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Digital Transformation in Indian Agriculture: Assessing the Impact on Crop Monitoring and Sustainable Farming Techniques

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ABSTRACT

This research paper investigates the role of digital tools in enhancing farming practices. Based on a survey of 500 farmers from Punjab, Uttar Pradesh, Haryana, and Bihar, the study evaluates the impact of digital awareness, farming efficiency, and crop yield. The findings reveal a positive correlation between farmers' awareness of digital technologies and improvements in agricultural productivity. Farmers utilizing digital tools for crop monitoring, weather predictions, and soil health management reported higher efficiency and yield, with a significant 20% improvement in productivity compared to those using traditional methods. Punjab and Haryana showed higher rates of technology adoption, while Uttar Pradesh and Bihar lagged due to limited infrastructure. The study highlights the transformative potential of digital agriculture in India while also addressing challenges in accessibility and adoption, emphasizing the need for improved infrastructure and training.

Keywords: Digital Transformation, Digital Agriculture, Crop Monitoring and Sustainable Farming.

I. INTRODUCTION

India, with its vast agricultural landscape and diverse climatic conditions, has embraced crop monitoring technologies to enhance agricultural productivity and sustainability. The integration of digital tools, satellite imagery, IoT devices, and advanced data analytics is transforming how Indian farmers monitor and manage their crops. Crop monitoring plays a critical role in optimizing resources, predicting yields, and minimizing losses due to pests, diseases, and unpredictable weather patterns.

i. History of Crop Monitoring in Indian Farming

Crop monitoring in India has evolved significantly over the centuries, transitioning from traditional practices to the integration of cutting-edge technologies in modern agriculture. The history of crop monitoring in Indian farming can be traced through various phases of agricultural development, from ancient techniques used by farmers to the sophisticated systems in place today.

1. Ancient and Traditional Crop Monitoring Practices

In ancient India, agriculture was deeply intertwined with the natural environment, and farmers relied on traditional knowledge to monitor crops. These early techniques were largely based on observation and experience, passed down through generations. Some key traditional methods included:

- Observation of Natural Signs: Farmers used environmental cues such as changes in wind patterns, bird migration, the flowering of trees, and the behavior of animals to predict rainfall and seasonal changes. For instance, the flowering of the Indian Coral Tree (Erythrina) was often seen as an indicator of the arrival of the monsoon.
- Crop Diversification and Rotation: To maintain soil fertility and prevent pests and diseases, farmers practiced crop rotation and intercropping. Different crops were planted in alternate seasons to balance nutrient uptake and control pest populations.
- Water Management: In regions like the Indus Valley Civilization (c. 2500 BCE), advanced irrigation systems were developed, including reservoirs, wells, and canal networks, which helped monitor water levels for effective farming. Traditional water harvesting techniques like "tankas" (rainwater harvesting structures) and "kuls" (water channels in the Himalayan region) were used to manage water availability.

2. Colonial Era and the Introduction of Modern Science (18th–20th Century)

During British colonial rule (1757–1947), Indian agriculture underwent significant changes. While traditional practices continued, the introduction of modern scientific methods began to shape crop monitoring in India.

- Agricultural Surveys: The British government conducted the first large-scale surveys and studies of Indian agriculture, leading to more organized systems of monitoring crop production, land use, and irrigation patterns.

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- Introduction of Scientific Tools: Modern tools such as rain gauges and temperature-measuring devices were introduced to monitor weather conditions and improve agricultural planning. Agricultural research stations were set up to study crop growth patterns and soil health.
- Agriculture Universities: The establishment of institutions like the Indian Agricultural Research Institute (IARI) in 1905 marked the beginning of formal research into crop monitoring, pest control, and soil management. These institutions started to explore ways to enhance agricultural productivity by monitoring crop conditions more scientifically.

3. Post-Independence Green Revolution (1960s–1980s)

After India's independence in 1947, the Green Revolution in the 1960s marked a major turning point in the history of Indian agriculture. Crop monitoring became more systematic as the country focused on increasing food production to combat hunger and food insecurity.

- High-Yielding Varieties (HYVs): The introduction of HYV seeds for crops like wheat and rice necessitated more precise crop monitoring to ensure optimal growth conditions. Farmers were encouraged to use fertilizers, pesticides, and irrigation in a controlled manner, leading to more detailed observation of crop growth stages.
- Irrigation Infrastructure: Large-scale irrigation projects like the Bhakra Nangal Dam helped farmers monitor and manage water usage for crops. Improved irrigation systems allowed for better planning and execution of crop cycles.
- Role of Research Institutes: Government-backed research institutions, such as the Indian Council of Agricultural Research (ICAR), played a crucial role in monitoring crops, studying soil health, and implementing strategies to increase yields. These institutes conducted field trials and monitored the effectiveness of new agricultural technologies and techniques.

4. Technological Advancements and Digitalization (1990s–Present)

From the 1990s onwards, the liberalization of India’s economy and the global rise of digital technologies ushered in a new era of crop monitoring.

- Satellite Monitoring and Remote Sensing: The launch of India's first remote sensing satellite, IRS-1A, in 1988 marked the beginning of satellite-based crop monitoring in India. Satellite data began to be used to estimate crop yields, track land use changes, and assess drought conditions. ISRO’s satellites like Resourcesat-1 (launched in 2003) became pivotal in monitoring crop health and soil moisture.
- Weather Forecasting for Agriculture: With the development of advanced meteorological tools, the Indian Meteorological Department (IMD) started providing more accurate weather forecasts, which farmers used to plan their sowing and harvesting seasons. This reduced the risks associated with unpredictable weather patterns.

- Agricultural Informatics: In the late 1990s, the National Informatics Centre (NIC) started creating digital platforms for agricultural monitoring. The launch of the Agricultural Resources Information System (AgRIS) and Bhuvan, ISRO's geoportal, provided farmers with access to satellite imagery and agricultural data.
- Mobile Apps and Agri-Tech Solutions: With the explosion of mobile technology in the 2000s, crop monitoring became more accessible to small and large farmers alike. The rise of agricultural apps like Kisan Suvidha, RML AgTech, and Agrostar empowered farmers with real-time weather updates, market prices, pest alerts, and crop health insights.
- Precision Agriculture: The development of IoT-based sensors, GPS-guided machinery, and drone technology marked the introduction of precision farming techniques in India. Precision agriculture helps farmers monitor and manage crops at a micro-level, optimizing the use of inputs like water and fertilizers, thus improving yields and sustainability.
- Crop Insurance Schemes: Government schemes like Pradhan Mantri Fasal Bima Yojana (PMFBY) integrated remote sensing and satellite monitoring to assess crop losses and process insurance claims, leading to faster and more accurate compensation for farmers.

ii. Crop Monitoring Techniques

Crop monitoring is a critical aspect of modern agriculture, utilizing technology to improve yields, optimize resource use, and enhance sustainability. It involves the collection and analysis of data related to crops, such as soil moisture, plant health, pest activity, and weather conditions. By continuously monitoring crops, farmers can make informed decisions that reduce wastage, increase productivity, and support sustainable farming practices.

1. Remote Sensing and Satellite Imagery

Satellite and drone-based monitoring provide real-time data on crop health, soil conditions, and pest infestations. This technology helps detect early signs of crop stress and allows farmers to address issues before they affect yields. For instance, remote sensing technologies can measure vegetation indices like NDVI (Normalized Difference Vegetation Index) to assess plant health by analyzing reflectance in different spectral bands.

India has made significant advancements in remote sensing, largely driven by organizations like the Indian Space Research Organisation (ISRO). ISRO's satellites, such as Cartosat, RISAT, and Resourcesat, provide critical data on crop health, soil conditions, and moisture levels. This data is made available to farmers through platforms like the Bhuvan portal and the Kisan Portal, empowering farmers with accurate, real-time information.

Through satellite-based crop monitoring, the government and research institutions track agricultural patterns, assess crop damage from natural disasters, and predict yields at a national scale. This helps in planning policies, managing food distribution, and ensuring food security.

Internet of Things (IoT) Sensors: IoT sensors placed in the fields measure various parameters such as soil moisture, temperature, and humidity. These sensors transmit data to cloud-based platforms where it is analyzed to provide actionable insights for farmers. By optimizing irrigation and fertilization based on real-time data, IoT-driven crop monitoring reduces the overuse of water and fertilizers, promoting sustainability. The Internet of Things (IoT) is being used in Indian agriculture to monitor soil health, temperature, humidity, and water levels. Farmers use sensors placed in fields to collect real-time data on these parameters. The data is then analyzed by software platforms, which provide actionable insights on irrigation, fertilization, and pest control. This has been particularly effective in precision farming, where resources like water and fertilizer are applied only where necessary.

Usually, it appears that such a big technology is limited to the big farms only. But informal methods also contribute to the crop monitoring. The crops monitoring systems are developed at domestic level using key components. Using MQ135 sensor (air quality), DST11 (Humidity and temperature), and Soil moisture sensors formers are developing their own monitoring system. J. Gautam (2020), has suggested that few informal activities can be formalised to retain the good in them. Similarly, if these indigenous projects are scaled, chances are high that the technology could shape a cost-effective structure.

2. Precision Agriculture

Precision agriculture, powered by data from sensors, GPS, and satellite imagery, allows for targeted interventions. Farmers can apply water, fertilizers, or pesticides only where needed, minimizing environmental impact. This technology ensures resource efficiency and reduces the carbon footprint of farming practices. Drone technology is gaining popularity in India for crop monitoring. Drones provide high-resolution aerial imagery, which can detect crop stress, plant diseases, and pest infestations early on. This allows farmers to take timely action to prevent significant damage to crops. Companies and startups, such as Aarav Unmanned Systems and Skylark Drones, are offering drone services to monitor large farms more efficiently.

Several agricultural apps, developed both by the government and private companies, are now empowering Indian farmers with real-time information on crop health, weather forecasts, and market prices. For example:

- Kisan Suvidha: Provides farmers with information on weather, input dealers, market prices, and plant protection measures.
- Agrostar: An e-commerce platform that also offers advisory services based on crop monitoring data.
- CropIn: This platform provides real-time monitoring, weather-based advisory, and predictive analytics to improve decision-making in farming.

These apps are bridging the digital divide by providing smallholder farmers with access to technology that was previously available only to large-scale commercial farmers.

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Precision Agriculture: Precision farming, which relies on technologies like GPS, GIS, and sensors, is becoming a key trend in India's crop monitoring landscape. By applying inputs such as water, fertilizer, and pesticides in precise amounts based on field data, precision farming helps in reducing input costs, improving crop health, and ensuring sustainable farming practices.

Government Initiatives: The Indian government has launched various programs to promote digital crop monitoring and support farmers. The Pradhan Mantri Fasal Bima Yojana (PMFBY) integrates satellite imagery to assess crop damage and estimate yield losses, allowing for quicker processing of crop insurance claims. Similarly, the National Agriculture Market (e-NAM) integrates digital platforms to facilitate transparent trade and real-time price discovery.

Agri-Tech Startups: Numerous agri-tech startups in India are revolutionizing crop monitoring. Companies like Ninjacart, DeHaat, and SatSure are providing farmers with insights using AI, big data, and remote sensing technology. These startups offer end-to-end services, from monitoring to market access, helping farmers make informed decisions and improve their incomes.

3. AI and Machine Learning

Advanced algorithms can predict crop diseases and pest outbreaks based on historical data and real-time monitoring. AI-driven crop monitoring platforms also provide recommendations for optimal planting times, irrigation schedules, and crop management practices, leading to higher yields and lower environmental impact.

iii. Sustainable Farming Techniques

Sustainable farming techniques aim to maintain productivity while preserving the environment and natural resources. These practices ensure the long-term viability of agricultural lands, protect biodiversity, and improve farmers' socioeconomic conditions.

1. Conservation Tillage: Conservation tillage involves minimal disturbance to the soil, preserving its structure and reducing erosion. This technique also promotes the retention of moisture and organic matter, enhancing soil fertility and reducing the need for chemical inputs.
2. Crop Rotation and Diversification: Crop rotation involves alternating different crops in a field across seasons to improve soil health, prevent pests and diseases, and increase yields. Diversified cropping systems also contribute to biodiversity and improve ecosystem resilience.
3. Agroforestry: Agroforestry integrates trees into agricultural systems, offering multiple benefits, such as improved soil fertility, carbon sequestration, and habitat for wildlife. The presence of trees can also prevent soil erosion and increase water retention.
4. Organic Farming: Organic farming eliminates synthetic pesticides and fertilizers, relying on natural methods such as composting, biological pest control, and green manure. This practice reduces the environmental impact of farming and produces healthier crops.

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5. Water Conservation Techniques: Drip irrigation, rainwater harvesting, and mulching are effective methods for conserving water. These techniques are particularly important in regions facing water scarcity and ensure that crops receive the necessary hydration without wasting resources.
6. Integrated Pest Management (IPM): IPM combines biological, cultural, and mechanical control measures to reduce the need for chemical pesticides. This approach minimizes environmental damage and promotes a balanced ecosystem by encouraging natural pest predators.

iv. Challenges in Crop Monitoring

Despite the many benefits, there are challenges in the adoption of crop monitoring technologies in India:

- Limited Digital Literacy: A large section of Indian farmers still lacks digital literacy, which limits the effective use of advanced crop monitoring tools.
- High Costs: Advanced technologies like IoT devices and drones can be expensive for smallholder farmers to adopt without subsidies or government support.
- Infrastructure Issues: In many rural areas, reliable internet connectivity is still a challenge, hindering the use of digital platforms for crop monitoring.

After observing the history of crop monitoring in Indian farming, the evolving techniques, sustainable farming practices, and associated challenges, the researcher identified the need for a comprehensive study on the impact of digital technologies in agriculture. The problem statement, "Digital Transformation in Indian Agriculture: Assessing the Impact on Crop Monitoring and Sustainable Farming Techniques," aims to explore how advancements in digital tools, and promoting sustainable agricultural practices in India.

2. LITERATURE REVIEW

Resource efficiency and environmental sustainability are critical components of modern agriculture, incorporating technologies like GPS guidance systems, remote sensing, and data analytics (Srinivasan, 2014). GPS-based tools, such as precision-guided tractors, enable farmers to conduct field operations with greater accuracy, minimizing overlaps and increasing operational efficiency. Internet of Things (IoT) devices and sensors gather real-time data on soil moisture, temperature, and crop health, enabling more informed decision-making (Jensen, 2017). Remote sensing through satellites and drones offers high-resolution imagery for monitoring crop conditions, detecting stress areas, and optimizing irrigation strategies (Thenkabail et al., 2017).

Regarding resource optimization, precision irrigation and Variable Rate Technology (VRT) play significant roles. IoT-enabled soil moisture sensors support precision irrigation by applying water exactly where and when it's required, thus reducing waste and enhancing water-use efficiency (Zhang et al., 2019). VRT allows for precise input application, such as fertilizers and pesticides, tailored to

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the specific needs of different areas within a field, thereby reducing overuse and mitigating environmental impact (Bullock et al., 2018).

In terms of reducing environmental impact, precision agriculture techniques enable the targeted use of inputs, cutting down on pesticide and fertilizer application, which helps lower pollution and enhances ecosystem health (Pannkuk et al., 2021). Additionally, practices like GPS-guided contour farming reduce soil erosion, helping to maintain soil structure and lessen the environmental footprint of agricultural activities (Jaynes et al., 2014). The review suggested that it will be suitable to conduct a study among Indian farmers to understand their perception about digitalization of crop monitoring and its impact.

3. RESEARCH METHODOLOGY

Research Design

This study adopts a mixed-methods approach to assess the impact of digital transformation on crop monitoring and sustainable farming techniques among farmers in the states of Punjab, Uttar Pradesh, Haryana, and Bihar. The research is based on primary data collected through structured surveys and interviews on digital agriculture.

Objective

- To study the Knowledge and usage of digital tools for farming and crop monitoring
- To study the impact of digital tools on crop monitoring

Hypothesis

H01: There is no significant level of awareness among the farmers about digital farming

H02: There is no significant impact of awareness among the farmers about digital farming and faming efficiency

H03: There is no significant impact of awareness among the farmers about digital farming and faming yield

Population

The target population for this research consists of farmers from Punjab, Uttar Pradesh, Haryana, and Bihar. These states represent a diverse range of agricultural practices, cropping patterns, and levels of technological adoption, making them ideal for studying the impact of digital tools on agriculture.

Sampling Strategy

A multistage random sampling technique will be used to select respondents:

Stage 1: Select three districts from each of the four states (Punjab, Uttar Pradesh, Haryana, Bihar) based on the extent of agricultural activities and the presence of digital farming interventions.

Stage 2: In each district, select two villages with different cropping patterns (one with traditional farming methods and one with significant adoption of digital tools).

Stage 3: A total of 500 farmers (125 from each state) will be selected using random sampling, ensuring diversity in terms of farm size, crops grown, and level of education.

Data Collection

Survey: A structured questionnaire will be designed to gather data on:

Farmer demographics (age, education, landholding size).

Knowledge and usage of digital tools for farming.

Impact of digital tools on crop monitoring (weather forecasts, soil health monitoring, pest control).

Influence of technology on sustainability practices (water conservation, precision farming, organic farming).

Challenges faced in the adoption of digital technologies (cost, accessibility, technical literacy).

- **Interviews:** In-depth interviews with a subset of farmers (25 from each state) will be conducted to gain qualitative insights into their experiences with digital tools, their decision-making processes, and socio-economic impacts.

Data Analysis

- **Quantitative Data:** Survey responses will be analyzed using descriptive statistics (mean, median, frequency distributions) and inferential statistics (correlation, regression analysis) to identify trends and relationships between the use of digital tools and farming outcomes.
- **Qualitative Data:** Thematic analysis will be employed to categorize and interpret data from interviews, focusing on key themes such as barriers to technology adoption, perceived benefits, and social impact.

Ethical Considerations

The study will adhere to ethical standards by ensuring informed consent, confidentiality of respondents, and voluntary participation. The survey questionnaire and interview protocol will be approved by an ethics committee before deployment.

4. ANALYSIS AND FINDINGS

i. H01: There is no significant level of awareness among the farmers about digital farming

The researcher has conducted the survey among 500 farmers. The Wilcoxon signed rank test on the data suggested that the observed mean is higher than the hypothesised mean. It has been established that there is a significant level of awareness among the farmers about digital farming. The farmers demonstrated familiarity with various digital tools, including weather forecasting apps, soil health

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monitoring platforms, and pest management technologies. The majority of the respondents had either used or were aware of platforms providing real-time data on weather conditions, crop health, and irrigation needs.

The survey results indicated that 65% of the farmers had access to smartphones, enabling them to download agricultural apps that assist in crop monitoring. Farmers in Punjab and Haryana showed a higher rate of technology adoption, primarily using mobile applications for precision farming and market price updates. In contrast, farmers in Bihar and Uttar Pradesh were more inclined to use weather forecasting and pest control tools. Although awareness levels were high, the survey also revealed challenges in the widespread adoption of digital farming, including limited internet access in rural areas, lack of digital literacy, and the high cost of some technologies. Despite these challenges, the study highlights that farmers in these states are gradually shifting towards technology-driven agriculture, recognizing its potential for enhancing crop yields and promoting sustainable farming practices.

ii. H02: There is no significant impact of awareness among the farmers about digital farming and faming efficiency

The corelation among the digital awareness and faming efficiency have been very high. The value of r= 0.681 shows that there is a significant impact of awareness among the farmers about digital farming and faming efficiency. Further the multiple corelation coefficient R value .671 supported the hypothesis testing. farmers from Punjab, Uttar Pradesh, Haryana, and Bihar revealed a significant impact of digital farming awareness on agricultural efficiency. The sample included farmers from diverse backgrounds, representing small, medium, and large landholdings, with varying levels of access to technology.

The survey found that 68% of the farmers were aware of digital tools such as weather forecasting apps, satellite-based crop monitoring, and precision farming techniques. Among these, a large number actively used digital platforms to receive timely weather updates, monitor soil health, and access information on pest management.

Farmers who adopted digital tools reported improved efficiency in terms of crop monitoring, irrigation management, and pest control. About 72% of users noted a reduction in input costs, particularly in water and fertilizer usage, due to precision farming technologies. Additionally, 65% of farmers reported increased crop yield and quality, attributing this to the accuracy of digital recommendations. However, the survey also highlighted barriers such as limited access to smartphones and low digital literacy, especially among older farmers. Despite these challenges, the findings indicate a clear positive correlation between digital awareness and farming efficiency, underscoring the potential of digital agriculture in improving farming outcomes in India.

iii. H03: There is no significant impact of awareness among the farmers about digital farming and faming yield

The corelation among the digital awareness and faming yield have been very high. The value of r= 0.611 shows that there is a significant impact of awareness among the farmers about digital farming and faming yield. Further the multiple corelation coefficient R value .671 supported the hypothesis testing. wareness of digital farming on agricultural yields. The survey targeted a diverse group of farmers, varying in age, education level, and farm sizes, allowing for a comprehensive analysis of the effects of digital farming tools.

The results indicated that farmers who were more aware of and engaged with digital technologies—such as weather forecasting apps, soil health monitoring tools, and precision farming equipment—reported higher crop yields and better farm management. Nearly 70% of respondents acknowledged using at least one digital platform for crop monitoring, pest management, or market price updates. This adoption was particularly high in states like Punjab and Haryana, where government initiatives and access to technology have been more prevalent.

Farmers who actively used digital tools reported up to a 20% improvement in crop productivity compared to those who relied on traditional methods. They attributed this to more accurate decision-making regarding irrigation, fertilization, and pest control. However, the survey also highlighted the need for greater infrastructure support, especially in rural areas of Uttar Pradesh and Bihar, where technological adoption remains lower.

5. CONCLUSION

The research paper titled "Digital Transformation in Indian Agriculture: Assessing the Impact on Crop Monitoring and Sustainable Farming Techniques" set out to explore the role of digital tools in improving agricultural outcomes. Focusing on the states of Punjab, Uttar Pradesh, Haryana, and Bihar, the study surveyed 500 farmers to assess their awareness of digital farming technologies, and how this awareness influenced farming efficiency and yield. The study employed digital awareness, farming efficiency, and yield as key variables, revealing significant relationships between these factors.

The study has faced challenges in reaching illiterate farmers, requiring assistance during data collection. Responses may be influenced by social desirability bias, particularly regarding the perceived benefits of technology adoption. The diversity of crops and farming practices in the selected states may limit the generalizability of the findings. The findings of the survey demonstrate a strong correlation between farmers' awareness of digital technologies and improvements in both farming efficiency and crop yield. An overwhelming majority of respondents, particularly in Punjab and Haryana, indicated that they had adopted at least one form of digital farming tool. These tools, ranging from weather forecasting applications to soil health monitoring and pest management systems, have significantly enhanced their ability to make informed decisions. Farmers who reported higher levels of digital awareness experienced better outcomes in terms of crop management, pest control, irrigation practices, and overall resource optimization.

One of the key insights from the study is the positive impact of digital technologies on farming efficiency. Farmers who utilized precision farming tools and apps for real-time data on weather, soil health, and crop conditions reported being able to manage their farms more effectively. They noted that these tools enabled them to reduce wastage, optimize the use of inputs like water and fertilizers, and make timely interventions to prevent crop damage. This heightened efficiency is directly linked to the farmers' increased digital awareness, which has allowed them to integrate more scientific and data-driven practices into their traditional farming methods.

Furthermore, the survey highlighted the role of digital tools in improving crop yields. Farmers who had embraced digital farming technologies experienced significant increases in their production, with some reporting improvements of up to 20% in crop output. The use of tools like satellite imagery, precision irrigation systems, and crop disease detection apps helped in enhancing their yield by providing timely, accurate information that led to better decision-making. However, the research also identified regional disparities in the adoption and impact of digital agriculture. While farmers in Punjab and Haryana were more digitally aware and benefited significantly from these tools, those in Uttar Pradesh and Bihar lagged behind in both awareness and adoption. This gap can be attributed to a lack of infrastructure, access to digital tools, and education, which limits the potential for digital farming to positively impact agricultural productivity in these regions. In conclusion, the study confirms that digital transformation is playing an increasingly vital role in Indian agriculture, particularly in improving farming efficiency and yields. However, to maximize the potential of digital agriculture, efforts must be made to address the infrastructural and educational barriers in states like Uttar Pradesh and Bihar. Policymakers should focus on expanding access to digital farming tools and training programs across India, ensuring that farmers in all regions can benefit from these technological advancements. By doing so, the country can foster more sustainable, efficient, and productive agricultural practices, helping farmers not only to meet the growing demand for food but also to contribute to more environmentally sustainable farming techniques.

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