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Agri-Tech and Sustainable Development: Emerging Opportunities for Indian Agriculture

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Abstract- Indian agriculture is undergoing a significant transformation driven by technological advancement, environmental challenges and the growing need to enhance agricultural productivity and farmer livelihoods. Although the relative contribution of agriculture to national Gross Value Added (GVA) has declined with structural transformation, the sector continues to be crucial for employment, rural livelihoods and food security. This study examines the role of agricultural technology in promoting sustainable agricultural development in India using secondary data. The study analyses selected indicators relating to the contribution of agriculture to GVA, agricultural employment, technological adoption, government initiatives and emerging Agri-Tech innovations. Secondary information is collected from government publications, the Ministry of Statistics and Programme Implementation (MoSPI), Economic Surveys, the Ministry of Agriculture and Farmers Welfare, World Bank reports, FAO publications and other relevant institutional sources. The study finds that technologies such as precision farming, artificial intelligence, Internet of Things (IoT), satellite-based monitoring, efficient irrigation, hydroponics, vertical farming, renewable energy and automation can improve resource efficiency and contribute to sustainable agricultural development. However, technology adoption remains constrained by limited awareness, inadequate finance, fragmented landholdings, weak infrastructure, insufficient technical support and limited access to markets. The study concludes that technological innovation should be integrated with sustainable farming practices, institutional support, farmer education, affordable finance and appropriate public policies. Such an integrated approach can contribute to higher productivity, improved farm incomes, climate resilience, food security and environmental sustainability.

Keywords- Agri-Tech; Sustainable Agriculture; Indian Agriculture; Agricultural Innovation; Precision Farming; Smart Farming; Artificial Intelligence; Internet of Things (IoT); Agricultural Drones; Digital Agriculture; Climate-Smart Agriculture; Farm Mechanization; Sustainable Development; Agricultural Productivity; Resource Efficiency; Rural Development; Food Security; Farmer Empowerment; Agri-Entrepreneurship; Agricultural Supply Chains.

I. Introduction

Agriculture remains a fundamental component of the Indian economy despite the country's rapid structural transformation towards industry and services. The sector continues to provide employment and livelihoods to a substantial proportion of the population and plays a critical role in food security and rural development. At the same time, increasing pressure on land and water resources, soil degradation, climate variability, rising input costs and declining farm profitability have created the need for more efficient and sustainable agricultural systems.

The increasing application of technology provides an opportunity to address several of these challenges. Precision agriculture, artificial intelligence (AI), Internet of Things (IoT), satellite-based technologies, remote sensing, automated irrigation, hydroponics, vertical farming and renewable-energy-based agricultural systems are creating new possibilities for improving the efficiency of agricultural resources. The existing source material identifies precision farming, agroforestry, vertical farming, hydroponics, renewable energy and robotics as important technological pathways for sustainable agriculture.

However, technology should not be viewed as a stand-alone solution. Its effectiveness depends upon the availability of finance, infrastructure, technical knowledge, extension services, market access and supportive government policies. The existing material identifies lack of awareness, limited finance, inadequate infrastructure, fragmented landholdings, weak market access, low productivity and climate change among the major constraints to sustainable agricultural development.

Therefore, the central issue addressed in this study is whether the emerging Agri-Tech ecosystem can contribute to sustainable agricultural development in India and what economic and institutional conditions are necessary for wider adoption.

II. Statement of the Problem

India faces a paradox in agricultural development. Agriculture continues to support a large share of the population, while its relative contribution to national output has declined. This indicates a persistent productivity and income challenge.

The available data in the source material show that agriculture accounted for around 18.29 per cent of GVA in 2019–20 while employing about 45.6 per cent of the workforce. The share of agricultural employment had also declined from approximately 60.5 per cent in 2000.

This structural imbalance highlights the need to increase agricultural productivity and income without compromising environmental sustainability. Technology may provide part of the solution, but its benefits will depend on the ability of farmers—particularly small and marginal farmers—to access and effectively use these technologies.

III. Period of Analysis

A suitable period for the empirical component is 2011–12 to 2023–24, subject to availability and consistency of the selected variables. This period provides a sufficiently long time series for examining changes in agricultural GVA and related indicators.

Changing Economic Significance of Agriculture in India
Agriculture's relative contribution to the Indian economy has changed considerably as the country has diversified towards manufacturing and services. According to the source material, agriculture accounted for around 18.29 per cent of GVA in 2019–20 while employing about 45.6 per cent of the workforce.

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More recent MoSPI data show that agriculture and allied activities accounted for 17.8 per cent of India's GVA at current prices in 2023–24. The absolute GVA of the sector increased substantially between 2011–12 and 2023–24, even though its relative share declined because non-agricultural sectors grew faster.

This indicates that the decline in agriculture's share of GVA should not necessarily be interpreted as a decline in the absolute importance of agriculture. Instead, it reflects the structural transformation of the Indian economy.

Table 1. Agriculture and Allied Sector: Selected Indicators

Indicator	Observation
Agriculture's share of GVA, 2019–20	18.29%
Agriculture's share of GVA, 2023–24	17.8%
Agricultural employment, 2000	60.5%
Agricultural employment, 2019–20	45.6%
Agriculture and allied GVA, 2023–24	₹4,878 thousand crore
Broad trend	Declining relative share, rising absolute GVA

Source: Compiled from the study material and MoSPI National Accounts data.

IV. Role of Technology in Sustainable Agriculture

1. Precision Agriculture
Precision agriculture uses sensors, GPS, satellite information and data analytics to monitor crop conditions and optimise agricultural inputs. It can contribute to more efficient use of fertilisers, pesticides and water while improving productivity.

2. Artificial Intelligence and Satellite Technology
AI and satellite-based technologies can support crop monitoring, weather analysis, groundwater assessment, pest detection and farm decision-making. Emerging Agri-Tech enterprises are increasingly applying these technologies to address agricultural problems.

For example, the source material identifies Aumsat as using satellite-based and AI-enabled hydrological analysis for groundwater assessment.

3. Internet of Things
IoT-based agricultural systems can connect sensors, irrigation equipment and digital platforms. Sensor-based irrigation can improve water-use efficiency and reduce unnecessary resource consumption.

The Sense It Out case discussed in the source material illustrates the application of soil sensors and IoT technology for irrigation management.

4. Hydroponics and Vertical Farming
Hydroponics allows crops to be cultivated using nutrient-rich water rather than soil, potentially reducing water consumption and enabling year-round production. Vertical

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farming can increase production per unit of land and may be particularly relevant to urban and peri-urban agriculture.

5. Renewable Energy
Solar and other renewable-energy technologies can be integrated into agricultural operations, reducing dependence on fossil fuels and potentially lowering long-term energy costs.

6. Robotics and Automation
Automation and robotics have the potential to reduce labour requirements, improve precision and enhance the efficiency of agricultural operations.

V. Farm Mechanisation as an Indicator of Agricultural Technology

Farm mechanisation is one of the most measurable dimensions of agricultural technology in India. The Economic Survey reported that overall penetration of powered machines in Indian agriculture was approximately 40–45%. For major crop operations during 2019–20, mechanisation levels were reported as:

Table: Mechanisation by Major Farm Operation

Agricultural operation	Mechanisation level
Seed-bed preparation	70%
Sowing / planting / transplanting	38%
Weeding / interculture / plant protection	31%
Harvesting / threshing	32%

Source: Economic Survey 2021–22, Government of India.

Interpretation
The data reveal substantial variation in technology adoption across agricultural operations. Mechanisation is relatively high in seed-bed preparation (70%), but considerably lower in sowing, weeding, plant protection and harvesting. This indicates that India's agricultural technology transition is incomplete and uneven

VI. Custom Hiring Centres and Technology Access

An important policy response to the high cost of agricultural machinery is the development of Custom Hiring Centres (CHCs).

Under the Sub-Mission on Agricultural Mechanization:
- 27,828 CHCs were established between 2014–15 and 2020–21.
- 9,432 CHCs were established during 2020–21 alone.

Interpretation
This is important because India's small and marginal farmers may not be able to purchase expensive machinery individually. The CHC model changes the economic

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structure of technology adoption from: “Farmer owns machinery” to “Farmer accesses machinery as a service.” This can potentially make mechanisation more inclusive.

VII. Agricultural Research and Technology

Technology adoption is supported by agricultural research and development. The Economic Survey notes that India's National Agricultural Research System has contributed to mechanisation, climate-resilient technologies and improved crop varieties. During 2020 and 2021, ICAR notified/released 731 new varieties/hybrids of field crops and 98 horticultural varieties. The same source reports that 35 special-trait varieties, including biofortified and stress-tolerant varieties, were developed during 2021–22.

VIII. Micro-Irrigation as a Water-Saving Agricultural Technology

Micro-irrigation is an important component of modern agricultural technology because it enables the efficient use of scarce water resources. It mainly includes drip irrigation and sprinkler irrigation. Unlike conventional irrigation, micro-irrigation delivers water closer to the root zone and can improve water-use efficiency. The Government of India implements the Per Drop More Crop (PDMC) programme to promote micro-irrigation among farmers.

Table 9.1: Expansion of Micro-Irrigation under Per Drop More Crop

Indicator	Achievement
Programme period	Since 2015–16
Area covered up to 2021	59.37 lakh hectares
Area covered by 2023–24	83.46 lakh hectares
Central assistance to small and marginal farmers	45%
Assistance to other farmers	Assistance to other farmers
Micro-Irrigation Fund	₹5,000 crore

Source: Department of Agriculture & Farmers Welfare, Government of India

The expansion from 59.37 lakh hectares to 83.46 lakh hectares demonstrates the increasing adoption of water-saving technology in Indian agriculture. Micro-irrigation is particularly important in the context of water scarcity and climate change.

IX. Digital Agriculture and E-Nam

Digitalisation is emerging as a new dimension of agricultural technology in India. Digital platforms can reduce information asymmetry, improve price discovery, provide market information and connect farmers with a wider range of buyers.

The National Agriculture Market (e-NAM) is an important example of digital agricultural technology. It integrates physical agricultural markets into an online trading platform.

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Table: Expansion of e-NAM

Indicator	Achievement
Year launched	2016
Mandis integrated by June 2025	1,522
States/UTs covered	23 States + 4 UTs
Farmers registered	1.79 crore
Traders registered	2.67 lakh
FPOs registered	4,518
Value of agricultural produce traded	₹4,39,941 crore

Source: Ministry of Agriculture & Farmers Welfare, Government of India, 30 June 2025

DRONE TECHNOLOGY IN AGRICULTURE

Agricultural drones represent an emerging form of precision farming technology. Drones can be used for spraying fertilisers, applying pesticides, crop monitoring, detecting crop stress, precision agriculture, reducing labour requirements. The Government has introduced the Namo Drone Didi Scheme to promote agricultural drone services

Table: Agricultural Drone Technology in India

Indicator	Achievement
Namo Drone Didi outlay	₹1,261 crore
Period	2023–24 to 2025–26
Drones targeted	15,000
Central financial assistance	80% of drone package cost
Maximum assistance	₹8 lakh per SHG
Drones distributed by LFCs in 2023–24	1,094
Drones distributed under Namo Drone Didi	500
Drone demonstrations by ICAR institutions, SAUs & KVKs (2023–24 to Nov. 2025)	41,010 hectares
Farmers benefited through demonstrations	4,52,291

Source: Ministry of Agriculture & Farmers Welfare, Government of India

Interpretation

The data indicate that drone technology is moving from an experimental technology towards a service-based agricultural technology.

An important feature is that drones are not being promoted only through individual ownership. Women SHGs can operate drones and provide agricultural services to farmers.

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The Government's research on the 500 drones distributed under the scheme reported that a Kisan Drone can cover approximately one acre in 7–8 minutes, demonstrating its potential for rapid agricultural operations.

Soil Testing and Soil Health Card Technology

Soil-health technology is another important dimension of scientific agriculture. Traditional farming may involve uniform application of fertilisers without adequate knowledge of the specific nutrient requirements of soil.

The Soil Health Card Scheme, introduced in 2015, uses scientific soil testing to provide farmers with information about soil nutrients and recommendations for appropriate fertiliser application.

Table: Soil Health Technology in India

Indicator	Achievement
Soil Health Cards generated by July 2025	More than 25 crores
Soil testing laboratories established by Feb. 2025	8,272
Static laboratories	1,068
Mobile laboratories	163
Mini laboratories	6,376
Village-level laboratories	665
Soil mapping completed	290 lakh hectares
Village-level fertility maps	1,987

Source: Ministry of Agriculture & Farmers Welfare, Government of India

The Soil Health Card provides information on 12 parameters, including nitrogen, phosphorus, potassium, sulphur, micronutrients, pH, electrical conductivity and organic carbon.

Interpretation

Soil-health technology helps farmers move from generalised input application to scientific and site-specific nutrient management. It can potentially reduce excessive fertiliser application, improve nutrient-use efficiency, reduce input costs, improve soil fertility, promote balanced fertilisation, support sustainable agriculture. The scale of the programme—more than 25 crore Soil Health Cards—indicates the substantial spread of scientific soil-management technology in India

Policy Suggestions

Promote Technology as a Service

Custom Hiring Centres should be expanded to include tractors, harvesters, drones, precision equipment, sensors and solar pumps.

Strengthen Micro-Irrigation

The government should promote drip and sprinkler irrigation, particularly in water-stressed regions.

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Develop Farmer-Centric AI
AI applications should provide information in regional languages and be designed around actual farmer requirements.

Encourage Agri-Tech Startups
Public–private partnerships can help scale innovative agricultural technologies.

Strengthen Agricultural Extension
Technology adoption should be accompanied by:
Promote FPO-Based Technology Adoption
Farmer Producer Organisations can enable farmers to collectively access expensive technologies.

Integrate Technology with Sustainability
Technology adoption should be combined with soil conservation, crop rotation, integrated pest management, agroforestry, water conservation and climate-resilient agriculture.

Improve Agricultural Data
Reliable agricultural data are essential for evaluating technology adoption and its economic impact.

IX. Conclusion

The present study examined the role of technology in the transformation and sustainable development of Indian agriculture using secondary data. The analysis demonstrates that Indian agriculture is gradually moving from traditional, input-intensive farming towards a more technology-enabled, resource-efficient and knowledge-based agricultural system. The growth of agriculture and allied-sector GVA, expansion of irrigation and cropping intensity, increasing adoption of micro-irrigation, farm mechanisation, agricultural research, digital marketing, drone technology, solar-powered agricultural systems and soil-health technologies collectively indicate the growing importance of technology in agriculture.

The evidence also shows that technological transformation is uneven and incomplete. While mechanisation has made considerable progress in operations such as seed-bed preparation, substantial gaps remain in sowing, weeding, plant protection and harvesting. Similarly, although micro-irrigation and digital agricultural services are expanding rapidly, their adoption is influenced by farmers' financial capacity, awareness, access to infrastructure and technical knowledge. This suggests that the mere availability of technology does not automatically ensure its widespread adoption or economic benefits.

An important finding of the study is that agricultural technology should not be viewed merely as the use of machines. It encompasses mechanical, water-management, biological, digital, precision, soil and renewable-energy technologies. Custom Hiring Centres provide an inclusive mechanism for accessing expensive machinery, while e-NAM expands digital market access. Drones facilitate precision agricultural operations, solar pumps connect agriculture with renewable energy, and soil-health technologies

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encourage scientific input management. Together, these innovations can contribute to higher productivity, lower production costs, efficient resource utilisation and improved environmental sustainability.

The secondary evidence therefore supports the view that technology has an important role in strengthening the economic, social and environmental sustainability of Indian agriculture. However, technology should complement rather than replace fundamental sustainable farming practices such as soil conservation, crop diversification, crop rotation, integrated pest management and efficient water management.

The study concludes that the future of Indian agriculture depends not simply on greater technological adoption, but on equitable and appropriate technological adoption. Policies should focus on making technologies affordable and accessible to small and marginal farmers through Custom Hiring Centres, Farmer Producer Organisations, subsidies, credit facilities, digital extension services and skill development. Greater investment in agricultural research, rural digital infrastructure and climate-resilient technologies is also essential.

Ultimately, the transformation of Indian agriculture should aim at "more production with fewer resources, higher farmer income with lower costs, and technological progress with environmental sustainability." An integrated approach combining Agriculture, Technology, Sustainability and Inclusive Institutions can provide a stronger foundation for resilient agricultural development and sustainable rural livelihoods in India.

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