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Revolutionising Indian agriculture through digital technologies

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Abstract
As an agrarian economy, India continues to struggle with issues including fragmented landholdings, unpredictable weather, declining productivity, and limited market access. However, the use of digital technology has the potential to transform India's agriculture sector. Digital technology can help farmers to make well-informed decisions on crop selection, irrigation, fertilization, and pest control due to the use of precision agriculture, the Internet of Things (IoT), data analytics, drones, and satellite-based technologies. These innovations support economic resilience and environmental sustainability in addition to increasing productivity and resource efficiency. By offering real-time weather, pricing, and crop advisory data, digital platforms assist in bridging the information and market access gaps. Continuous crop and livestock health monitoring is made possible by technologies like GPS-enabled equipment, remote sensing, and Internet of Things-connected sensors, which maximize usage of resources and lower input costs. Despite the assurance, the digital divide, limited digital literacy, and infrastructure issues prevent widespread adoption. It is crucial to address these obstacles through extension services, governmental assistance, and public-private partnerships. Farmers will be empowered if mental health, decision-making skills, and equitable access to technology are prioritized, particularly in rural and underserved areas. Indian agriculture may be transformed by digital technologies and policies, guaranteeing resilience, sustainability, and national food security.

Keywords: Global Positioning System (GPS) technology, remote sensing, sensor technology, weather monitoring, data analytics, Internet of Things (IoT) technology, satellite images

Introduction

India's economy has long been based on agriculture, which supports a sizeable chunk of the population's livelihoods. (Mann, 2018) [30]. With the incorporation of digital technologies, the agriculture industry has recently seen a significant revolution. (Chapman.*et al.*, 2022) [7] A new age known as "Digital Agriculture" or "AgTech" has begun as a result of the fusion of conventional farming methods and cutting-edge technology. (Mtshali & Jili 2022) [34]. The application of digital technology in agriculture is essential due to India's varied agro-climatic zones and the immensity of its agricultural landscape. (Sarkar, 2008) [53].

The country faces the combined issue of feeding its expanding population and preserving the financial security of its farmers because more than 60% of its people depend on agriculture (Nugent, 2000) [37]. By increasing the effectiveness, productivity, and sustainability of agricultural practises, digital technology offers to address these issues. (Shepherd *et al.*, 2020) [56]. The varied uses of digital technology in Indian agriculture will be covered in this introduction, along with their relevance, effects, and potential to completely transform the industry. (Lajoie *et al.*, 2020) [27]. Biodiversity provides in maintaining life, ensuring food and nutritional security, and promoting cultural and health well-being (Padhy *et al.*, 2022) [40]; digital technologies support biodiversity by empowering farmers to use more sustainable crop rotations and intercropping techniques, which enhance soil health (Farm rise, 2024) [16]. Understanding how digital technology works and its ramifications for farmers, politicians, and other stakeholders is crucial as the nation moves towards a more technologically advanced agricultural industry (Di Vaio *et al.*, 2020) [13].

Digital innovations can assist developing countries for overcoming global poverty and hunger quicker in rural areas (Padhy *et al*, 2022) [41]. The continuous integration of the digital economy with the rural economy has gradually become an emerging driving force for sustainable

agriculture (Chunfang *et al*., 2024) [9]. Entrepreneurship is a driver of sustainable development in agriculture (Pattanayak and Padhy, 2022) [47, 42]. Indian entrepreneurship is changing quickly in the twenty-first century due to innovation, global integration, and technologies like blockchain, artificial intelligence, and renewable energy (Mishra *et al*., 2023) [32]. In order to address the challenges of global food security, digital agriculture is transforming agri-food systems by improving productivity, sustainability, and resource efficiency (Abiri *et al*., 2023) [1]. The need for focused agricultural extension initiatives to improve farmers' knowledge, abilities, and incomes was highlighted by a study on 240 cotton farmers in the Gajapati and Rayagada districts of Odisha that found a partial adoption of suggested crop management practices, with significant gaps associated with socioeconomic and extension-related factors (Padhy *et al*., 2021) [38, 39]; the use of Internet of Things (IoT) technology is changing cotton farming methods in the quickly changing agricultural environment of today (Farmonaut.com, 2025) [15].

Precision farming

- Precision agriculture or smart farming, is a cutting-edge farming technique that uses technology, data, and analytics to optimise several elements of agricultural production (Karunathilake *et al.,* 2023) [24]. Precision farming aims to improve crop yields, reduce resource waste, and boost overall farm productivity (Finger *et al.,* 2019) [17]. To increase the sustainability of farming operations, it requires using a variety of technology and data-driven practises. Components and methods used in precision agriculture (Tantalaki *et al.,* 2019) [62].
- Global Positioning System (GPS) Technology: Tractors and harvesters are two examples of agricultural machinery that can be precisely mapped and tracked using GPS technology (Momin *et al.,* 2019) [33]. This facilitates the creation of accurate field maps and guarantees that farming operations take place in the appropriate locations (Rosell & Sanz 2012) [52].
- Remote sensing: To keep an eye on crop health, soil conditions, and environmental factors, remote sensing technology, such as satellites and drones, are used Inoue, Y. (2020) [20]. These tools can record data and photos that offer perceptions into crop development and stress levels (Zohar, 2000) [66].
- Automated Farm Equipment: Farm equipment with connectivity and automation characteristics can do duties more precisely (Jha, 2019) [22]. For instance, agricultural harvesting and seed placement can be improved by automated planting and harvesting systems (Suprem *et al.,* 2013) [60].

The Internet of Things (IoT) Technology

It entails the use of sensors, gadgets, and connection to gather information and automate several agricultural processes, ultimately enhancing efficiency, productivity, and sustainability in farming (Javaid *et al.,* 2022) [21].

- **Sensor technology**

In the field, IoT sensors are used to track a variety of characteristics, including soil moisture, temperature, humidity, light, and nutrient levels. (Mekala & Viswanathan 2017, August) [31]. Real-time data from these sensors can be utilised to plan irrigation, fertilisation, and crop management strategies (Ragab *et al.,* 2022) [50].

- **Remote Monitoring**

Using IoT-connected equipment, farmers and other agricultural experts can remotely monitor their livestock and crops (Gupta *et al.,* 2020) [19]. This enables them to monitor the health of their livestock and land without really being there (Patel and Patel, 2016) [46].

- **Weather monitoring**

Decisions about planting, harvesting, and other agricultural activities can be made using real-time weather data from IoT-connected weather sensors (Paul *et al.,* 2022) [48].

- **Data analytics**

By analysing the data gathered by IoT devices, it is possible to learn more about the health of the crops, forecasts for the yield, and overall farm performance Based on this data, predictions and suggestions can be made using machine learning and AI. (Rajeswari *et al.,* 2017) [51].

- **Energy Efficiency**

IoT can aid in optimising farm energy use. Smart systems, for instance, can manage the lighting and heating in greenhouses based on current conditions (Ullah *et al.,* 2022) [63].

Satellite images

- The Indian Space Research Organisation (ISRO) offers satellite-based services like Bhuvan and MOSDAC that give satellite images and weather data for agriculture. These tools can be used by farmers for crop planning and monitoring (Nayak, 2020) [35].
- Bhuvan: Developed by ISRO, Bhuvan is an online geoportal that gives users access to a variety of geospatial data, including satellite pictures (Karnatak *et al.,* 2014) [23]. Farmers can utilise Bhuvan to observe particular areas of interest, evaluate the state of the soil, monitor changes in the land's cover, and make appropriate plans for their agricultural endeavours (Kumar *et al.,* 2022) [26]. In order to assist farmers in making decisions, Bhuvan also provides themed maps that contain details about different types of soil, how land is used, and weather predictions (Giribabu *et al.,* 2018) [18].
- MOSDAC (Meteorological and Oceanographic Satellite Data Archival Centre): Another ISRO programme, MOSDAC, focuses on offering satellite information and services for agriculture and meteorology. (Shah, 2016) [55]. It provides data on numerous meteorological characteristics, satellite photos, and real-time weather information. Farmers can utilise MOSDAC to access weather forecasts, precipitation data, temperature data, and other meteorological data to properly organise their farming activities. (Verma & Gupta 2020) [64]. Monitoring weather patterns and their effects on crops can be aided by MOSDAC's satellite photography (Sawant *et al.,* 2021) [54].
- For Indian farmers, Bhuvan and MOSDAC are both essential tools that support them in making decisions

about crop management, irrigation, pest control, and other facets of agriculture. (Sawant *et al.,* 2021) [54]. These tools help the agricultural industry and the nation's food security by utilising the capabilities of ISRO's Earth-observing satellites (Dastagiri & PV 2020) [11].

Livestock Management

The incorporation of Internet of Things (IoT) technology, livestock management has experienced a substantial revolution. (Sinha & Dhanalakshmi 2022) [58]. IoT technologies are increasingly commonly used in agriculture to track and manage livestock, ensuring their welfare, streamlining processes, and raising overall output. (Taneja *et al.,* 2019) [61]. Radio-frequency identification (RFID) tags are frequently employed in the management of cattle. These tiny, passive gadgets can be fastened to an animal's ears or other body parts (Voulodimos *et al.,* 2010) [65]. A wirelessly scannable unique identifier is present on every tag. Farmers can maintain thorough records of specific animals, including their birthdates, medical histories, and other vital information, thanks to RFID technology. (Ponschock, 2007) [49]. It enables automatic tracking and observation of animals' movements when used with readers positioned across the farm. (Mainetti *et al.,* 2014, September) [29]. Data analysis and GPS collars Larger livestock, including cattle and buffalo, are often the ones that use GPS collars. In addition to having a GPS, these collars occasionally have accelerometers and temperature sensors. (Džermeikaitė *et al.,* 2023) [14]. They give farmers access to real-time location information, enabling them to keep track of the animals' grazing patterns, spot any aberrant behaviour or distress, and stop theft or loss. (Neethirajan, 2023) [36]. A central system processes and analyses the data that is gathered from numerous IoT devices. Ahmed *et al.,* 2021) [4]. On the basis of historical data, machine learning algorithms can be used on this data to advise breeding techniques, anticipate disease outbreaks, and improve feeding regimens. (Cockburn, 2020) [10].

Agricultural drones

In some situations, crop monitoring, pesticide application, and even seed sowing are done with the help of drones that have cameras and sensors on board. (Ahirwar *et al.,* 2019) [3]. Precision agriculture drones, sometimes referred to as agri-drones or ag-drones, have grown significantly in popularity in recent years due to their capacity to improve productivity, sustainability, and efficiency in farming operations. These drones can carry out a range of agricultural activities thanks to their numerous cameras, sensors, and other technological features. Some important uses are found by agricultural drones (Chaturvedi & Tiwari 2022) [8].

By facilitating real-time data collection for well-informed decisions on irrigation, fertilization, and pesticide use, drone technology—a key component of precision agriculture—is revolutionizing modern farming and increasing yields while decreasing resource waste and fostering environmentally friendly practices (Anusha and Padhy, 2024) [2]. Drones can detect changes in temperature and humidity linked to insect infestations or diseases in crops using thermal imaging cameras and sophisticated sensors (Maddikunta *et al.,* 2021) [28]. Crop Spraying: Some agricultural drones come with sprayers or fertiliser dispensers for use on crops. (Krishna, 2017) [25]. The use of chemicals is decreased and the environmental impact is reduced because these drones can precisely target the problem locations. (Stehr, 2015) [59]. Drones can be used in some situations to plant seeds by accurately scattering them across a specified region. Reforestation activities and extensive planting initiatives benefit greatly from this technique. (Castro *et al.,* 2021) [6]. In order to modernize Indian agriculture and manage complex difficulties while increasing production and sustainability, digital technologies like as artificial intelligence (AI), drones, and the Internet of Things (IoT) require effective 21st-century leadership that is marked by adaptability, empathy, and technological competency (Padhy *et al*., 2022) [40].

Conclusion

Farmers may improve their mental health and resilience through improved connectedness and well-informed decision-making by receiving timely weather alerts, market information, telecounseling services, and support networks (Padhy *et al*., 2020) [43]. By getting real time decision support tools farmers' stress can be alleviated (Padhy and Raju, 2018) [44]. Mental health challenges of farmers can be addressed by availing to telemedicine, virtual counseling and peer support groups (Padhy and Raju, 2020) [45]. In cotton, measurement and grading plays an important role (Padhy *et al*., 2021); farmers may now access sophisticated data and analytics capabilities using AI, which will promote better farming and increase productivity (Ashoka *et al*., 2023) [5]. Digital technologies address urgent issues like food security and climate resilience by encouraging sustainable habits like biodiversity conservation and resource efficiency. Digital inequalities, infrastructural deficiencies, and data privacy issues, however, continue to be major obstacles. It is crucial to address issues through focused rules, extension initiatives, public-private partnership, and funding for digital infrastructure in rural areas. Ensuring comprehensive access to technology—especially for smallholders and rural populations—will empower farmers, boost earnings, and promote equitable agricultural growth. India can assure a profitable and sustainable future for its agriculture sector and the country as a whole by utilizing digital technology via concerted efforts.

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