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Precision Horticulture: Transforming Modern Agriculture Through Smart Technologies

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The role of horticulture in food security, nutrition, and health, as well as the generation of employment and additional income through farming, is difficult to overestimate. Nevertheless, horticulture, especially the production of fruit, vegetables, and ornamental plants, is vulnerable to variations in the composition of the soil, the state of the natural environment, access to water resources, and the threat of pest invasions. Traditional agricultural practices are usually oriented to uniform management of a crop within a given area regardless of the specific needs of individual plants, groups of plants, or entire plots or groves. Precision horticulture was created to address this challenge by implementing targeted approaches through the use of sensors, internet of things (IoT), remote sensing technologies, unmanned aerial vehicles (UAVs)/drones, artificial intelligence (AI), geographic information systems (GIS), and automated data processing. Using these technologies, growers are able to gather and analyze information about plant hydration levels, plant growth rates, local weather patterns, and plant development stages. As a result of this analysis of this data, growers are able to make better decisions about when to irrigate their field(s)/garden(s), how much fertilizer to apply to their field(s)/garden(s), how best manage pests and diseases in their field(s)/garden(s), and when to harvest their field(s)/garden(s). Recently, researchers at the Indian Council of Agricultural Research (ICAR) defined "digital horticulture" as combined application of IoT, AI, remote sensing, UAVs, and precision techniques to augment efficiency and sustainability of horticultural practices. The report describes precision horticulture, identifies key components, gives applications of precision horticulture, explains the benefits and limitations of adopting precision horticulture, and describes possible future applications to expand the adoption of precision horticulture.

Keywords: precision horticulture, smart farming, IoT, sensors, AI, UAVs, remote sensing, smart

Introduction-Horticultural Crops: Meaning and Features

Horticultural crops may be defined as a wide range of agricultural products, encompassing fruits, vegetables, flowers, herbs/spices, medicinal plantation crops and high value crops. Unlike most of the field crops, horticultural commodities are more sensitive to environmental variations. Minor changes in the moisture level in the soil, temperature, nutrient status or the

level of pest attack will cause significant alterations in the developmental pattern of the crop, its productivity and quality. Conventional horticultural practices typically involve the use of observations made directly from the field along with a single application of irrigation, fertilizer and/or plant-protecting chemical(s) throughout the entire area. However, it is possible that this method does not adequately take into consideration all of the variables that exist within a particular orchard or vegetable field. Alternatively, precision horticulture offers a different strategy. Precision horticulture utilizes field-level information to identify exactly what inputs should be applied at which locations and at what time. According to recent research, precision horticulture can be considered to be an approach that utilizes various technologies including sensors, drones, robots and data-driven methods to manage the spatial and temporal variability found in horticultural production.



Figure 1: Precision horticulture using sensors and different Smart Technologies

As opposed to most field crops, horticultural commodities tend to be very sensitive to changes in the environment. Even a slight change in the amount of moisture present in the soil, the temperature, the availability of nutrients or the level of pest pressure will result in a change in the development of the crop, its productivity and overall quality. Conventional horticultural practices typically involve the use of observations made directly from the field along with a single application of irrigation, fertilizer and/or plant-protecting chemical(s) throughout the entire area. However, it is possible that this method does not adequately take into consideration all of the variables that exist within a particular orchard or vegetable field. Alternatively, precision horticulture offers a different strategy. Precision horticulture utilizes field-level information to identify exactly what inputs should be applied at which locations and at what time. According to recent research, precision horticulture can be considered to be an approach that utilizes various technologies including sensors, drones, robots and data-driven methods to manage the spatial and temporal variability found in horticultural production.

Role of Sensors

Early detection of different plant diseases, nutrient deficiencies etc. is essential in horticulture because the loss due to pests and diseases can quickly cause losses in market value and quality. In the past, traditional methods of scouting were done by walking through the field and observing the plants. Soil-moisture sensors play an important role and they will tell you if you need to irrigate. Temperature and humidity sensors give you insight into the micro-climate of your crops. You may also find it useful to install other types of sensors such as those that measure electrical conductivity, pH levels, leaf wetness and plant stress. All of this data can be sent to your mobile device via the Internet of Things (IoT) network. This will allow you to make better decisions regarding irrigation, fertilizer applications and pest control.

Internet of Things (IoT) and Real-Time Crop Monitoring: Internet of Things (IoT) are well connected with sensors, communication systems and software platforms. In horticulture, IoT can provide continuous information about field conditions.

A typical system may work as:

Sensor → Data collection → Internet/IoT network → Cloud platform → Data analysis → Farmer's decision → Automated action

This approach can reduce dependence on occasional manual observations.

A 2025 review of IoT-based smart farming in horticultural crops reported that sensor-based systems can support real-time monitoring of plant growth and help improve resource allocation.

Precision Irrigation

Water management is one of the main areas in which precision horticulture can be applied. The majority of fruit and vegetable crops are rather sensitive to water deficits (drought) or surpluses (overwatering).

Precision irrigation integrates

- soil-moisture sensors,
- weather information,
- crop water requirements,
- automated valves,
- drip irrigation and
- irrigation scheduling software.

This allows irrigation to be adjusted according to actual field conditions.

The recent ICAR literature regarding digital horticulture indicates that precision irrigation has been studied in a variety of crops including grapes, bananas, and tomatoes; all of which have been studied to increase water-use efficiency. This approach will be most beneficial in areas that have limited water resources.

Drones/Remote Sensing

A drone may be equipped with an RGB camera, a multispectral camera, or a thermal camera to provide high-resolution data collection from orchard and vegetable fields.

They can be used to identify:

- variations in plant growth;
- water stress;
- nutrient-related stress;
- disease symptoms;
- pest-affected areas;
- gaps in plant population;
- canopy development; and
- variation in fruit or crop condition.

Drone-based Unmanned Aerial Vehicle (UAV) remote sensing is now an essential technique for precision agriculture due to its fast, non-invasive nature and high spatial resolution of field observations.

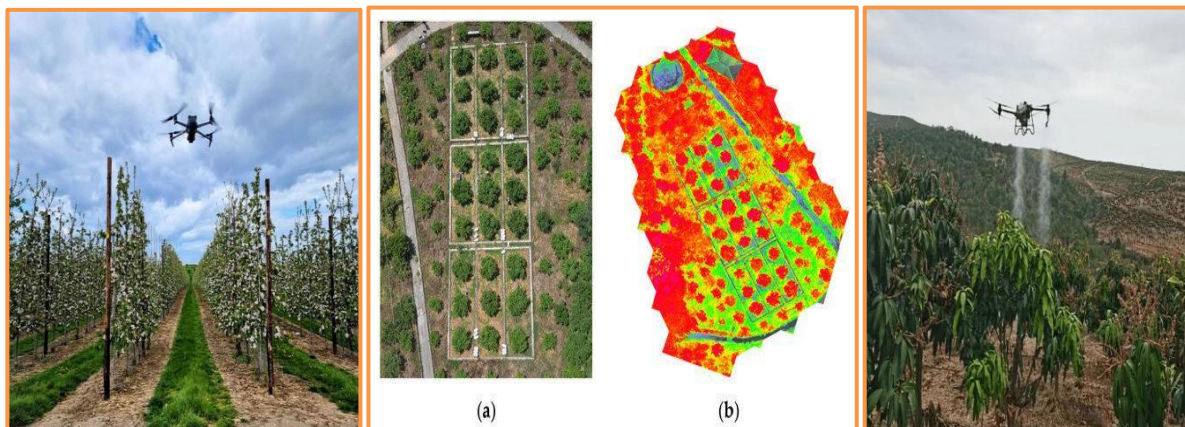


Figure 2: Precision horticulture technologies make use of drone-based crop monitoring.

Artificial Intelligence (AI) and Machine Learning (ML)

Artificial Intelligence are commonly used to turn substantial amounts of agricultural data into actionable information. For instance, Artificial Intelligence (AI) -based image analysis can detect symptoms of diseases and nutrient deficits in examining images of leaf and fruit surfaces. Further, machine-learning models can be developed to estimate crop yield, schedule irrigation, predict pest risks, and evaluate crop health. Recent studies have shown convergence of Artificial Intelligence (AI) and the Internet of Things (IoT) as a great milestone in precision agriculture for both crop monitoring and autonomous decision-making. But the accuracy of Artificial Intelligence totally depends upon the quality of the input data.

Precision nutrient management

When applying fertilizer, it does not necessarily mean that all parts of a field or orchard will receive the same amount of nutrient that each part requires. Precision nutrient management is a method of determining which parts of a field or orchard require which types of nutrients at what times using soil tests, crop sensors, yield data, and fertigation systems. For example, a drip fertigation system allows for the delivery of nutrients via irrigation water; however, the sensor data used to create the irrigation schedule is also used to create the nutrient delivery schedule. The combination of soil test data, sensor data, fertigation data, and crop monitoring provides more specific nutrient management.

Pest and Disease Management

Detection of various plant diseases, nutrient deficiencies, etc., is of utmost importance in horticulture, since losses due to pests and diseases can quickly lead to losses in the market value and quality. Traditional scouting methods have so far been applied by walking around the field and looking at the plants. Today, precision technologies allow scouts to monitor larger areas much faster than they could before. Technologies such as drones, digital cameras, remote sensing, and artificial intelligence-based image recognition can assist scouts in identifying areas with abnormal crops. Once these areas are identified, targeted treatments can be applied rather than treating the whole field. Precision technologies provide support for IPM by enhancing the scout's ability to monitor conditions in the field and direct their efforts towards those areas where they believe problems may exist.

Smart Orchards

A Smart Orchard refers to the integration of various technologies into an orchard. These technologies include sensors, weather stations, the Internet-of-Things (IoT), remote sensing, automation technology, and decision support systems. ICAR-CISH, Lucknow has developed Smart Orchard methodologies for several crops including mango and guava. Smart Orchard methodologies utilize sensor-based monitoring, weather information, precision irrigation, IPM approaches, and digital decision support tools.

Table 2: Examples of smart orchard applications

Orchard operation	Conventional approach	Precision approach
Irrigation	Fixed schedule	Sensor-based scheduling
Fertigation	Uniform application	Crop/soil-based application
Disease monitoring	Manual scouting	Imaging + field scouting
Weather monitoring	General weather information	Orchard-level sensors
Pest management	Calendar spraying	Monitoring-based intervention
Yield estimation	Visual estimation	Sensor/image-based estimation
Harvest planning	Experience-based	Maturity and quality data

Robotics and Automation

Labor supply concerns are significant in horticulture due to the fact that a number of horticultural operations (such as harvesting, pruning, sorting, and grading) require trained personnel. Robotic technology can help to automate some of the more labor intensive and

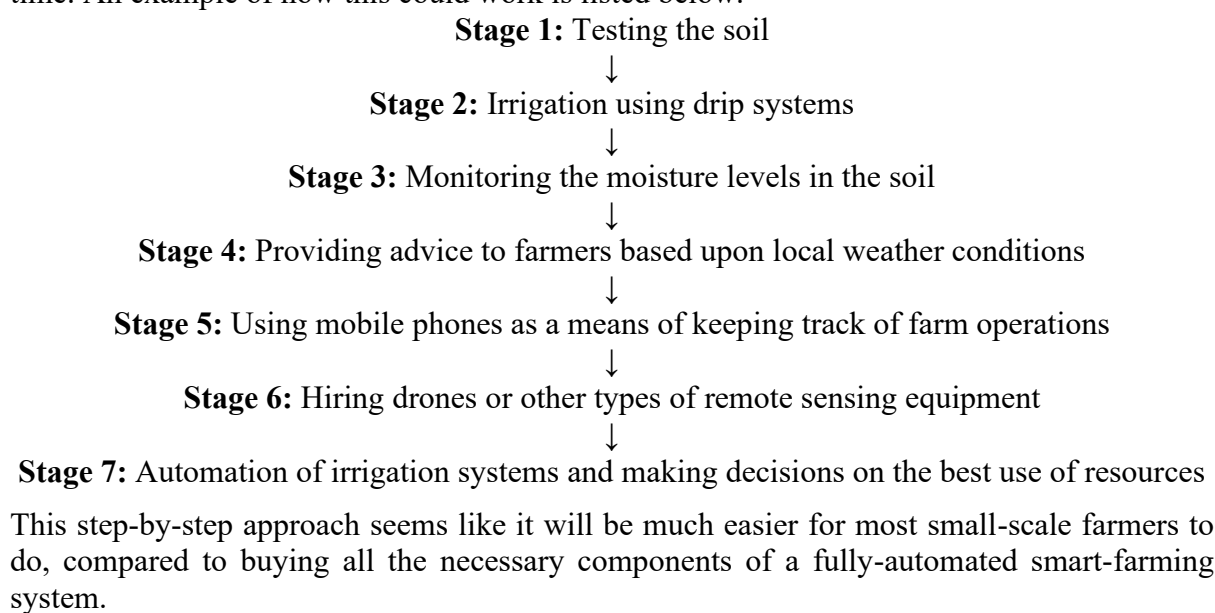
repetitive horticultural operations. Machine vision technologies can be used to determine fruit quality by assessing characteristics such as size, color and maturity. Robotic devices can also be utilized to aid in harvesting or to monitor crop growth. Even though robotic harvesting is currently under development for most horticultural crops, there have been recent improvements in the areas of machine vision, sensing technologies, and artificial intelligence which are expanding the possibilities for robotic harvesting.

Benefits of Precision Horticulture

- Precision horticulture can provide several potential benefits.
- Resource-use efficiency
- Water, fertilizer and plant-protection inputs can be applied more carefully.
- Better crop monitoring
- Continuous monitoring can help identify problems earlier than occasional field inspection.
- Improved crop quality
- Better control of water, nutrients and crop environment may contribute to uniform crop development and quality.
- Reduced environmental pressure
- Targeted application can potentially reduce unnecessary use of agricultural inputs.

Precision Horticulture for Small Farm Owners

The use of technology is not always required to start out using automation. There are many ways that marginal and small-scale farmers can implement precision farming methods over time. An example of how this could work is listed below.



Future Prospects

Precision horticulture: Drones AI, and Smart tools play an important role. Horticultural applications include sensor-based post-harvest quality monitoring and IoT-based precision vertical farming for high-value vegetables under controlled environments. Future systems are likely to move from simply collecting data toward providing actionable recommendations such as:

“Irrigate this section today.”

“Inspect these plants for disease.”

“Apply nutrients only in this management zone.”

“Harvest this block based on maturity.”

Such systems could make horticulture more responsive, efficient and data-driven.

Conclusion

Precision horticulture represents a progression from a single approach to farm management (uniform) to a site-specific approach to managing crops. Sensor technology provides data, Internet of Things (IoT) links the field to digital platforms, drone technology and remote sensing provide a broader perspective on crop health, and artificial intelligence (AI) and data analytics assist in translating observations made by all of the above technologies into actionable decisions regarding crop care. The most significant benefit of using the aforementioned technologies is not just that they are based on advanced technology; rather, their true value comes from using the correct quantity of inputs in the correct area at the correct moment. Therefore, precision horticulture has the potential to contribute significantly to the creation of efficient, profitable, climate-resilient and environmentally sustainable horticultural production systems.

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