

Digital horticulture: Status and future prospects

Horticulture faces significant challenges due to the variability of natural conditions such as weather, pests, soil, and climate. Indoor production in greenhouses, along with digital horticultural innovations, provides a controlled environment that can optimize conditions for crop growth. Digital horticulture integrates digital technologies like IoT, AI, and precision farming, enabling enhanced efficiency, quality, and sustainability in horticultural production. Key digital tools include remote sensors, drones, and machine learning, which support informed decision-making for crop management and resource allocation. IoT and digital twins enable real-time monitoring, automation, and remote management in greenhouse settings. AI aids in pest and disease monitoring, crop health analysis, and optimal harvest timing, while precision irrigation systems increase water-use efficiency, as seen in trials on grapes, banana, and tomato crops. Digital solutions also enhance post-harvest management, traceability, and e-commerce. Despite adoption challenges due to high costs, limited access, and security concerns, digital advancements are expected to transform horticulture, driving productivity, sustainability, and climate resilience in the face of evolving global food security needs.

HORTICULTURE is characterised by 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 and diseases, soil condition, season and climate. Indoor production in greenhouses is a strategy to cope with these uncertainties, resulting in a more controlled production environment to optimise weather conditions, fertigation, light and moisture. Due to the existing uncertainties resulting from the erratic weather patterns, pests and quality loss, as well as new challenges, especially concerning to energy management, growers continuously have to reassess the cultivation strategies and reschedule planned activities based on the timely monitoring of the greenhouse operations to achieve their goals.

Digital horticulture refers to the use of digital technologies to improve the efficiency, quality and productivity of horticultural crops. This includes technologies such as remote sensors, drones, precision irrigation systems, and GPS-guided machinery, as well as the use of data analytics, AI and machine learning to make informed decisions about crop management and farm resource allocation. 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 can provide various benefits such as increased efficiency, reduced costs, improved crop yields, and reduced environmental impact. It also helps farmers make more informed and appropriate decisions about crop management and resource allocation, thus

helping to improve production and sustainability by maximizing the production and minimizing waste.

Technologies at hand

Digital farming

Digital farming is the integration of precision farming and smart farming, and is achieved through the implementation of intelligent software and hardware. Precision farming is popularly defined as a technology-enabled approach to farming management that observes, measures, and analyses the need of individual fields and crops. Smart farming is more focused on the use of data acquired through various sources (historical, geographical and instrumental) in the effective management of the farm activities.

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) or they can be software as a service (SaaS) based agtech. When hardware transfers data over a network they become 'smart devices' and become part of the IoT. Since IoT utilizes hardware, it requires solid technical knowledge for operating the equipment along with high maintenance and setup cost. The high capital input cost is what keeps IoT out of the reach of most farmers.



AI and IoTs in horticulture

Digital twins

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 technology 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.

Artificial intelligence

Artificial intelligence (AI) refers to systems that display intelligent behaviour by analyzing their environment and taking actions—with some degree of autonomy—to achieve specific goals. Looking at its modernity, it is being adopted in the large agricultural sector in India as well. Artificial intelligence is becoming an increasingly integrated and important part of agricultural applications. It is being used for its ability to process large amounts of data and make accurate predictions. Artificial intelligence is being used to improve crop yields, optimize irrigation and fertilizer practices, and reduce the impact of pests and diseases. One of the major areas where artificial intelligence is being applied in agriculture is the development of algorithms. It

can generate and interpret large datasets. An algorithm is being used to identify patterns and trends in agricultural data. It is used to develop agricultural practices. 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.

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.

Software as a service (SaaS)

Software as a service (SaaS) is the more economical and scalable way to upgrade to digital farming.

Merits of digital interventions in agriculture

- 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 temperature, humidity and 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 Offline Device consisting of Arduino microcontroller, 5 MP camera module and data logger with SD card storage, and Cloud-Based Camera Network: ESP32-cam microcontroller with built-in camera and cloud connectivity. The device 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.

The IoT technology offers a sustainable solution for efficient water management in banana farming. Moisture sensors measure soil moisture and transmits real-time data through internet to cloud and processed through AI for precise irrigation scheduling. The preliminary data of the work initiated at ICAR-NRC for Banana, Trichy shows that < 25% of water is saved over and above the drip irrigation method without compromising the yield and quality of the fruit.

In a trial on IoT based fertigation scheduling for improving water productivity and nutritional density in Nagpur mandarin at ICAR-CCRI, Nagpur, it was found that IoT based fertilizer scheduling increased water saving by 10-15% and fruit yield was increased from 150 to 171 kg/plant. The root density and quality of the fruit was also improved by this system. The studies conducted at ICAR-IIVR, Varanasi showed that wireless sensor-based drip irrigation and nitrogen scheduling significantly improve crop yield and water-use efficiency in tomato and capsicum cultivation, highlighting the importance of appropriate application of N and irrigation management. The sensor-based irrigation and fertigation system also resulted in better quality traits, *i.e.* phenolics, acidity, and flavonoids contents. This study indicates that automation of drip irrigation and fertigation scheduling may be helpful in enhancing input-use efficiency in tomato and capsicum. The FIS diagnostic system to adjust temperature and humidity in outdoor oyster mushroom growing unit at ICAR-IIHR, Bengaluru saved 30% water in comparison to time based manual operation system. These preliminary

Assessment of the crop acreage



Papaya tree identification in between tomato



Low altitude remote sensing of multi crop identification



Mosaic image of test site (approx. 30 acre). Multi crop identification, segregation and count



Numbering of each tree to identify crop, age



Module and protocol for assessment of the crop acreage (area) with crop signature of mango using ground truth, UAV and satellite data together with > 85% accuracy



Sensor-based irrigation and fertigation modules in tomato

studies indicate that Wireless Sensor Networks (WSNs) can provide accurate and highly effective services to achieve improved yield and quality. The real-time data collected by sensors located in the cultivated fields may be used by experts or by automated systems to make decisions. Additionally, since a WSN does not require the deployment of wires, the need for human intervention is minimized. Thus, it is expected that WSNs will become a low cost yet effective approach for the monitoring of fields in the near future.

In water management, early detection of possible floods or water logging conditions in the field that could be destructive for the crops, can be mitigated by timely pumping of the water by streamlined coordination between different working groups.

Digital solution for greenhouse horticulture

In smart and data-driven greenhouse horticulture, every object in the greenhouse such as plants, containers, greenhouse sections, and equipment can be virtualised and remotely controlled. The growers are able to monitor and control operations remotely, based on real-time digital information instead of direct observation and manual tasks on-site. The alert sent by the sensors /system of any expected issues, can be inspected by desktops or smartphone by viewing a rich digital image of the plants or equipment concerned. The growers can simulate corrective and preventive actions. This offers an optimum environment for the crop which leads to a better quality harvest. The sensor-based irrigation and fertigation system provided higher yield with better quality traits such as TSS, phenolics, and lycopene in polyhouse grown tomatoes as compared to open field grown produce. The disease and pest monitoring, even pollination management in greenhouse horticulture, can be managed with the sensors and desired action may be taken.

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 besides improving the crop quality. Along with this, when it comes to data collection, the use of artificial intelligence enables us to reduce

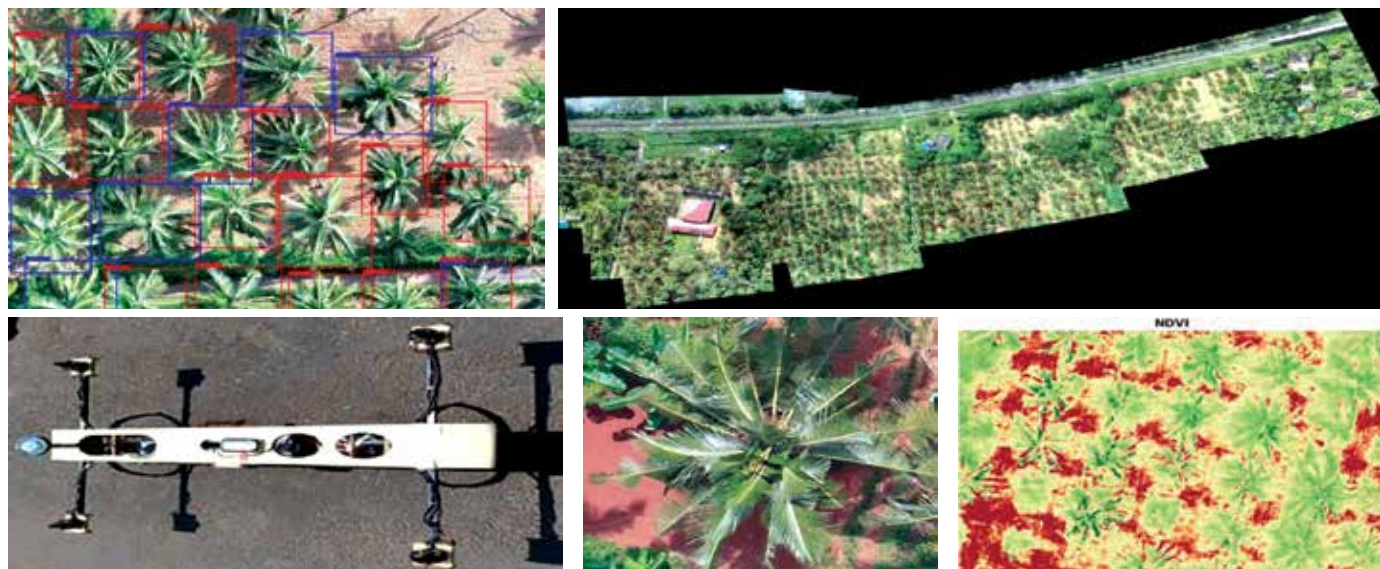
the inaccuracies. This helps in improving the decision making processes. In an effort made at ICAR-NRC for Banana, Trichy to characterize weather factors to predict the development of disease (Sigatoka leaf spot) and pest (scaring beetle) in addition to disease mapping in banana growing areas, it was found that the AlexNet program has predicted the leaf spot disease with full accuracy and deployed into the mobile application, which predicts and classify the banana leaf diseases. In mango, YOLO v.5 (You Only Look Once) model, which 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.

Post-harvest 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



e-Crop-based smart farming



UAV and AI initiatives for pest and disease surveillance

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 been taken by research organizations for the use of digital technologies in post-harvest sector. The grading of banana fruits at ICAR-NRC for Banana, Trichy is done through CNN and it acts as the trainable feature extractor of the images and XGboost acts as the identifier of ripening stage. Development of classification tool for varietal separation of mango using machine learning has been initiated. At ICAR-IIHR, Bengaluru, sensors-based grading and quality assessment mode with a firm is in progress under PPP mode. At ICAR-IIOPR, Pedavegi, quality evaluation of oil palm fresh fruit bunches using Artificial Intelligence and Machine Learning approaches, developing device for predicting oil content in FFB has been initiated. Currently, image acquisition and image processing of different oil palm bunches is being done. Further plan is to work on SVM / ANN machine learning algorithms to classify the degree of ripeness in oil palm fresh fruit bunches (FFBs) and correlate them with the oil content and free fatty acid levels, which may be useful in ensuring low free fatty acid content on palm oil.

Supply chains are increasingly virtualised in response to market challenges and to opportunities offered by now-a-days affordable new technologies. The Internet of Things concept can be used to enhance virtualisation of supply chains in the Floriculture sector. Virtualisation is expected to have a big impact in this sector where currently most products still physically pass through auction houses on their fixed routes from growers to customers.

E-commerce has seen a stable growth over the last few decades. The COVID-19 pandemic enhanced such habit as 30% of consumers claimed to have started using e-commerce during lockdown. Among the available platforms for e-commerce, mobile phone apps were chosen as a focus because of higher number of mobile phone users. The fruit and vegetable vending vans along with mobile apps have played a vital role in ensuring the supply of fresh vegetables in several metro cities. At

ICAR-IIHR, Bengaluru, fruit and vegetable vending vans have been developed which played a vital role during the pandemic period.

Digital solution for seed and planting material production, processing, tracking, distribution and sales

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 faced by farmers today 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 do not 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.

Crop timing prediction

Artificial intelligence can be used to predict the optimal harvest timing. It can also be used to help in enhancing crop yield and increase profits. With artificial intelligence algorithms, agriculture can be managed more efficiently and produce more output than traditional methods. Data collected about the environment such as rainfall forecast, water quality etc. can be leveraged by it. It can identify issues that farmers may otherwise miss. With its insights, farmers can make much better decisions to manage their crops for maximum yield and quality.

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.

Assessment of the crop acreage

The assessment of crop area is important for agricultural management and monitoring. It helps in 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.

Challenges of digital farming

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

High cost of adoption

Many digital farming technologies can be expensive, which may be a barrier. The cost of in-house development is almost 10 times or more than the cost of implementation of a SaaS Product. Further, additional software infrastructure in terms of Servers, Maintenance, and Software Licenses (Microsoft, SQL, Google License, etc.) is a huge cost that the organization has to bear independently.

Limited access to technology

In some cases, access to digital farming technologies may be limited, particularly in developing countries or rural areas with limited infrastructure.

Training and knowledge

There may also be a learning curve associated with

using digital farming technologies, and farmers may need to be trained in order to use them effectively.

Data security and warehousing

Organizations would require to have teams as well as products for data security and warehousing so that the information can be effectively used across the years for analysis and decision-making. Many organizations having their inhouse product have missed this part, thus data utilization has become a big challenge.

Changing industry and Business needs

The industry is dynamic and the need for products, reports, and ways of farmer engagement is changing very fast. By the time one product is developed, the needs may change. Management companies take into consideration all such changing environments and provide the best solution suitable for that time. For example, Cropin was just mobile-based in an earlier version, now it is an intelligent agriculture cloud-based solution.

SUMMARY

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. Digital smart interventions would make this sector more technology-driven, productive, input and energy efficient, environment-friendly, complete value-chain development and globalizable.

For further interaction, please write to:

Dr Sanjay Kumar Singh (Deputy Director General), Horticultural Science Division, Indian Council of Agricultural Research, Pusa, New Delhi 110 012. *Corresponding author: ddghort.icar@gov.in

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Indian Council of Agricultural Research

Krishi Anusandhan Bhavan, Pusa, New Delhi 110 012.

Telefax: 011-2584 3657; E-mail: bmicar@gmail.com