small, single-row robotic platforms. While initial laboratory-to-field trials demonstrate potential, current systems are often too slow and inefficient for large-scale commercial use, underscoring the need for further development before these technologies can be widely deployed.

CONCLUSION: EASING THE SWEAT BEHIND THE FIBER

India's cotton production reveals the paradox of modern agriculture: a globally vital commodity still produced under arduous and archaic labor conditions. Despite its importance to the economy, harvesting remains almost entirely manual, demanding billions of labor hours annually and exacting a heavy physical and social toll.

While automation and robotics may not be a panacea, they do offer a path to significant advancement. Recent advances in robotic arms, boll detection, and navigation systems, though still largely experimental, demonstrate the potential to reduce drudgery, improve efficiency, and restore dignity to labor. Startups such

as GRoboMac illustrate early steps toward solutions tailored to India's context, but challenges of affordability, efficiency, and scalability remain.

The way forward for India's cotton sector demands a holistic approach that transcends mere technological breakthroughs. It requires creating machines and robots that are cheap and easy for small farmers to use while also being part of shared ownership and training programs. This comprehensive strategy is vital to ensure that women and migrant laborers, currently bearing the brunt of manual harvesting, are not displaced but rather repositioned into higher-value roles within an evolving agricultural landscape. Policymakers, research institutions, and industry leaders must collaboratively work to bridge the gap between innovative prototypes and widespread, field-ready, and socially equitable solutions.

Ultimately, the long-term vision for India's cotton economy is one where technology serves as an enabler for sustainable growth and social equity. By thoughtfully integrating advanced robotics and automation, India can not only enhance its productivity and global competitiveness but also significantly ease the physical burden on its agricultural workforce. This transformation promises to shift India's cotton narrative from one defined by struggle to one characterized by innovation, improved livelihoods, and a dignified future for millions of farmers and laborers.

Fruit Blotching Disorder in Cherry Tomato under Hydroponic Protected Cultivation

Suryaprakash Kukyan, Bhanothu Shiva, Suresh Rao EY, Ranjit Gopal Patil, Venuteja Reddy
Simply Fresh Private Limited, Siddipet, Telangana
Corresponding author: shiva.b@simplyfresh.co.in

INTRODUCTION

Cherry tomato (Red) is one of the most attractive and profitable crops cultivated under hydroponics and protected cultivation in India. With rising consumer demand for exotic vegetables and fruits in metropolitan markets, cherry tomato fetches a premium price due to its appealing size, bright red colour, and sweet taste. Uniform ripening and appearance are critical for maintaining this premium quality.

However, many growers face the challenge of fruit blotching or uneven ripening, especially under conditions of high temperature, fluctuating humidity, and nutritional imbalance. Fruits that fail to ripen uniformly are downgraded in quality, reducing their market value by 30–40%.

Adding to the complexity, blotchy ripening is often mistaken for viral infections such as Tomato Spotted Wilt Virus (TSWV) or Tomato Mosaic Virus (ToMV), since the external symptoms appear similar. This misdiagnosis may lead to unnecessary pesticide use and inappropriate management practices.

At the core of this problem lies lycopene, the natural red pigment that gives tomato fruits their characteristic colour. Lycopene biosynthesis is highly sensitive to temperature, light, and nutrient availability. Temperatures above 30–32°C suppress lycopene formation, while inadequate potassium nutrition or excess nitrogen further disturbs the process. As a result, parts of the fruit remain yellow or green, producing the blotchy ripening effect.

Therefore, distinguishing physiological disorders from viral causes is essential for hydroponic and greenhouse tomato growers. This article explains the symptoms, suspected viral look-alikes, underlying physiological causes, and effective corrective measures to minimize losses and improve fruit quality.

SYMPTOMS

Blotchy ripening in tomato shows up as greenish, yellow, or orange patches on the fruit surface, mostly on the outer walls, which fail to ripen uniformly. These discoloured areas are often low in sugars, organic acids, and dry matter.

Closely related disorders include:

- **Blotchy ripening** – parts of the fruit surface remain green, yellow, or orange due to poor lycopene development.
- **Gray wall** – brown or gray collapse of the outer fruit wall.
- **Internal whitening** – fruit walls (outer and inner) become corky and white.

Despite blotching, in most cases the foliage remains healthy and virus-free, which is a key clue that the disorder is physiological and not pathogenic.

SUSPECTED VIRAL DISEASES THAT CAN MIMIC BLOTCHING

Blotchy ripening symptoms are often

https://doi.org/10.52151/aet2026501.1909

confused with viral diseases such as:

- Tomato Spotted Wilt Virus (TSWV)

Source: UC Agriculture and Natural Resources "The Backyard Gardener" blog, Dustin W. Blakey, 2019 — https://ucanr.edu/blog/backyard-gardener/article/tomato-spotted-wilt-virus

- Tomato Mosaic Virus (ToMV)

Source: Aggie Horticulture, Texas A&M AgriLife Extension Service – "Tomato Mosaic Virus (ToMV)" article, Tomato Problem Solver: Green Fruit Disorders page

- Tomato brown rugose fruit virus (ToBRFV)

Source: PIRSA – Government of South Australia, Biosecurity, "Tomato brown rugose fruit virus," 2023.

- Tomato Fruit Blotch Virus (ToFBV)

Transmission of tomato fruit blotch virus by the tomato russet mite: epidemiological implications for an emerging/re-emerging tomato disease.

These viruses can cause uneven fruit colour, but they are usually accompanied by leaf symptoms (mottling, mosaic, curling, or chlorosis), which are absent in pure blotchy ripening(u.osu.edu, 2024). Correct diagnosis is crucial before adopting control measures.

Fig 1: Cherry tomato fruits showing blotchy ripening with uneven green and yellow patches

Fig 2: Fruits showing uneven colour development with collapsed outer walls and shrivelling

Fig 3: Tomato fruits showing characteristic concentric rings, chlorotic blotches, and uneven ripening caused by Tomato Spotted Wilt Virus (TSWV)

Fig 4: Tomato fruits showing necrotic brown patches and yellow blotches associated with Tomato Mosaic Virus (ToMV) infection.

CAUSES OF BLOTCHY RIPENING

Research and field observations suggest the following causes:

1. **Nutritional Imbalances**
   - Inadequate potassium supply during fruit development.
   - Excess nitrogen and calcium, which antagonize potassium uptake.

Fig 5: Tomato fruits infected with Tomato Brown Rugose Fruit Virus (ToBRFV), showing blotchy ripening with irregular red, yellow, and green patches.

   - Too low electrical conductivity (EC) of nutrient solution in hydroponics.

Fig 6: Cross-section of tomato fruit showing internal whitening where outer and inner walls

2. **Environmental Stresses**
   - High temperature (>32 °C) reduces lycopene synthesis.
   - Low light intensity and sudden alternations between cloudy and sunny weather.

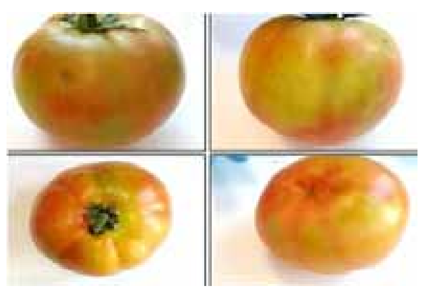


Fig 7: Blotchy ripening symptoms observed in tomato fruits infected with Tomato Fruit Blotch Virus (ToFBV).

   - High humidity combined with poor air circulation in dense canopies.
   - Heat stress interferes with chloroplast-to-chromoplast conversion, leaving fruits partially green.
3. **Crop Canopy and Ventilation**
   - Excessive vegetative growth creates dense foliage, restricting aeration and light penetration.
   - Poor greenhouse ventilation traps heat and humidity, worsening stress.

CORRECTIVE MEASURES AND CULTURAL PRACTICES

1. **Nutrient Management**
   - Ensure balanced fertigation with higher potassium (K) during fruit maturation.
   - Avoid excess nitrogen; maintain optimal N:K ratio.
   - Monitor EC of nutrient solution to ensure balanced potassium availability, stable lycopene biosynthesis, and reduced risk of fruit blotching.

2. **Environmental Management**
   - Maintain greenhouse temperatures between 20–30 °C for optimal lycopene synthesis.
   - Avoid extremes below 16 °C and above 32 °C.
   - Use shading nets, UV screens, and humidity curtains to regulate temperature and RH.

3. **Canopy and Ventilation**
   - Prune to avoid dense canopy and improve air circulation.
   - Operate fans, exhausts, or natural ventilation to reduce humidity and heat buildup.

4. **Cultivar Selection**
   - Choose varieties those tolerant to high temperatures under protected cultivation(Picha & Hall, 1981).

5. **Integrated Crop Care**
   - Monitor and control sucking pest populations to minimize associated viral risks.
   - Ensure regular scouting to differentiate between viral and physiological blotching.

CONCLUSION

Fruit blotching in cherry tomato is a complex physiological disorder, primarily linked to high temperature, fluctuating humidity, and imbalances in potassium nutrition. While the symptoms resemble viral infections, the absence of leaf symptoms and the presence of healthy foliage indicate a non-pathogenic cause.

By ensuring balanced fertigation, optimal greenhouse climate management, and proper canopy ventilation, growers can significantly reduce the incidence of blotchy ripening and maintain high-quality cherry tomato production.Uniform ripening not only improves market value but also strengthens consumer trust in hydroponically grown produce, ensuring sustainability and profitability for protected cultivation systems.

Small-scale Farm Mechanization in Hills-Gender Perspective

Dr. Sukhbir Singh[1] and Dr. Omprabha[2]
[1]Project Coordinator, AICRP on ESAAS, ICAR-CIAE, Bhopal
[2]Senior Research Fellow, AICRP on ESAAS, ICAR-CIAE, Bhopal

Mechanization in India shows marked regional disparities, with northern states achieving higher adoption while many regions still rely on manual labour. Small and marginal farmers, who constitute over 86% of India's farming community, face limited access to costly machinery. Women's role in agriculture is rising, with their workforce share increasing from 57% in 2017-18 to 64.4% in 2023-24, while men's participation declined from 40.2% to 36.3%. In hill regions, women contribute 60–80% of total farm labour amid increasing male out-migration. This review emphasizes the need for lightweight, ergonomic, and affordable women-friendly tools and outlines challenges and strategies for inclusive mechanization in hill agriculture.

INTRODUCTION

In India, mechanization has made significant pace in certain regions particularly in northern states but many areas still rely on manual labor and animal power. This regional disparity in mechanization levels is influenced by factors such as landholding patterns, terrain and the socio-economic conditions of farmers. The available farm power in hilly states is in the range of 0.37 to 1.33 kW/ha which is quite low against the National average of 3.12 kW/ha (2024-25). In most of the hilly states, animate power is predominantly used in agriculture whereas in some states mechanical and animate power sources are being used for performing farm operations. Most of the hilly regions still rely on human and animal labor for 60% to 80% of their total power needs. Additionally, small and marginal farmers who constitute the majority of India's farming population face challenges in accessing expensive machinery. Efforts to reduce drudgery through farm mechanization must focus on affordable location-specific equipment that is accessible to small-scale farmers. Women in rural India play a major role in shaping the economy particularly in the agriculture and allied sectors.

The Economic Survey of India 2024-25 states that there has been a significant increase in the share of women workers in the agriculture sector. It has increased from 57 per cent in 2017-18 to 64.4 per cent in 2023-24. During

https://doi.org/10.52151/aet2026501.1910

this period, men's participation in agriculture sector has declined from 40.2 per cent to 36.3 per cent. The Economic Survey also says female agricultural employment has increased from 73.2 per cent in 2017-18 to 76.9 per cent in 2023-24 while male participation has declined from 55 per cent to 49.4 per cent. The agriculture sector contributes about 16 per cent to the country's GDP and supports about 46.1 per cent of the population.

Hill agriculture is characterized by unique physiographic constraints such as small and fragmented landholdings, difficult terrain having steep slopes, narrow terraces, high rainfall variability, and poor road connectivity. Mechanization levels in hills remain significantly lower than in plains due to technological, economic, and social limitations. At the same time, women contribute 60–80% of the total labor in Himalayan and north-eastern hill regions. With growing male out migration, hill agriculture is increasingly becoming feminized, placing higher pressure on women. Traditional tools and heavy machinery are unsuitable for hilly terrain and often incompatible with women's ergonomic needs. Thus, small-scale, lightweight, ergonomic, and affordable mechanization is necessary to bridge gender gaps and enhance livelihood security to support sustainable agricultural growth. This review synthesizes the current status, technological options, challenges, and future strategies for promoting women-friendly mechanization in hill agriculture. It identifies research gaps and proposes policy and technological interventions for inclusive mechanization in hilly regions of India.

Table1. Farm Power Availability (kW/ha) in Hilly States in India

Name of State	Fam power availability, kW/ha	Key Power Source
Jammu & Kashmir	1.33	Mixed (Mechanical/ Animate)
Himachal Pradesh	1.32	Mixed (Mechanical/ Animate)
Uttarakhand	1.15 (Hill) and	
3.05(Valley)	Mixed (Mechanical/Animate)	
Mizoram	0.69	Animate (Human/ Animal)
Sikkim	0.69	Animate (Human/ Animal)
Manipur	0.64	Animate (Human/ Animal)
Nagaland	0.61	Animate (Human/ Animal)
Arunachal Pradesh	0.57	Animate (Human/ Animal)
Meghalaya	0.37	Animate (Human/ Animal
Tripura	1.63	Mixed (Mechanical/ Animate)

Source: 1. PricewaterhouseCoopers (PwC) & Federation of Indian Chambers of Commerce and Industry (FICCI). (2024, February). Farm mechanization: A catalyst for sustainable agricultural growth. PwC India. www.pwc.in;
2. Standing committee on agricultural, animal husbandry, and food processing, 2022-23, Research and development in farm mechanization for small and marginal farmers in the country; https://sansad.in/getFile/lsscommittee/Agriculture

GENDER ROLES IN HILL AGRICULTURE

Women in hills perform the majority of operational and household-linked agricultural tasks:

- Sowing, transplanting, weeding, manuring
- Fodder collection, grass cutting, fuelwood gathering
- Harvesting, threshing, winnowing
- Livestock management
- Post-harvest processing and storage

Men generally participate in heavy operations such as ploughing, marketing, machine repair and handling of heavy tools. The shift towards female-headed farming systems calls for gender-responsive mechanization solutions, as women face higher drudgery, restricted mobility, and limited access to


Fig.1. Terraces view in hills

Table 2. Gender Roles in Hill Agriculture

Activity Category	Women's Participation (%)	Men's Participation (%)
Ploughing & Other Heavy Work	10–20	80–90
Sowing & Transplanting	70–85	15–30
Weeding	80–90	10–20
Harvesting	60–75	25–40
Livestock Management	75–90	10–25
Fodder/Grass Collection	85–95	5–15

resources.

CHALLENGES IN HILL MECHANIZATION FROM A GENDER PERSPECTIVE

➢ **Topographical Constraints**
- Small size of fields and undulating topography
- Narrow terraces restrict movement of large machinery like tractors etc.
- Steep slopes make machinery unstable and unsafe. Majority of fields are 50-100 m² having vertical interval 0.8 meter.
- Scattered landholdings increase transport difficulty.
- No approach road from village to fields

➢ **Ergonomic Limitations**
- Lack of ergonomically designed tools and equipment for women.
- Traditional tools are not suitable for women's because these tools are designed based on male anthropometry.
- Women face difficulty in operating heavy machines and conventional tools and equipment.
- High incidence of musculoskeletal disorders (back pain, knee strain).

➢ **Economic Constraints**
- High cost of improved tools and machines
- Low purchasing power and poor credit access.
- High cost of transportation and maintenance in remote areas.

➢ **Social & Institutional Barriers**
- Limited involvement of women in training or demonstrations.
- Social norms often restrict women's use of powered machinery.
- Low exposure to technology and technical skills.

SMALL-SCALE MECHANIZATION TECHNOLOGIES SUITABLE FOR HILL REGIONS

➢ **Land Preparation**
- Light weight/Mini/Power Weeders/Tillers (5–8 hp & weight up to 80-100 kg): Easy maneuverability, multifunctional.
- Micro tillers: Ideal for small terraces and kitchen gardens.
- Power tiller (10-15hp & weight > 150 kg): For valley and terraces having less vertical interval.
- Lightweight ploughs and ridgers : Ergonomically designed for women.
- Remote controlled turning mechanism of power tiller during field operation

➢ **Interculturing and Weeding Tools**
- Ergo-compliant battery-assisted walk-behind power unit for weeding-cum-interculture operation in wide-row crops
- Twin-wheel hoe
- Women friendly cono weeder and rotary weeder
- Garden weeder (stand-up type)
- Battery-operated brush cutters
- Improved women-friendly weeders reduce bending time by 50–60%.

➢ **Sowing & Planting Technologies**
- Manual seed drill
- Power operated mini rhizome planter
- Battery powered manual drill/ planter
- Manual multi-crop planter
- Battery powered 2-rows manual paddy transplanter
- Manual and power operated drum seeder
- Seed-cum-fertilizer drills for mini-tillers
- Precision planters suitable for small plots

➢ **Spraying Devices**
- Battery assisted knapsack sprayer
- Solar battery & manual knapsack sprayer
- Smart ergo-compliant gender friendly knapsack sprayer for tall crops

➢ **Harvesting Tools**
- Battery-operated cereal crop harvester for women farm workers
- Improved serrated sickles: 25–30% less effort than traditional plane sickle/tools.
- Lightweight reapers and mini harvesters
- Battery powered pruners for pomegranate orchards
- Improved large cardamom harvesting knife
- Semi-automatic pineapple harvester

Fig.2. Capacity building program of women farmers

- Ergonomic pruning tools/ secateurs
- Ergonomic kiwi vine pruners
- Power operated fruits/ vegetables leaves pruning device
- Women friendly tea plucker and pruner
- Tea leaf plucking aid
- Easy harvest bag
- Manual orange harvester
- Manual apple harvester
- Fruits plucking ladder for hilly region
- Ergo refined sugarcane detrasher
- Manual sugarcane stripper-cum-detopper
- Orchard bamboo ladder

➢ **Post-Harvest Technologies**

- Manual lever and pedal operated coconut dehuskers
- Manual device for segregation of capsules (bulbs) from large cardamon spikes
- Light weight multicrop thresher
- Pedal operated/solar powered paddy thresher
- Mini rice mills, millet threshers-cum-pearler, maize shellers
- Pedal/ battery-operated win-nowers
- Solar dryers for horticultural crops

Table 3. Gender Roles in Hill Agriculture

Operation	Traditional Time (h/ha)	Mechanized Time (h/ha)	Time Saving (%)	Drudgery Reduction (%)
Weeding	180	80	55	60
Harvesting	150	95	35	45
Land Preparation	100	50	50	52
Fodder Cutting	6 h/day	3.5 h/day	40	50

- Fish dressing platform

➢ **Fodder & Livestock-Related Devices**

- Women-friendly chaff cutters with safety gadgets/devices
- Dung scraper and telescopic fodder/tree cutting stick
- Brush cutters with harness
- Improved sickles for grass harvesting
- Power operated poultry excreta scraper

➢ **Transport & Supporting Tools**

- Variable height platform for operations in greenhouse
- Low cost gravity based ropeway
- Exoskeleton for load carrying in NER
- Backpack for load carrying in sherpa mode
- Pack baskets, trolley systems, headload reducers
- Lightweight water carriers (20–25 L)

IMPACTS OF SMALL-SCALE MECHANIZATION ON WOMEN IN HILLS

➢ **Reduction in Drudgery**

- Up to 60-70% reduction in physical exertion for operations like weeding, harvesting, water/ fodder carrying.
- Significant reduction in musculoskeletal injuries.

➢ **Time Saving**

- Mechanized weeding saves 40–60% time.
- Mini-tillers reduce land preparation time by 40-50%.

➢ **Productivity Improvement**

- Better timeliness of operations leads to 15–25% increased yield.
- Post-harvest tools reduce losses and improve grain quality.

➢ **Social Empowerment**

- Training and machine ownership enhance women's self-confidence.
- Women-led Custom Hiring Centers (CHCs) improve access and community acceptance.

BARRIERS TO ADOPTION

➢ **Economic Barriers**

- High initial cost even for small machines
- Poor market linkages and access to spare parts
- Lack of collateral for loans

➢ **Institutional Barriers**

- Insufficient women-targeted schemes
- Limited availability of gender-friendly prototypes
- Poor extension outreach in remote villages

➢ **Social & Cultural Barriers**

- Gender norms discouraging women from operating machines
- Low mobility due to household responsibilities

RESEARCH GAPS IDENTIFIED

- Lack of ergonomically validated tools for women in hill specific conditions.
- Limited biomechanical studies on women's drudgery in steep slopes.
- Insufficient gender-disaggregated data on technology adoption and impacts.
- Lack of multipurpose and multi-functional machines that combine operations for small terraces.
- Scarcity of low-cost mechanization suitable for marginal and women farmers.
- Poor repair & maintenance and services infrastructure in remote hill villages.
- Poor integration of women's needs in design, testing, and feedback loops.

FUTURE STRATEGIES FOR GENDER-SENSITIVE HILL MECHANIZATION

➢ **Technological Strategies**

- Use of smart sensors, IoT for safety and ease of operation
- Designing ultra-light, modular, multi-operation tools.
- Ergonomic redesign of tools based on hills women's anthropometry.
- Battery-operated and solar-powered tools for remote regions.

➢ **Institutional Strategies**

- Setting up Women-led Custom Hiring Centers (CHCs) and Hill Farm Mechanization Service Centre at block level.
- Appointment of Agricultural Engineer at each KVK.
- Local artisans should be trained in fabrication of women friendly tools and equipment and support for establishment of fabrication workshop.
- Involving women in prototype testing and feedback.
- Front Line Demonstrations program of improved tools and machine should be arranged at farmers' field.
- Training of operation and minor repair & maintenance of improved machines for women
- Strengthening skill development through FPOs, SHGs, KVKs.

POLICY INTERVENTIONS

- Directorate of Agricultural Engineering should be established by respective state government with provision of posting of at least one agricultural engineer at block level.
- Dedicated mechanization programs for hill state/districts.
- Higher subsidies for women farmers on women friendly tools and machines.
- Inclusion of gender indicators in agricultural schemes.

CONCLUSION

Farm mechanization is crucial for enhancing productivity, reducing drudgery, and completing farm operations on time, especially amid labour scarcity, rising input expenses, and intensifying climate challenges. Small-scale mechanization offers a transformative pathway for hill agriculture by easing women's drudgery, improving productivity, and enhancing socio-economic resilience. A gender-responsive mechanization ecosystem-integrating ergonomic design, capacity building, policy support, and women-centric institutions is essential to ensure inclusive and sustainable agricultural development in hilly regions.

Energy Efficiency Enhancement in Open Pan Jaggery Furnaces through Design and Combustion Innovations

S.I. Anwar*
Principal Scientist, Division of Agricultural Engineering, ICAR-Indian Sugarcane Research Institute, Raebareli Road, Lucknow - 226002 (U.P.)
*Corresponding author e-mail: sianwar@yahoo.co.in

INTRODUCTION

Sugarcane is a major cash crop of India. Sugar, jaggery and *khandsari* are major products of sugarcane. However, nowadays ethanol is also produced for blending with petrol for vehicles. Sugar, jaggery and *khandsari* are used as sweeteners, but jaggery is considered a food material as well due to the presence of important constituents of human diet. More than 70% of the total world jaggery production is done in India. It is popularly known as the "medicinal sugar" and is nutritionally comparable to honey. In *Ayurvedic* Medicines, it has been used for 3000 years. Jaggery is produced in nearly 25 countries with a total production of about 13 million tonnes per year. India is the largest producer of jaggery in the unorganised agro-processing sector, accounting for 55% of the total world production, followed by Colombia (11%). The major states involved in jaggery production are: Uttar Pradesh, Maharashtra, Madhya Pradesh & Chhattisgarh, Karnataka, Bihar, Andhra Pradesh and Tamil Nadu. Jaggery is not only consumed in India, but it is also exported to foreign countries to earn foreign exchange. The major unit operations involved in jaggery production are: sugarcane crushing (juice extraction), juice filtration, heating, clarification, boiling and concentration, cooling/puddling of concentrated mass, moulding and packaging. Sugarcane juice heating, boiling and concentration are the most energy intensive operations, which are mostly done over open pan furnaces. These furnaces have low thermal

https://doi.org/10.52151/aet2026501.1911

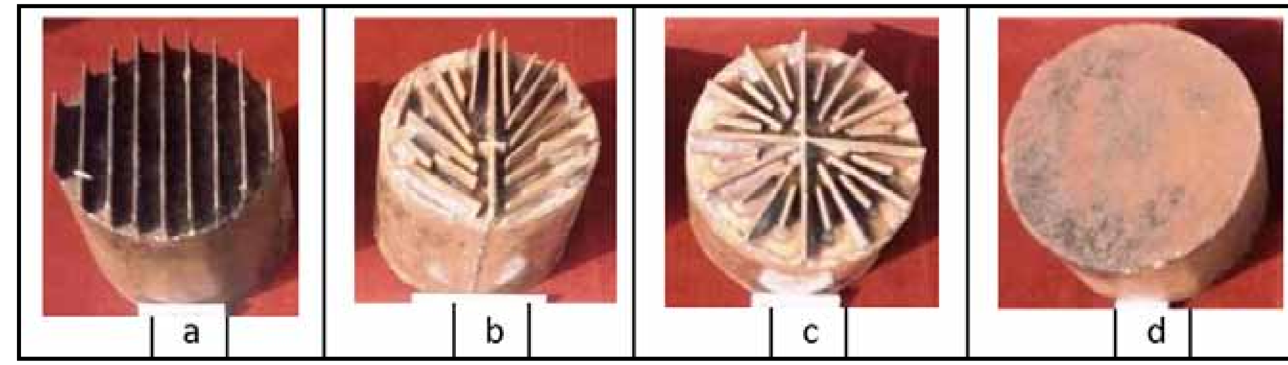


Fig.1. Fin configurations. (a) PF (b) FSF (c) RF (d) Plain pan

efficiency and mostly shortage of fuel is experienced. Therefore, efficiency enhancement of jaggery furnaces is of foremost importance, as it not only will save fuel problem but will help in improving jaggery productivity per unit of energy consumed.

PROCESSING OF SUGARCANE JUICE

Sugarcane juice is first filtered for removal of major impurities followed by heating, boiling and concentration. Juice clarification is done at $80^{o}C$ by using vegetative clarificant (*Deola-Hibiscus ficulneus*), and impurities are removed in the form of scum. For juice processing mostly open pan furnaces, made by local artisans, are used. Different kinds of furnaces have been developed in India. Over time, many attempts have been made in design modifications, including variation in size and number of pans, leading to development of some improved furnaces. Size and number of pans depend on system of jaggery making and capacity of jaggery plant. However, there has always been a need for an energy-efficient furnace for bagasse saving and increase in jaggery productivity. Some of the efforts have been carried out at ICAR-Indian Institute of Sugarcane Research (IISR), Lucknow.

MODIFIED PANS

Pans are an integral part of any furnace. Efficient 2-pan and 3-pan furnaces have been developed at ICAR-IISR, Lucknow. Flat and hemispherical bottom pans are used in 2-pan and 3-pan furnaces respectively. A novel idea of increasing area of heat receiving surface has been conceptualized with the hypothesis that more the heat receiving area, more heat energy would be transferred to juice. For this reason, fins have been provided to the pan bottom.

Three fin configurations *viz.* parallel fins (PF), flame spreader fins (FSF) and radial fins (RF) were considered for testing the hypothesis. Additional area provided by fins was kept same for all three configurations. These configurations were compared with conventional plain bottom. All these fin configurations are shown in Fig.1.

Mild steel flats (25 x 3 mm) were welded to each of the three finned pans. The total length of flats was kept equal in all cases. These configurations were tested through water boiling test, and the results are summarized in Table 1:

It can be seen from table that pans with fins performed better as compared to plain pan in terms of water evaporation and thermal/heat utilization efficiency. Parallel fins gave best results followed by flame spreader and radial fins.

Based on above results, pans of 2-pan IISR furnace were modified and provided parallel fins. These pans are shown in Fig. 2.

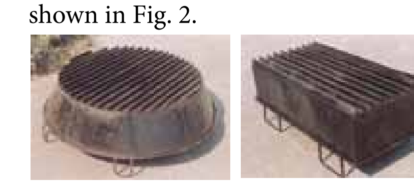


Fig. 2. Modified main and gutter pans of IISR 2-pan furnace

Table 1. Performance of pans with different fin configurations

Sl No.	Performance parameters	Fin configuration/geometry				
		Plain	PF	FSF	RF	Avg. (fins)
1	Water evaporation (kg)	1.720	2.273	2.180	2.143	2.199
2	Thermal efficiency (%)	9.93	12.47	12.06	11.90	12.14
3	Heat utilization efficiency (%)	7.52	9.94	9.53	9.37	9.62
4	% increase in thermal efficiency as compared to plain pan	---	25.58	21.45	19.84	22.29
5	% increase in heat utilization efficiency as compared to plain pan	---	32.18	26.73	24.60	27.93

Due to fins, per cent increase in area of heat receiving surface of main and gutter pan was found to be 118 and 131 per cent respectively.

These pans were evaluated by water boiling test and actual juice processing for jaggery making. Modified system was found to be capable of evaporating about 15 kg more water with 75 kg bagasse in 90 minutes as opposed to 100 kg bagasse in 120 minutes with plain pan. Therefore, 0.71 kg more water per kilogram of bagasse was evaporated with modified system. The heat utilization efficiency improved by 9.44%. Bagasse saving was also observed to the tune of more than 30% and 25% per unit weight of water evaporated and per unit of jaggery made respectively. Jaggery production was also increased by 20% with 17% time saving.

PARALLEL FINS OPTIMIZATION

Optimization of parallel fins has also been done for maximization of efficiency. For this, smaller mild steel pans with increased area of heat receiving surface up to 311 per cent by providing fins were fabricated. In second set of experiments, increase in area was kept constant but the size of fins varied. Water boiling test was performed. Heat utilization efficiency increased with increase in number of fins *i.e.* area of heat receiving surface. It was also found that for a particular increase in area of heat receiving surface, more number of smaller fins is a better choice than smaller number of larger fins.

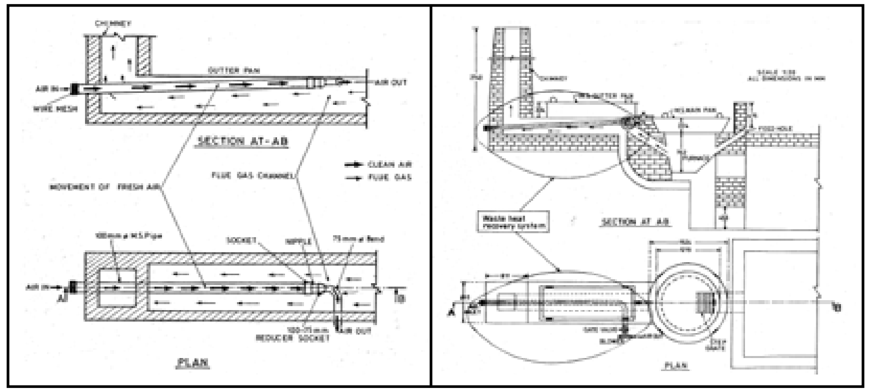


Fig. 3. (a) Counter-current type heat exchanging unit and (b) installation of WHRS in IISR 2-pan furnace

WASTE HEAT RECOVERY SYSTEM (WHRS)

Despite many improvements, still lot of heat energy wasted through flue gases. A novel concept of WHRS was conceptualized for recovery of part of waste heat for other useful purposes like bagasse/jaggery drying or space conditioning.

A counter-current type of heat exchanger in the form of 100 mm dia. mild steel pipe was fixed in flue gas channel. One end of pipe is exposed to open air at the base of chimney for sucking fresh and clean air. A blower was used with a flow regulating valve for sucking in air through the pipe. Heating of air was done through convective mode of heat transfer. Whole system is shown in Fig.3.

WORKING OF WHRS

Blower of WHRS is also operated during furnace operation. It sucks fresh air through the pipe. Since the whole pipe is surrounded by hot flue gases, the air moving in it also gets heated. A bend was installed at a position where flue gases come out of combustion chamber and striking the bend making it very hot. Air takes a sharp turn at bend where maximum heat transfer takes place. As a result, clean heated air is obtained. A temperature rise of 30°C was obtained at full blower speed at steady-state conditions. This heated air can effectively be utilized for bagasse/jaggery drying and/or space conditioning.

EFFICIENCY BOOSTING DEVICE (EBD)

It was found that flames, which are formed during bagasse combustion in jaggery furnaces, drift towards flue gas opening and many of these flames do not even touch pan bottom. Therefore, a device, which can direct flame towards pan bottom and also make turbulence for increased heat transfer will be useful for more effective utilization of energy. Therefore, an Efficiency Boosting Device (EBD) has been conceptualized for forcing flames towards pan bottom for more heat transfer. The air supplied through this device would also help in complete combustion of unburnt gases, which would have otherwise gone to waste.

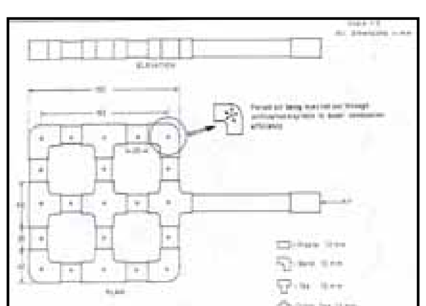


Fig.4. Line diagram of EBD

Fig.5. Miniature model of EBD

A miniature model of EBD was developed by Anwar, 2015. It was made of G.I. nipples, sockets, tee, cross tee and bends (Fig.4 & 5). Holes (4 mm dia.) were drilled at specific locations for air. The size of efficiency booster was kept matching with a pan of 203 mm diameter. This was installed on a wood stove at such a height that did not affect normal fuel feeding and was connected to a hand blower with suitable attachments. This was kept close to the pan bottom so that air coming out of holes would be able to strike pan bottom.

The unit was tested through water boiling test and it was observed that it required less time for water to reach boiling point. More turbulence in the flames was also observed, which facilitated greater heat transfer. Lesser quantity of fuel was consumed with EBD, and it had a positive effect on all the performance parameters.

In second set of experiments, nipples were provided on 4 mm holes for directing flames and hot air towards pan bottom for more heat transfer. Nipples of 20 mm length and 4 mm diameter were provided. The unit was tested and compared against the unit with simple holes of 4 mm diameter and the results are summarized in Table 2.

Table 2: Comparison of EBD with 4 mm holes and nipples

Parameter	EBD with only 4 mm holes	EBD with nipples	Per cent increase/ decrease
Water evaporation, kg	1.96	2.16	10.20 (increase)
Evaporation/kg fuel, kg	0.75	0.82	9.33 (increase)
Fuel consumed/kg water evaporated, kg	1.33	1.22	8.27 (decrease)
Time requirement/kg water evaporation, hours	0.36	0.34	5.56 (decrease)

The performance of EBD further improved with nipples of 4 mm diameter and 20 mm length. Hence, based on above results, scale-up model of efficiency boosting device suitable for IISR 2-pan furnace has been developed.

SCALE-UP MODEL OF EBD

A scale-up model of the EBD was developed and installed in the IISR two-pan jaggery furnace. The performance of the EBD was evaluated in combination with the Waste Heat Recovery System (WHRS) (Anon., 2020). Both systems were interconnected through pipelines, and gate valves were provided to regulate airflow. Furnace performance was assessed in terms of water evaporated per unit of bagasse consumed, bagasse consumed per unit of water evaporated, rate of water evaporation, and heat utilization efficiency (HUE), among other parameters. With the EBD fully open and the WHRS half open, the HUE and net energy gain (NEG) were 30.4% and 2.03 MJ/h, respectively. When both the EBD and WHRS were fully open, the HUE and NEG were 28.2% and 4.82 MJ/h, respectively. The overall system efficiencies under these two operating conditions were 30.67% and 28.67%, respectively. However, the maximum heat utilization efficiency (33.32%) was achieved when the EBD was operated alone. These results indicate that both systems, individually and in combination, contributed to improved thermal performance of the furnace.

CONCLUSION

The studies conducted at ICAR–Indian Institute of Sugarcane Research, Lucknow, clearly demonstrated that substantial improvement in the energy efficiency of traditional open pan jaggery furnaces is achievable through systematic design and process modifications. Enhancement of the heat-receiving surface area by providing optimized parallel fins significantly improved water evaporation rate, heat utilization efficiency, bagasse saving, and jaggery productivity. Optimization studies confirmed that increasing the number of smaller fins was more effective than fewer larger fins for the same surface area increment. The Waste Heat Recovery System enabled partial recovery of flue gas heat for useful applications such as drying and space conditioning, thereby improving overall energy utilization. The Efficiency Boosting Device improved combustion characteristics, increased flame–pan interaction, reduced fuel consumption, and enhanced heat transfer, with further gains observed in the scaled-up model.

Collectively, these interventions addressed major inefficiencies in conventional jaggery furnaces by improving combustion efficiency, heat transfer, and energy recovery. The integrated application of modified pans, EBD, and WHRS offers a practical and technically feasible approach for reducing bagasse consumption, enhancing thermal efficiency, increasing productivity, and improving the sustainability of jaggery production systems in the unorganised sector.

Status, Constraints, and Prospects of Mechanical Paddy Transplanters in Punjab



Davinder Singh[1*], Dr Baldev Dogra[2], Dr Mahesh Kumar Narang[3]
[1] PhD Scholar, Department of FMPE, Punjab Agricultural University, Ludhiana
[2]Former Dean, COAET, CCSAU, Hisar and now Professor (FMPE), PAU, Ludhiana
[3]Former Head, Department of FMPE, and now Principal Extension Scientist (FMPE), PAU, Ludhiana
* Corresponding author: Email: davindersaini1997@gmail.com

INTRODUCTION

Rice (*Oryza sativa* L.) is known as the "global grain" and serves as the primary staple food for over half of the world's population. Particularly in Asian countries, rice accounts for 50-80% of daily caloric intake. The economic and agricultural significance of rice is paramount, needing the production of ~140 million tonnes of rice annually by 2030-31 to meet growing food demands . The majority of paddy is traditionally farmed by hand transplanting. Manual transplantation is expensive and labour intensive. Lack of enough labour is a significant issue in certain paddy-growing regions of the country. Manual transplanting requires 250–300 man-hours per hectare, accounting for approximately 25% of the crop's total labour requirement. Labour shortages for farming have happened due to urban migration and higher-paying non-farm jobs. Consequently, there is a pressing need for sustainable, labour-efficient, and cost-effective mechanised paddy transplanting.

The integration of mechanised farming techniques in the paddy sector has resulted in a range of advantages and challenges. The use of tractors, transplanters, and harvesters has been considerably enhanced the efficiency of paddy cultivation, leading to increased yields and reduced labour requirements. Mechanised operations enable farmers to carry out planting, weeding, and harvesting at the best time, which is crucial for achieving the highest paddy yield. Additionally, mechanisation allows for cost effective precise operations, resulting in better seed placement and spacing, which improves crop quality.

Mechanical paddy transplantation is considered the most promising method, as it saves labour, ensures timely transplanting, and achieves optimal plant density, thereby increasing yield. According to published information (2012), mechanical transplanting of paddy was performed using three types of transplanters. The specifications of these transplanters are presented briefly in Table 1. The

https://doi.org/10.52151/aet2026501.1912

three types of paddy transplanters, viz., self-propelled walk-behind (SWBT), self-propelled four-wheel ride-on (SFWT), and self-propelled single-wheel transplanter (SSWT), are presented in Fig. 1 and were compared with the manual transplanting. In one of the experimental studies conducted during the year 2013 in Punjab, SWBT transplanting gave a 9.3% higher yield, followed by SFWT transplanting, in comparison with manual transplanting. A better establishment and more panicles/m² were responsible for the increase in grain yield with SWBT. Transplanting with SWBT also resulted in higher net returns and labour savings. In comparison to farmers' practice, SWBT increased net returns and saved man-hours/ha by 14.7 and 87 %, respectively. The mechanical transplanter performed well, requiring 3 man-days per hectare compared to 33 man-days for manual transplanting. Traditional paddy transplantation had a benefit-cost ratio of 2.5:1, while mechanical transplanting could increase it up to 3.8:1, under experimental conditions. Despite the clear advantages, the adoption rate of paddy transplanters in Punjab remained notably low. According to a 2023 survey by the Indian Council of Agricultural Research (ICAR), less than 20% of paddy farmers in this region used transplanters, preferring traditional manual transplantation methods. The number of mechanical transplanters in Punjab and the area they covered is presented in Table 2.

Table 1. Typical specifications of different types of paddy transplanters surveyed

S. No.	Specification	Observation		
1	Machine	Self-propelled single wheel riding type (SSWT)	Self-propelled walk behind (SWBT)	Self-propelled 4-wheel type (SFWT)
2	Type of nursery used	Mat type	Mat type	Mat type
3	Power Source	Diesel Engine, 2.94 to 3.68 kW	Petrol Engine, 3.20 kW	Petrol Engine, 12.5 kW
4	Type of Steering	Mechanical	Handle type	Hydraulic
5	No. of gear	Forward – 3 (2 for Field and 1 for Road) Reverse – Not Provided	Forward – 1 Reverse – 1	5 Forward and 5 Reverse Speeds
6	Number of rows	6 and 8	4 and 6	6
7	Row to row spacing, cm	23.8 and 30	30	30
8	Plant to plant spacing, cm	12-14, 14-17	12, 14, 18, 21	12, 14, 16, 18, 21
9	Number of hills transplanted/m²	Two settings	Four settings	Five settings
10	Transplanting depth	Adjustable	Adjustable	Adjustable
11	Type of planting finger	Needle type	Plate bar with notch	Plate bar with notch
12	Material of tray	Galvanized iron sheet	Plastic	Plastic
13	Type and material of traction wheel	Iron wheel with iron lugs	Iron wheel with rubber lugs	Two front non-puncture rubber wheels and two rear iron wheels with rubber lugs
14	Transport wheel type	Pneumatic	Pneumatic	Pneumatic
15	Float type and material	Single piece, fibre	Split bars, plastic	Split bars, plastic

REASONS FOR LOW ADOPTION OF THE PADDY TRANSPLANTER

Despite proven advantages in labour saving and timeliness, the adoption of paddy transplanters in India is still limited in Punjab. The constraints are structural, economic, technical, and institutional in nature.

Structural Constraints: As per the Agriculture Census 2015–16, about 86.1% of operational holdings in India belong to small and marginal farmers (below 2 ha). The fragmented and scattered nature of these holdings, particularly in parts of Punjab, reduces operational efficiency of paddy transplanters. These machines perform best in large, levelled, and contiguous fields. Irregular field shapes, poor land levelling, and narrow bunds restrict effective machine movement and reduce field capacity.

High Initial Investment and Associated Costs: The capital cost of paddy transplanters is a significant barrier for small and marginal farmers. Although long-term savings in labour may be possible, the upfront investment is often beyond the financial capacity of individual farmers.

In addition to the machine cost, mechanical transplanting requires mat-type nursery raising using plastic trays. Many trays are needed per hectare, increasing initial expenditure. The cost of nursery preparation, handling, and transportation adds to overall operational expenses. These factors reduce the economic attractiveness of the technology, particularly in areas where manual labour is still available.

Nursery Management Challenges: Mechanical transplanting requires mat-type seedlings of uniform thickness and density. Many farmers are not fully familiar with the technical requirements of mat nursery preparation. Improper nursery management adversely affects seedling quality and machine performance, leading to missing hills, uneven spacing, or increased damage.

Studies have shown that mat nursery preparation accounts for a substantial share of the total energy requirement in mechanical transplanting systems, considerably higher than the energy share for traditional nurseries used in manual transplanting. The added operations involved in tray filling, sowing, watering, and mat handling further increase labour and energy inputs.

There is also a need for improved nursery seeders to ensure uniform seed distribution in trays and consistent seedling stands.

Table 2: Number and area covered (in ha) with different types of paddy transplanters in Punjab

Year	Self- propelled walk Behind type (SWBT)		Self- propelled Four-wheel type (SFWT)		Self- propelled Single wheel type (SSWT)	
	Numbers	Area covered, ha	Numbers	Area covered, ha	Numbers	Area covered, ha
2012	140	1470	28	532	0	0
2013	148	1628	28	532	0	0
2014	169	2028	31	775	0	0
2015	169	2366	32	1120	0	0
2016	193	2895	32	1120	0	0
2017	212	4240	35	1400	0	0
2018	235	4700	39	1560	0	0
2019	310	6200	59	2360	8	64
2020	765	16544	152	8180	43	301
2021	800	17600	175	9450	42	310
2022	950	21850	200	11000	43	325
2023	1000	22785	255	2363	42	320
2024	1050	23245	305	13773	42	332

Technical and Design Limitations: Existing transplanter models are primarily designed for standard mat-type seedlings. In some regions, there is a requirement for machines capable of handling larger or thicker mats to improve operational flexibility. Design modifications and region-specific adaptations are needed to enhance suitability under diverse field conditions.

Limited Service and Support Infrastructure: Concerns about machine reliability, availability of spare parts, and access to trained mechanics affect farmer confidence. Breakdowns during the narrow transplanting window can result in crop delays. In many areas, the service ecosystem is still developing, which discourages investment.

Training and extension support on machine operation, calibration, and nursery management are not uniformly available. Inadequate capacity building reduces effective utilisation even where machines are bought.

POSSIBLE SOLUTIONS TO ENCOURAGE ADOPTION

In response to farmers' concerns, Punjab Agricultural University (PAU), Ludhiana, addressed major challenges associated with mat-type nursery seeding by developing a dedicated mat-type nursery seeder. The tractor-operated mat-type nursery seeder (Figure 2) is a multifunctional machine capable of performing all nursery operations in a single pass, thereby making the process faster, simpler, and more labour- and cost-efficient.

Two persons can prepare mat-type nursery sufficient for two hectares in one day using the machine. About 10–12 kg of seed is required to raise nursery for one acre of paddy field. In one day, the machine can sow mat-type nursery sufficient for transplanting in approximately 125–150 acres of paddy area. Cost savings of 70–75% and labour savings of 80–85% have been reported compared to the conventional manual method of mat-type nursery sowing.

Fig 1. View of self-propelled single wheel type paddy transplanter in operation (Left side), self-propelled walk behind type paddy transplanter in operation (Middle), self-propelled 4-wheel type paddy transplanter in operation (Right side)

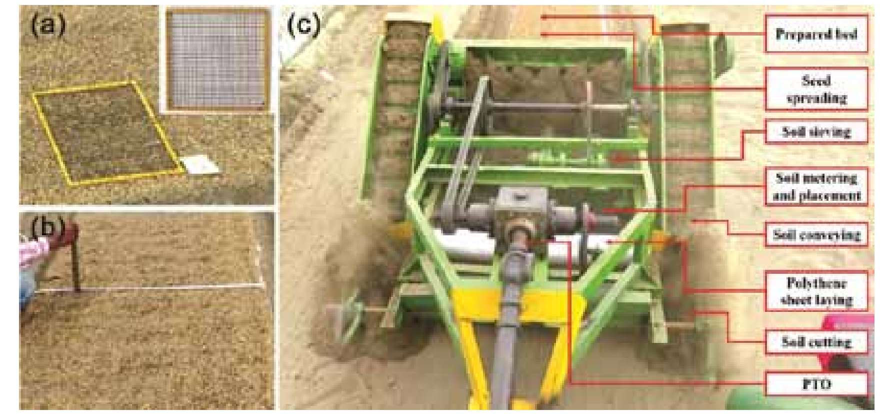


Fig. 2: Tractor-operated mat-type nursery seeder

Cutting of mat-type paddy nursery seedlings can be carried out using a manually operated paddy nursery cutter developed by PAU, with a capacity of 325–425 mats per hour. The cutter has a low initial cost of about Rs. 3,000, with operational costs ranging from Rs. 71–89 per hectare (200–250 mats). It reduces labour requirement by 58.65–58.95% and cutting cost by 55.55–55.85% compared to manual cutting methods, thereby improving operational efficiency.

The cost of purchasing and maintaining agricultural machinery is still a major constraint for small and marginal farmers. Access to affordable financing options is essential. While farm mechanisation has improved operational efficiency in paddy cultivation, adoption challenges need to be addressed in a systematic manner. Establishment of custom hiring centres, where farmers can rent paddy transplanters as needed, can improve access without high initial investment.

CONCLUSION

Comparative evaluation of mechanical paddy transplanters: Self-Propelled Walk-Behind (SWBT), Self-Propelled Four-Wheel (SFWT), and Self-Propelled Single-Wheel (SSWT), showed clear gains in productivity and economic performance over manual transplanting. Mechanical transplanting showed a 9.3% increase in grain yield and a 14.7% rise in net returns. Labour requirement was reduced by about 87%, declining from 33 man-days/ha under manual transplanting to nearly 3 man-days/ha with mechanical operation. Consequently, the benefit–cost ratio improved from 2.5:1 to 3.8:1 under field conditions.

Despite these advantages, adoption in Punjab remained below 20%, largely due to structural constraints, particularly land fragmentation, with 86.1% of farmers operating less than 2 hectares. The number of SWBT units increased from 140 in 2012 to 1,050 in 2024, and the area covered expanded from 1,470 ha to 23,245 ha. Similarly, SFWT units rose from 28 to 305 during the same period, covering 13,773 ha by 2024. These trends reflected growing acceptance where technical and institutional support was available.

Initially, preparation of the mat-type nursery accounted for nearly 40% of the total energy requirement in mechanical transplanting and acted as a major constraint to the adoption of mechanised paddy transplantation. This limitation was addressed with the introduction of the tractor-operated nursery seeder. The seeder helped adoption by simplifying nursery operations and reducing both cost and labour requirements. It provided 70–75% cost savings and 80–85% labour savings, with the capacity to prepare nursery sufficient for 125–150 acres per day. In addition, low-cost implements such as the manually operated nursery cutter (approximately Rs. 3,000) reduced cutting costs by about 55%, thereby improving overall system efficiency.

Although mechanical paddy transplanting showed clear agronomic and economic advantages under experimental conditions, its sustained adoption will depend on the extent to which comparable benefits are realised under actual field situations. Field-level performance, cost implications, and practical constraints need careful evaluation for large-scale promotion of mechanised paddy transplantation.

Beyond Tractors and Ploughs: Pollinating the Future with AI and Nano-Drones in Indian Farming

Dr. Jolly Masih[1] and Ms. Pashma[2]

[1]Associate Professor & Agri-tech Scientist at BML Munjal University
[2]Scholar at BML Munjal University

It is a cold winter morning in Karnal, Haryana. Farmer Ramesh Kumar is standing at the boundary of his wheat crop, not with a sickle in his hand or checking the leaves with his bare fingers, but gazing at his smartphone screen. A tiny nano-drone is hovering above his wheat field, moving in organized, pre-programmed routes across the field. Soon, a message pops up: "Early nitrogen stress identified in Zone 3. Suggested micro-dosing: 12 kg." Ramesh Kumar is pleased. He would have identified the problem in his field a decade ago only when the affected area turned yellow, and the yield potential was already lost. Now, he knows before the crop does.

This is the quiet revolution that is sweeping the Indian agricultural sector. Not loud like tractors, not dramatic like combine harvesters—but intelligent, precise, and aerial. ***The Rise of Nano-Drones***: What Exactly Are They? To grasp the revolution, we need to start with a definition. A nano-drone is an ultra-lightweight unmanned aerial vehicle (UAV), weighing less than 250 grams, with sensors, cameras, and increasingly, Artificial Intelligence processors. Unlike larger agricultural drones used for heavy spraying, nano-drones are designed for agility, micro-precision, and data gathering. They can fly through irregular landholdings, orchards, narrow farm strips, and even greenhouse farming with ease.

In the Indian context, where more than 86% of farmers are small and marginal, large-scale mechanized farming systems often prove inefficient. Nano-drones are suited to the Indian environment. They are cheap, lightweight, and flexible. However, what makes them revolutionary is not merely their size, but their intelligence. Artificial Intelligence: The Invisible Agronomist, AI enables nano-drones to go from flying cameras to decision-

https://doi.org/10.52151/aet2026501.1913

support systems. When these drones record multispectral images, thermal maps, and chlorophyll reflectance values, machine learning algorithms decode minute differences in plant health.

According to NITI Aayog reports, precision agriculture using AI can potentially boost crop productivity by 15-20% and lower input costs by as much as 25%. The agricultural drone market is expected to cross USD 10 billion by 2030, and India is one of the fastest-growing markets.

WHY? BECAUSE ECONOMICS WORKS.

The Financial Equation: How Drones Boost Farm Revenues
Let's go back to Ramesh's farm.
Conventional methods meant he used to spray pesticides over his entire 3-acre farm. That used to cost him around Rs.2,500 per acre per session. However, analysis by the AI-powered nano-drone showed that only 30% of the farm needed pesticide spraying.

With precision spraying, his pesticide bill reduced by almost Rs.3,000 per year. And with an additional 10-15% increase in farm production because of stress detection, his overall annual profit increased substantially.

For high-value crops such as fruits, vegetables, and oilseeds, increased production and reduced costs can raise the profitability of a farm by Rs.15,000-Rs.40,000 per acre per year, depending on the type of crop.

Multiply this effect over the 140 million hectares of agricultural land in India, and the macroeconomic effects are staggering. Pollinating the Future: When Bees Need Backup

In Himachal Pradesh, apple farmer Meena Devi observed a reduction in fruit production despite regular blooming. Researchers attributed this to a disturbing trend: pollinator loss. Research worldwide shows that about 35% of the world's food production is a function of pollinators, but bee populations are declining due to pesticide poisoning and climate change. This is where technologies such as the Beebuz nano-drone line come in.

Beebuz nano-drones, inspired by real bees, employ swarm intelligence algorithms to replicate pollination patterns. They systematically traverse blooming crops, transferring pollen. They are not a replacement for nature but an aid in regions where natural pollination has been impacted.

In orchard tests, assisted pollination has been shown to increase fruit setting by 10-15%, thereby directly impacting the quality and quantity of produce. For a farmer like Meena Devi, this margin makes all the difference between a good and a great crop year.

Precision Protection: The Agri Fly Edge. In Maharashtra, soybean farmer Arjun Patil struggled with regular pest attacks. It wasn't until he saw damaged leaves that he realized the extent of the problem the pests had already spread. That changed with the Agri Fly nano drone range, which Arjun Patil began to use on his fields every week. With AI-powered pest identification algorithms, the drone could identify early signs of pests in his fields.

The impact? A decrease of almost 30% in pesticide consumption and improved produce quality. His crop yield remained consistent for two years, despite unpredictable monsoons.

Precision protection goes beyond cost savings. It also has a positive impact on the environment. With reduced chemical usage, there is less chemical runoff, which in turn translates to cleaner groundwater, a healthier soil microbiome, and a lower ecological footprint.

MONITORING FROM ABOVE: THE ROBOTIC EAGLE PERSPECTIVE

In major wheat and rice-growing regions, the Robotic Eagle nano-drone has a complementary role.

It is meant to glide effortlessly over large areas of farmland, providing a wide-scale health analysis of the crops. Its AI system identifies minute details moisture stress from irregular watering, initial signs of fungal diseases, or micronutrient deficiencies.

Farmers no longer need to physically examine their acres on foot. They get digital maps of their fields, highlighting stress areas in color-coded patterns. Decisions about farming practices change from experience to data.

GOVERNMENT PUSH: TURNING POLICY INTO POSSIBILITY

The Government of India realized the revolutionary possibilities of drone technology and initiated programs like Drone Shakti, encouraging startups to develop and integrate drones into agriculture. Subsidies for agricultural drones and the development of Custom Hiring Centers enable farmers to lease drones rather than buying them. The government has eased regulations for drones through the Drone Rules 2021 and encouraged the "Make in India" initiative for the production of drones.

Financial structures are being developed. Farmer Producer Organizations (FPOs) come together to buy drones collectively. Banks and agri-fintech companies are starting to provide credit lines specifically for technology.

BARRIERS IN THE SKY

Even with the momentum, there are barriers to adoption. The cost of initial investment is still high for small farmers. The lack of digital literacy makes AI dashboard interfaces daunting. Connectivity issues in rural areas hinder real-time analysis. And the cultural acceptance of automation is slow. But innovation diffuses through visibility. Seeing the benefits to other farmers in the neighborhood increased output, reduced costs, improved quality changes doubts to curiosity. Based on diffusion theory, technologies gain speed once early adopters show tangible benefit. That point is near in many areas.

BEYOND ECONOMICS: THE PSYCHOLOGICAL SHIFT

The most fundamental change is psychological. Agriculture has always been a gamble. A farmer plants seeds and waits with hope but no certainty. Nano-drones with AI capabilities eliminate uncertainty. They provide foresight warnings before damage, advice before disaster.

Ramesh no longer walks his field wondering what might happen. He watches it in real time.

THE BIGGER PICTURE: SUSTAINABLE INTENSIFICATION

India has to support a population expected to surpass 1.5 billion in the coming decades. It has to do so while protecting its soil, water, and biodiversity. Nano-drones driven by AI can help India achieve sustainable intensification doing more with less. Less use of chemicals means less harm to the ecosystem. Water conservation through optimized irrigation systems means more water for drinking. Helping pollinators means filling biodiversity gaps. Data farming is more efficient. The future of farming will not do away with tractors and plows. It will use them in conjunction with the intelligence that comes from the sky.

THE STORY CONTINUES

As the nano-drone touches down softly beside him, Ramesh surveys his wheat crop—not with puzzlement, but with understanding. The whir of its rotors grows quiet, but its information does not. Indian agriculture has always been changing. From wooden plows to diesel engines, from water by hand to drip irrigation.

Now, it is changing once more.
This time, the revolution has wings.

And in fields across the land, the sky is no longer just a source of rain.

PRADHAN MANTRI
KISAN URJA SURAKSHA EVAM UTTHAN MAHABHIYAN (PM KUSUM) SCHEME

Promoting Solar Energy in Agriculture

- Decentralised Ground/Stilt Mounted grid connected Solar Power Plant setup
- Installation of Stand alone solar pumps
- Solarisation of grid connected agri pumps including feeder level solarisation
- Interest subvention benefits and credit guarantee coverage under AIF
- CFA/SFA to the tune of 30% & above
- Minimal Margin & Collateral Requirement
- Attractive ROI