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Digital initiatives and innovations in transforming the horticulture sector

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ABSTRACT

Digital Agriculture may refer to the application of an array of digital Technologies to improve the efficiency, quality and productivity of different crops. This can include technologies such as remote sensors, drones, precision irrigation systems, and GPS-guided machinery, data analytics etc. Similarly, AI and Machine Learning is expected to make precise decisions about crop zoning, management, farm resource allocation, plant health management, cost effective harvesting, value chain management, *etc*. These digital technologies can be used to collect data about soil conditions, crop health, weather patterns, and other factors that impact the plant growth and yield. This data can provide various practical solutions, namely, increased efficiency, reduced cost, improved crop yield, and reduced environmental impact. It can also thus help the farmers to make more informed and take apt decisions about crop management and resource allocation, thus help in improving production, productivity, quality, traceability and sustainability by maximizing the production and minimizing waste.

Keywords: ICT, dron, precision horticulture, decision support, input use efficiency.

INTRODUCTION

India's digital revolution has made a significant impact on governance and service delivery, establishing digital identities and secure payment systems. This progress has fostered a robust digital ecosystem across various sectors such as finance, healthcare, education, and retail, positioning India as a global leader in citizen-centric digital solutions. In a bid to bring similar transformation to the Agriculture and allied sector, the Union Cabinet Committee, chaired by Prime Minister Narendra Modi, approved the 'Digital Agriculture Mission' on September 2, 2024. With a total financial commitment of Rs. 2,817 crore, including Rs. 1,940 crores from the central government, the mission aims to leverage digital technologies to revolutionize agriculture sector across the value-chain.

The Digital Agriculture Mission (DAM) is designed as an umbrella scheme to support various digital agriculture initiatives. These include creating Digital Public Infrastructure (DPI), implementing the Digital General Crop Estimation Survey (DGCES), and supporting IT initiatives by the Central Government, State Governments, and Academic and Research Institutions. This Mission aims to extend the benefits of India's digital revolution to the agriculture sector, transforming it into a more efficient, transparent, and farmer-centric industry. Under this mission, three key digital public infrastructures is to be developed: AgriStack, the Krishi Decision Support System (DSS), and Soil Profile Mapping (SPM). These initiatives will integrate data on farmers, crops, soil, and weather parameters into a unified digital platform, enhancing decision-making and improving service delivery.

The ultimate goal of Digital Agriculture is to make farming more profitable and sustainable by leveraging Information and Communication Technologies (ICT) and data science. This will help ensure food and nutrition security, improve farm profitability, and promote environmental sustainability in the face of climate change challenges. Some of the initiatives under Digital Agriculture Mission are as;

AgriStack

AgriStack is designed as a farmer-centric Digital Public Infrastructure (DPI) to streamline services and scheme delivery to farmers. It is the digital foundation being set up by the government to make it easier to bring various stakeholders together to improve agriculture in India and enable better outcomes and results for the farmers by using data and digital services. It is an effort to bring together high-quality data and to make this data easily available to the stakeholders that need it so that they can create new services using the data. Evolved from the thinking of the InDEA 2.0 Architecture by MeitY, Agri Stack is being built by the Ministry of Agriculture & Farmers Welfare in an open manner, with a federated structure-keeping States at the centre of the design, ensuring participatory and inclusive design to ensure the sector evolves collectively to help shape the next decade of agriculture in India.

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It comprises three key components:

i. *Farmers' Registry*: Farmers will be given unique digital ID (farmer ID)
ii. *Geo-referenced village maps*: Farmer ID will be linked to the State's land record, demographic details, family details, *etc.*
iii. *Crop sown registry*: Crop sown by the farmers will be recorded through mobile-based ground surveys, *i.e.*, digital crop survey during each season.

AgriStack aims to make it simple for farmers to get easier access to cheaper credit, higher-quality farm inputs, localized and specific advice, and more informed and convenient access to markets. These interventions would thus make it easier for governments to plan and implement various farmer and agriculture-focused benefit schemes. The implementation of AgriStack is progressing through partnerships between the Central and State Governments, with 24 states having signed MoUs with the Ministry of Agriculture and Farmers Welfare. The Pilot projects have been conducted in six states to test the creation of Farmer IDs and the Digital Crop Survey.

Krishi decision support system

The Krishi Decision Support System (Krishi-DSS) will integrate remote sensing data on crops, soil, weather, and water resources into a comprehensive geospatial system. It will help in generating information related to geospatial data and weather data, drought and flood monitoring, ground water availability, modelling for crop yield and crop insurance. This programme has been launched on August 17, 2024 by the Union Minister of State for Agriculture and Farmers Welfare, to make Indian Agriculture smart and resilience to meet the challenges of Climate change. With the launch of this a satellite-based geospatial platform farmers across the country will be rendered information on the weather, groundwater levels, soil health, reservoir storage levels etc. and also data related with satellite images, which can be easily accessed from anywhere at any time. With crop mapping and monitoring, one will be able to understand the cropping patterns by analyzing parcel-level crop maps over the different years. This information helps in understanding crop rotation practices and thus promote sustainable agriculture by encouraging the cultivation of diverse crops. Further, the Drought monitoring will help to provide near real-time information on various indicators, *i.e.* soil moisture, water storages, crop conditions, dry spells etc., while crop weather watch will keep us informed about how weather is impacting the crops, crop harvest status, crop residue burning *etc.* One Nation-One Soil Information system will provide comprehensive soil data through digital mode, *i.e.* soil type, soil pH, soil health *etc.* that can ideally be used for assessing crop suitability and land capability for implementing soil water conservation measures.

Ground Truth data library of Krishi-DSS will foster innovation by providing essential resources like ground truth data and spectral libraries for different crops to the researchers and industry. It will provide holistic solutions from flood impact assessment to Crop insurance and many more. It's about empowering our farmers, informing our policies, and nourishing our nation. By integrating various data sources available on the Krishi Decision Support System (DSS), various farmer-centric solutions can be developed such as right individual advisories to farmers, early disaster warning like pest and pathogen attack, unseasonal heavy rains, occurrence of Hail storm *etc.* Thus, it would act as catalyst for innovation and sustainability in Agriculture.

Soil profile mapping

Under the mission, detailed soil profile maps on a 1:10,000 scale for approximately 142 million hectares of agricultural land have been envisaged, with 29 million hectares of soil profile inventory already being mapped. Aims to enable farmer-centric digital services to provide timely and reliable information for the agriculture sector.

Furthermore, under the Digital Agriculture Mission, the Digital General Crop Estimation Survey (DGCES) will be used for harvesting experiments to provide precise yield estimates, enhancing agricultural production accuracy. The mission is expected to create direct and indirect employment in agriculture, providing opportunities for around 2,50,000 trained local youth and Krishi Sakhis.

By leveraging modern technologies like data analytics, AI, and Remote Sensing, the mission will improve service delivery for farmers, including streamlined access to government schemes, crop loans, and real-time advisories.

Benefits of the mission

By aligning technology, governance and market forces, the mission sets the pace for developing a resilient ecosystem where farmers thrive, policies are pro-active, and businesses innovate.

For farmers, the mission ensures access to high-quality inputs such as seeds and precision agriculture technologies, financial inclusion through instant credit and subsidies, reduced post-harvest losses via improved cold chains, and AI-driven advisories in regional languages to mitigate risks and bridge information gaps on weather, pests, and markets.

For policymakers, the mission enables decision support system for departments for planning, resource allocation and timely policy intervention. A new age of data-driven governance and strategic planning will emerge bringing transparency, accountability and climate adaptation. Digital Crop Surveys will provide granular data on horticulture acreage and production, forecasting; Krishi DSS for evidence-based interventions such as drought response, subsidy targeting through geospatial and thematic data layers.

For the private sector, the mission can spur innovation, growth opportunities and market expansion for the private sector in agriculture. The standardized data will encourage private investments and open avenues for the AI-ML startups, drone manufacturers, and fintech firms to develop tailored horticulture solutions on crop insurance, precision tools etc. Cold chain and logistic networks will reduce the cost enabling private players as well as boost India's export competitiveness. Collectively, this ecosystem drives sustainable growth, empowers smallholders, and positions India as a global horticulture leader through proactive policies, technological inclusivity, and market-led resilience.

AVENUES AND PROSPECTS OF DIGITAL HORTICULTURE

Horticulture is characterized by a great variety and variability of production because of involvement of living and perishable commodities, and production depends on natural conditions such as weather situation, pests & diseases, soil conditions, seasons and climate. Indoor production in greenhouses is a strategy to cope with these uncertainties resulting in a more controlled production environment to optimize weather conditions, fertigation, light and moisture.

The Horticulture production in India in 2023-24 is estimated (3rd advance estimate) to be about 353.19 million tonnes, in which production of fruits is expected to reach 112.73 million tonnes and production of vegetables is envisaged to be around 205.80 million tonnes. In the past few decades, the horticultural crop production is continuously increasing steadily. The high yielding varieties, proven plant protection measures and other horticultural production technologies have contributed immensely to increase the production every year. Precision farming started early in the 21st century to manage the farming following efficient technologies later the digital technologies were introduced in the last decade.

DIGITAL SMART TECHNOLOGIES

IoT (Internet of things)

This technology comprises the use of sensors, drones, robots, and digital cameras. Sensors, cameras, and robots are installed on the farms to record the data. Digital farming can be done through the installation of network-connected 'smart' devices as part of IoT (Internet of Things). In Horticulture, IoT involves the use of interconnected devices and sensors to collect real-time data on various parameters. Sensors placed in fields monitor soil moisture, temperature, humidity, and nutrient levels. Automated irrigation systems use this data to optimize water usage, reducing wastages and improve the crop health. IoT also enhances supply chain management by tracking produce from farm to market, ensuring quality and thus reducing spoilage ranging from 5-25% in different commodities.

Artificial intelligence (AI)

It complements IoT by analysing the huge data sets collected, providing the actionable insights and predictions. Machine Learning (ML) algorithms process data to predict weather patterns, pest outbreaks, and crop diseases, enabling farmers to take preventive measures. AI-powered drones and remote sensing technologies monitor crop health and field conditions, identifying issues like nutrient deficiencies, pest infestations, and disease outbreaks early. AI also aids in precision farming by recommending optimal planting schedules as well as irrigation and fertilization practices based on data analysis. The combination of IoT and AI in Horticulture leads to more efficient resource use, higher crop yields, and reduced environmental impact. It empowers farmers with real-time information and predictive analytics facilitating informed decision-making. This technological convergence is crucial for addressing challenges such as climate change, population growth, and food security, ensuring a sustainable and productive agricultural future. Another area where it is being applied in agriculture is the development of autonomous robots. Autonomous robots can perform tasks such as weed control and crop monitoring.

Digital twins

The Digital Twins can significantly enhance the needed control capabilities by allowing growers to act immediately in case of (expected) deviations and simulating interventions based on real-life data. Moreover, the scale of greenhouse horticulture has increased in recent years. In large-volume production, it is no longer possible to keep track of the cultivation process manually. This is reinforced by the increasing scarcity of green labour, *i.e.* experienced employees with horticultural knowledge. Digital Twins can be a suitable enabler to deal with these challenges because they remove fundamental constraints

concerning place, time and human observation. Greenhouse horticulture would no longer require physical proximity, enabling remote and automated execution, monitoring, control and coordination of greenhouse operations by different stakeholders. This caters for the decoupling of physical flows from information aspects of horticultural processes.

Drone or unmanned aerial vehicle (UAV)

A drone or unmanned aerial vehicle (UAV) is a flying robot that can fly without a pilot on board. Drones can be remotely controlled or fly autonomously using software-controlled flight plans. They are powered by an electric motor and have modern equipment like GPS, radar control, infrared and high-resolution cameras. Drones in agriculture can be used as pay per services or can be bought and stationed on farms.

Benefits

Some of the merits of digital interventions are as follows –

- Near real-time monitoring.
- Standard package of practices.
- Readily available and accessible management through smartphones and PCs.
- Geotagging for accountability and accurate predictability.
- Satellite and weather input-based advisory.
- Robust and flexible system for farm management.
- Alert log and management of pest infestation, diseases etc.
- Crop reports and insights- easy reporting.

DIGITAL SOLUTION IN CROP PRODUCTION AND MANAGEMENT

The integration of automated procedures in horticulture increases the productivity as well as the quality of the products. The crop is affected by many factors such as the temperature, the humidity and the topography of the surrounding environment. Achieving ideal values for these factors and optimizing their consequences depend on the type of the crops cultivated.

Precision irrigation

The design of an efficient irrigation system should consider climatic as well edaphic factors to achieve a successful and high-quality harvest. The process of grape maturation is affected by the photo-synthesis that produces the sugars that are stored in the berries. In grapes, the balance among sugar, acid, pH and potassium is fundamental in determining the quality of the produced wine. This balance depends to a large extent on the frequency of the irrigation of the cultivated fields. In grapes, automated monitoring and advisory system for intelligent viticulture programme, classification of biotic and abiotic stresses on grape berries using transfer learning has been initiated. The transfer learning was used to test the performance of six major deep learning image classification architectures with variations in training conditions and hyper parameters for 8 stress conditions on grape berries. Two prototypes have been developed for automated vineyard monitoring at ICAR-NRC Grapes, Pune. These are: i) Offline Device consisting of Arduino microcontroller, 5 MP camera module and data logger with SD card storage, and ii) Cloud-Based Camera Network: ESP32-cam microcontroller with built-in camera and cloud connectivity. Uploads images directly to the cloud using 4G Wi-Fi hotspot. These prototypes offer automated triggers for capturing data based on pre-defined time-lapse ideal for remote monitoring and data access.

Smart greenhouses

It is estimated that by 2050, the IoT will increase the yield by 70% in horticulture. IoT is a powerful technical support to agriculture. Smart greenhouses are one of typical IoT agriculture examples. A smart farm is capable of automatically controlling environmental conditions such as temperature based on its database customized for different crops. Even sprinkling of pesticides can be done without the intervention of farm labour. All environmental elements such as humidity, light and ventilation are managed by the smart farming system. It is believed that the amount of produce can increase approximately 30% with the help of the solution. Retractable greenhouses equipped with IoT would transform future farming of floricultural crops. Mechanization in protected cultivation of flowers Protected cultivation is an intensive production system which requires high investment and operational costs thereby limiting its usage in production systems. Automation and robotics are the only ways to circumvent these constraints. The unstructured and variable crop environments pose challenges for implementation of automation and robotics.

Mechanization of nursery operations

To minimize drudgery in nursery industry and also address the dwindling labour force, smart automation is crucial for different operations like bed making, media mixing, media filling, sowing, watering, makings cuttings, weeding, periodical pruning *etc.*

Drone technology

Drone usage has become a reality in floriculture in recent times with the introduction of ambitious programme of Ministry of Agriculture and Farmers

Welfare, Government of India to promote drone usage on a large scale. A special proramme Drone Didi is launched by Hon'ble Prime Minister where in drones will be given to around 3,000 women self-help groups (SHGs) across several states with a subsidy of ` 8.00 lakh to procure agriculture drones. ICAR-DFR, has initiated research on crucial parameters like speed, height, discharge rate, droplet size, spray volume, dosage of different chemicals on flower crops and ornamental nurseries besides conducting demonstrations in farmer's fields. Drones can be effectively utilized not only for plant protection but also regular monitoring of crop health, estimation of damage during calamities for determining the crop insurance. Global effort include, RIPPA (Robot for Intelligent Perception and Precision Application) which is a small drone like a ladybird used for identification of pest and diseases besides precision application of chemicals.

Real-time pest and disease monitoring

The use of sensors, real-time images, data analysis, artificial intelligence and robots can help in catching any problem or disease early. This is because it can identify any changes in the environment or behaviour of the crop. It can alert the workers to take immediate action. This helps in preventing the disease. It is even improving the crop quality. Along with this, when it comes to data collection, the use of artificial intelligence enables us to reduce the inaccuracies. This helps in informing the decision making processes. In an effort made at ICAR-NRC Banana, Trichy to characterize weather factors to predict the development of disease (Sigatoka leaf spot) and pest (scaring beetle) and disease mapping in banana growing areas, it was found that the AlexNet program has predicted the leaf spot disease with full accuracy and deploy into the mobile application, which predicts and classify the banana leaf diseases. In mango, YOLO v.5 (You Only Look Once) model, is a vision AI model that is designed for object detection, image classification, and instance segmentation has been initiated at ICAR-CISH, Lucknow. Initially five leaf spot diseases namely, anthracnose, red rust, phoma blight, gall and powdery mildew were considered for training, validation and testing the model. A custom program based on YOLO model is developed in Python and image augmentation is in progress.

Postharvest management and food processing

Digital technologies can significantly contribute towards addressing the challenges faced by the post-harvest sector at every level of the supply chain. The digital technologies at farm level such as sensors, robots and drones, can provide precise information to farmers and help them increase yields in a climate-friendly way. Blockchain technology can enhance traceability and sustainability by monitoring the food chain from the field to the consumer. The studies on opportunities offered by digital technologies in the field of nutrition concluded that they are helpful in providing tailored health advice but warned against their potential threats to the privacy of health information. Some initiatives have already taken by research organizations for the use of digital technologies in post-harvest sector.

Digital solutions for seed and planting material: complete value chain

Digitalization in the seed production can be used by field workers to record the data on the field in an MIS for management to monitor activities from breeders. Smart loggers can be used in plant growth observations, crop health detection, and crop stress detection. Smart loggers can be designed specifically to be used by the management to monitor the location of field workers. After harvesting, the management of seeds can be done digitally through loggers. One of the biggest issues today faced by farmers is fake seed and planting material. Traceability can solve this problem as it tracks the source of seeds/ plants. Traceability can also be used for tracking and removing of seeds and plants from the market that don't meet the certification standards. QR codes on the packet can be scanned to view the complete history of the packet of seeds and hence farmers know whether the seeds are genuine. Seed producers and suppliers can manage their entire seed distribution and sales by this way. Likewise it can be used meticulously for all operations.

Digital farming and agri-insurance

Cloud-based Agri tech SaaS solutions find a breakthrough application in agri-lending and agri-insurance by providing actionable insights on the associated risk of the farm plot. MIS keeps cloud storage for the storage of history that is available about the farms. Suppose a farmer comes in and asks for a loan, the bank can use agritech SaaS to look into the farmer's records related to the yield and profits in the last ten years. This helps the Insurance companies to estimate the crop loss and pay the payments.

Assessment of crop acreage

The assessment of different crop area is important for agricultural management and monitoring. It helps with identifying seasonal crops, tracking crop growth, and providing information for agricultural planners

and cultivators. The accuracy of crop production estimates depends on the accuracy of crop area estimates. This data will help in making swift decision in planning storage, retails, logistics, exports and processing demands.

CHALLENGES OF DIGITAL FARMING

The different challenges include the high cost of equipment, implementation, and management of digital farming technologies, limited access to data and connectivity in rural areas, and potential data privacy and security issues. Further, there is a learning curve involved in implementing new technologies, as it may take time for farmers to adopt digital farming solutions.

FUTURE THRUSTS

It is expected that digital interventions will play a key role in addressing global food security challenges and in helping farmers adopt climate-smart agriculture practices. It has major role in horticultural systems since the crop vary from annual to perennial in nature and quite distinct in their agrometeorological needs. Using emerging technologies like the internet of things (IoT)-enabled devices such as smart agricultural sensors and robotic drones, satellite imagery, and GPS-enabled instruments, real-time data are collected on soil, crop, hyper-local weather predictions, equipment available, and other variables. This is supplemented by inputs from IoT and AI/ML-driven predictive analytics software to enhance production and productivity of floricultural crops. Digital Smart interventions would make this sector more technology-driven productivity input and energy efficient, environment-friendly, complete value-chain development and globalization.

I hope that the Horticultural fraternity present here could get to know the nations preparedness to adopt and promote the Digital Technologies to meet the growing demand for agricultural produce. I am sure together, we'll march ahead during the *Amrit Kaal* and build a tech-led, smart, resilient, sustainable, and prosperous Agri-/Horticulture sector for India.

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