Revolutionary technology in horticultural crops

ABSTRACT

Globally, the topic of agricultural automation is becoming more and more popular. Crop management system enables the systematic management of crops, incorporating all aspects of farming. India offers the opportunity to grow a wide variety of horticultural crops due to its diverse soil and climate conditions as well as its varied agro-ecological regions. These crops enhance farm output, generate employment opportunities, and supply raw materials to a variety of food-processing industries, all of which have a substantial positive economic impact on India. Although very little area is set specifically for horticulture, there is a strong demand for the production of horticulture crops. As a result, it can be difficult to meet demand with the least amount of resources. However, this can be done by introducing revolutionary technological interventions, such as nuclear technology, artificial intelligence, blockchain technology, Internet of Things technological interventions, remote sensing, various breeding programs, hydroponics systems, and others. Remote sensing technologies for monitoring and recognizing plants, weeds, pests, and diseases have been developed and used by means of recent advancements in computer vision, robotics, artificial intelligence, and machine learning. Numerous studies examine the new digital tools and services that farmers may use to purchase inputs, handle their money, and obtain input-output pricing and farm management data.

KEYWORDS: Automation, Blockchain, Artificial Intelligence, IoT, Vertical Farming, Remote Sensing

1. INTRODUCTION

1.1 Indian Horticulture: An overview

Horticulture may benefit greatly from automation and digitization. Artificial intelligence, robotics, creative sensor-controlled solutions, and data management systems can all contribute to horticulture production becoming more sustainable and competitive by performing more complicated duties related to production system control and management. Digital methods are therefore essential in (Shamshiri *et al.,* 2018), even though their usage and development are still in their infancy. As the population grows, it is predicted to reach 9 billion by 2050. Supporting the fact, it is one of the primary issues facing the present situation (Tomlinson, 2013). Consequently, it is necessary to boost production by both direct and indirect methods, such as expanding planted area and productivity or decreasing post-harvest spoiling (also known as hidden harvest). Because horticulture crops are more productive than any other crop category in this situation, they can help satisfy the demands of the population, which is approximately 5.4 times greater (Tiwari *et al.*, 2015). The Indian economy benefits greatly from horticulture crops since they increase agricultural productivity, provide jobs, and supply raw materials to a range of food-processing industries (Qingxue and Wu, 2016). The growth of horticultural land has led to a significant rise in fruit output. Nevertheless, it was not possible to plan the selling of fruits concurrently. The pricing of fruits is set by intermediaries who now control most markets. If farmers don't establish cooperatives and shop in cities, there won't be a decrease in middlemen exploitation. In certain regions, farmers' collective action has established fruit producers' cooperatives. Fruits and vegetables suffer significant losses as a result of a broken cold chain. In certain grape-growing regions, cold chains have formed. Grape shelf life, storage, transportation, and export have all benefited from this.

There were sometimes novel traits that have persisted. It is known as the "green revolution" because of the significant increase in grain output brought about by the use of various changes in crop breeding, such as the semi-dwarf variety of cereal crops (PengJ *et al.,* 1999). Particularly profitable are novel varieties chosen from spontaneous mutations in perennial horticulture, such as the recently developed red-skinned Fuji apple (Ban Y *et al.,* 2007), the large-berry tetraploid Kyoho grape (Alleweldt and Possingham, 1988), and other unusual-looking ornamentals. This approach to making the most of one's natural abilities is still quite popular today. There is a considerable demand for horticultural output despite the small quantity of land allocated for it. As a result, achieving a sustainable environment requires the adoption of sustainable behaviors, which makes satisfying demand with the fewest resources rather difficult (Cappelli *et al.,* 2022). Additionally, it has been noted that Asian nations, like India, have been exporting more in recent years. Despite this, there are still some obstacles to overcome, such as paying for exports and reaching international quality requirements.

1.2 Digitization and Automation

The population of the world is predicted to increase quickly, reaching 10 billion people by the year 2050. This places a great deal of pressure on the agriculture industry to raise yield per hectare and improve crop productivity (FAO, 2017). Climate change and other environmental issues have constantly threatened horticulture in recent years, making it extremely difficult to achieve increased output. Increasing land use and large-scale farming, or using best practices and technological support to boost production, are two potential solutions to the food supply problem. The only option in emerging nations with densely populated areas, where expanding land space is practically unfeasible is to become more intelligent through the use of cutting-edge technology like artificial intelligence (AI), the Internet of things (IoT), and other interventions in horticulture. Better insights may be produced from field data by utilizing digital technologies like artificial intelligence and the internet of things, which also make it possible to organize farming methods methodically with the least amount of human effort. The agricultural industry has come to understand the value of precision farming over the years. By precisely measuring inputs and minimizing the misuse of potentially harmful pesticides and other inputs, precision farming offers a sustainable option that will increase productivity.

Better insights may be produced from field data by utilizing digital technologies like artificial intelligence and the Internet of things, which also make it possible to organize farming methods cautiously with the least amount of human effort. The agricultural industry has come to understand the value of precision farming over the years. By precisely measuring inputs and minimizing the misuse of potentially harmful pesticides and other inputs, precision farming offers an environmentallytally friendly choice that will increase productivity.

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1.3 The development of horticulture technology

Better insights may be produced from field data by utilizing digital technologies like artificial intelligence and the Internet of Things, which also make it possible to organize farming methods cautiously with the least amount of human effort (Shamshiri *et al.*, 2018). The agricultural industry has come to understand the value of precision farming over the years. By precisely measuring inputs and minimizing the misuse of potentially harmful pesticides and other inputs, precision farming offers an environmentally friendly choice that will increase productivity. Real-time analysis made possible by digitization in horticulture facilitates better land management, water management, spraying, and even field monitoring. Utilizing cutting-edge digital technology will enable the agriculture sector to reap several more benefits, including decreased input prices and waste, adoption of sustainable practices, and increased production to fulfill the world's expanding food needs (Bernhardt *et al.*, 2021).

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2. OVERVIEW OF TECHNOLOGIES AND THEIR FUNCTIONS

The technologies that may be used in horticulture, including cloud computing, blockchain, big data, and the Internet of things (IoT), are shown in Figure 1. Horticultural technologies include automation of actuators, disease detection, supply chain and marketing, fertilizer management, irrigation control, maturity identification, and weather patterns. The Internet of Things (IoT) is the main technology that makes it possible to provide real-time information, which is necessary for other technologies to carry out their responsibilities. The Internet of Things (IoT) is an open network of intelligent objects with the ability to communicate data, resources, and information as well as to self-organize and react to changes in the environment and circumstances (*Kaburuan et al.*, 2019). Artificial Intelligence (AI) is a multidisciplinary technology that combines machine learning, cognition, emotion detection, data storage, and human-computer interaction (Arya and Gangwar, 2021).

With the expansion of computing power, the bottleneck in AI was broken, allowing for the evolution of deep learning and better learning based on massive amounts of data. The successful development of specialized processors and increasing computer capacity has coincided with the ongoing innovation of GPUs, creating the foundation for the explosive growth of AI. For the management of soil, crops, disease, and weeds, artificial neural networks (ANNs), decision-support systems (DSSs), genetic algorithms (Gas), support-vector machines, and computer vision are some of the AI approaches that are frequently used in the agricultural industry (Caiming and lu, 2021). The Internet of Things is being used by horticulture to gather data for production, management, and service from field planting and horticultural facilities. As part of the Internet of Things, horticulture uses robots, drones, remote sensors, and computer images to monitor crops, survey, and map fields as well as to give farmers data for sensible farm-management techniques that will save costs and save time (Alireza and Ludena, 2013). Food safety may be increased by using blockchain horticulture to enable information to be tracked along the food supply chain. The term traceability, which is produced by blockchain's capacity to store and handle data, is used to improve the development and use of innovations for index-based horticulture insurance and intelligent farming. Applying blockchain to gardening has benefits for better food safety and quality control. Greater productivity tracking along the supply chain will result in more equal compensation for farmers (Sun *et al.*, 2010).

Large databases provide farmers with comprehensive information on various areas, including rainfall patterns, water cycles, fertilizer requirements, and more. To optimize their revenues, businesses may use this information to determine which crops to grow and when to harvest it (Coble *et al.*, 2018). Cloud computing is used for the collection, analysis, and storage of horticultural data. Via, employing machine learning algorithms to evaluate real-time data collected from the field via wireless sensors connected to the cloud, farmers may gain a better understanding of crop conditions (Ruthie, 2019). Augmented reality plays a major role in precision horticulture farming. In horticulture, farmers can employ virtual reality to increase yield, decrease crop waste, and impart knowledge to other farmers (Kamilaris *et al.*, 2019). A growing number of advanced technologies, including sensors, robotics, aerial and satellite photography, and GPS, are being used to improve the whole agricultural value chain and increase the profitability, efficiency, safety, and environmental friendliness of farming operations. In this regard, the soilless plant cultivation technique known as hydroponics is a great fit for the concepts of Horticultural technology. To develop a wide range of goods, major corporations are taking use of advancements in artificial intelligence, plant biology, and indoor vertical farming (Hati and Singh, 2021). With the help of cutting-edge science and technology, hydroponics has definitely cemented a key position in food production systems of the future.

3. ARTIFICIAL INTELLIGENCE IN HORTICULTURE

Artificial intelligence (AI), often known as machine intelligence, is the branch of computer science that trains robots to imitate human bodily actions and react in ways that are similar to those of humans. John McCarthy first used the phrase "Artificial Intelligence" in 1950. Artificial intelligence (AI) technologies aid in the production of healthier crops, arranges data for farmers, reduce their workload, and improve the food supply chain. They also provide information on current weather conditions, including temperature, rain, wind speed, wind direction, solar radiation, pest control, and soil and growing conditions (Manaware, 2020). The possibilities for agricultural mechanization have expanded in the current digital era due to increased automation generated by digital technology, particularly when combined with the Internet of Things and related technologies. (Pekkeriet *et al.*, 2015) stated that cost reduction is the primary element influencing the application of technological innovation in horticultural production. In the Netherlands' greenhouse production of vegetables and flowers, labor expenses account for almost thirty percent of overall expenditures, energy system costs account for another thirty percent, and variable costs make up the remaining portion. By utilizing technology advancements, farmers want to reduce labor costs, since most workers—who account for over 30% of total production costs—will be replaced by robots, and machine learning, will raise profit.

(Nturambirwe and Opara, 2020) noted that the application of artificial intelligence in horticulture facilitates a number of crucial operations. These processes are broken down into several steps: production, postharvest, final product quality assessment, storage methods, and packing. Artificial intelligence in horticulture requires machine learning techniques like hyperspectral imaging, intelligent packaging, and near-infrared spectroscopy (Sousa-Gallagher *et al.,* 2016).

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3.1 Current approaches and achievements of AI in horticulture

Digital insect traps: In modern horticulture production, insect pest monitoring is done visually by specialists on or off the farm, utilizing tools like yellow sticky cards or other insect traps. The professional judgment of farmers is used to guide management decisions on pest control strategies, such as when and how often to use pesticides. The goal of digitizing pest monitoring is to replace manual and visual inspection using trap systems like yellow sticky traps, with a focus on pest insects in open fields and greenhouses. Two methods for detecting insects are being developed: an auditory detection system using microphone arrays (Jelto *et al.,* 2021) and an optical detection system using digitalized traps (Bieganowski *et al.,* 2020; Böckmann *et al.,* 2021). Both methods of detecting insects can be used in conjunction with platforms that move independently and flexibly across the rows of crops. Nonetheless, it is also feasible to identify insect pests at permanent locations in fields or greenhouses without the need for an autonomous platform. Apart from the digitalization of insect pest monitoring that will be implemented in the initial two phases, farmers can receive help for pest management decision-making through a digital assistance system. Specific data from the digitalized bug traps, farm-specific crops, and general pest control information will be provided to the tablet or mobile application that serves as an interface between the user and the digital pest management DSS. As a result, the DSS includes data on the crop that was grown, pest organisms, such as types of pests and their damage thresholds, and pest management chemicals, including usage guidelines and application rates(Sinn *et al.,* 2021).

Agricultural consulting and information services are also often used to assist these decisions. SPLAT (Specialized Pheromone and Lure Application technology) is a newly developed pheromone dispensing technique that controls the release of semio compounds or scents with or without pesticides. It is a unique matrix formulation of biologically inert components. This product is an important tool in the IPM toolbox that may be used to combat a variety of insects that are advantageous to the economy

Fruit Harvesting Robots: These robots have to gather fruit from the tree without breaking any of the branches or leaves. All sections of the tree that have to be picked must be accessible to the robots, and they must be able to differentiate between leaves and fruits utilizing video image capture. The robot arm has a camera installed, and the characteristics kept in the memory are compared with the colors identified. Harvesting the fruit occurs if a match is found. If leaves are obscuring the fruit, you may use an air jet to push the leaves aside so you can see the fruit more clearly. Though not enough to smash the fruit, the pressure exerted on it is enough to remove it from the tree. The gripper's form is dependent on the fruit being removed (Vipin kumar *et al.,* 2023).

AI in crop production: Environmental challenges such as temperature increases and frosts can cause crop loss in horticultural production nowadays. However, artificial intelligence (AI) has made it possible to predict changes in environmental parameters, which enables farmers to take proactive measures to protect their crop, such as early harvesting or other measures. AI is also applicable in the field of greenhouses, where variations in the environmental parameters within the structure can be monitored and controlled. In 1997, Robinson and Mort undertook a study that led to the development of a neural network system for the prediction of the appearance of frost. In the absence of this system, crop damage might occur, leading to the loss of trees, the harvest, or in severe situations, the whole orchard. An organization called Sentiment has developed a system that can rigorously monitor variables including temperature, salinity, light intensity, and water stress. If any changes are found, the system can notify users and establish an environment that is beneficial to basil development (Sahni *et al.*, 2021).

AI in yield forecasting: Calculating the number of fruits can help with production forecasts and scheduling harvesting times to maximize output. Using image processing, (Lomte *et al.*, 2019) created an automatic and effective fruit counting method. It uses an image as the input, and when a picture is taken, the camera's sensor gathers little pieces of data, which is then converted into a collection of characteristics for the image.

AI in harvesting: Sixty percent of the expenses of production are related to the manual harvesting of horticulture crops. The use of AI to harvesting can help address the dual labor challenges of scarcity and high costs. A fruit-picking robot that can differentiate between fruits and leaves using video image capture was created by (Kitamura *et al.*, 2005). The camera that supports the robot arm can identify colors and compare them to attributes that are stored in memory. If a match is discovered, the fruit is selected. The fruit is not crushed; rather, the pressure exerted on it is just enough to remove it from the tree.

AI in reducing postharvest loss: Horticultural goods suffer postharvest loss as a result of physiological, biochemical, and physical causes. According to (Siregar *et al.,* 2017), the wavelength range of 700–1200 nm is appropriate for hyperspectral imaging to forecast the moisture content of banana fruit tissue. According to (Kader, 2002), the main factor causing postharvest losses in horticulture produce is a decrease in moisture content. Neural networks and genetic algorithms were employed by (Morimoto *et al.*, 1997) to efficiently regulate the relative humidity in the environment utilized for fruit preservation. In this study, ventilation-related changes in relative humidity were identified using neural networks, and genetic algorithms were utilized to simulate and find the best functions for modifying the relative humidity.

4. THE INTERNET OF THINGS (IOT) INTERVENTION IN HORTICULTURE

It is well accepted that all pests and diseases are detrimental to plants and can seriously destroy horticulture. The IoT system was developed to reduce the frequency of pesticide and fungicide application and to predict when pests may emerge (Kumar *et al.,* 2022). Fruit identification is accomplished by integrating color, shape, and texture—the three fundamental aspects of an object—using soft computing technology. The feature vector's dimensions are decreased by using this technique. Consequently, with fewer training data, the integrated and normalized image features yield higher classification accuracy (Rajasekar and sharmila, 2019). In order to reduce the impact of climatic disasters on vegetable development, researchers developed an IoT-based technology platform for environmental data collection, disaster warning, transmission, remote control, and information push in vegetable greenhouses in real-time (Khan *et al.,* 2020). It is anticipated that machine-learning models for the creation of intelligent, automated indoor microclimate horticulture crops would be trained using the data gathered by an IoT board (Bhujel *et al.,* 2020). In the early days of the Internet of Things, when devices were simpler, relatively little data was collected. It was only utilized to send out basic alarm signals with little processing. The AI algorithms had no place there. Data analysis became necessary as the complexity and sophistication of IoT systems increased, resulting in massive amounts of data, or Big Data. Artificial intelligence (AI) algorithms can process data and extract significant insights, resulting in superior decision-making. Problem resolution and automation have become easier with new concepts and techniques like machine learning, natural language processing, machine vision, artificial neural networks (ANN), etc. (Jha *et al.,* 2019).

4.1 IoT in Agricultural automation

Innovative farm machinery: Researchers have used deep learning based computer vision techniques to construct autonomous tractors, fruit harvesters etc. with almost the same human efficiency. According to (Blok *et al.*, 2016), the autonomous fruit harvester prototype was primarily composed of an image capture module and an image manipulator module installed on a self-propelled carriage. To identify the fruits and vegetables that needed to be harvested, the input was entered into an object detection algorithm based on computer vision.

Fertilizer application: IoT technology can aid in more intelligent fertilizer applications. A light-emitting diode (LED), a light-dependent resistor, and resistors may be used to create an NPK sensor, which measures the amounts of potassium (K), phosphorous (P), and nitrogen (N). The concepts of colorimetric and photo-conductivity explain the sensor's operation. At CIAE, Bhopal, a low-cost SPAD was created for the indirect assessment of the chlorophyll content of crop leaves in the field. It is a small, portable device that may be used to record and show SPAD values on an Android smartphone that supports OTG. It aids in determining the crop's need for nitrogen. Since scalable, timely, continuous connectivity is provided by cloud services such as Google Cloud

Platforms, SMS service can make use of this alternative. Typically, text messages with the suggested fertilizer amounts are delivered to farmers' cell phones (Lavanya *et al.,* 2019).

Weed and Pests Control: With the aid of soil sensors, meteorological sensors, and cameras, an intelligent monitoring system based on the Internet of Things (IoT) was proposed, utilizing a global packet for radio service (GPRS) and Zigbee communication protocol for pest warning, planting operations, and production-quality checks of apples (Salgado-Salazar *et al.*, 2018).

Drones: Drone use in agriculture has proven to be a significant advancement in automating various chores including monitoring land and applying pesticides. The drone gadget is made up of a central processing unit, a collection of sensors (laser, radar, camera, gyroscope, accelerometer, compass, GPS receiver for reading environmental data), and actuators and motors for carrying out essential operations. This is communicated with via a remote control and radio frequency range communication (El Hoummaidi *et al.,* 2021; Mogili and Deepak, 2018). In horticulture, drones are used to monitor crops, irrigate fields, apply pesticides, monitor plants, and evaluate plant health (Tripicchio *et al.,* 2015; Gharibi *et al.,* 2016). Additionally, drones equipped with AI and vision-based technologies make it easier to identify weeds and track the growth phases of plants during pre-, harvest, and post-harvest. To reduce product damage and loss during storage and shipping, drones may be used to monitor the grading and quality evaluation of horticultural crops.

5. BLOCKCHAIN

Artificial intelligence (AI) helps in horticulture by assisting farmers in increasing farming productivity and mitigating negative environmental effects (Kumar and Bhatnagar, 2020). Food safety may be increased by using blockchain horticulture to enable information to be tracked along the food supply chain. The invention and implementation of innovations for index-based horticulture insurance and intelligent farming are facilitated by the traceability that is produced by blockchain's capacity to store and manage data. Applying blockchain to gardening has benefits for better food safety and quality control. Fairer compensation for farmers will result from improved production tracking along the supply chain (Sun *et al.,* 2010). Blockchain technology is one possible approach to supply-chain traceability in the pineapple business. The fruit-chain protocol, which was introduced, is fair with an overwhelming likelihood and possesses the same consistency and liveliness as expecting the truthful majority of computing power (Zhang *et al.*, 2022).

Blockchain technology can assist the food and horticulture sectors in managing recognized risks and preserving systemic affordability. Blockchain technology in horticulture makes it possible to connect different horticultural firms and visualize data on distributed database networks, ranging from production to supply. Big data provides farmers with detailed information on water cycles, fertilizer requirements, rainfall patterns, and other concerns. This helps them to make informed choices about when to harvest and which plants to propagate for maximum profit (Abbas *et al.,* 2018).

6. REMOTE SENSING IN HORTICULTURE

Since the 1970s, satellite remote sensing has emerged as a key technique for local, regional, and worldwide crop monitoring (Macdonald *et al.,* 1980). Rather than the more general phrase of agricultural monitoring, which covers livestock, horticulture, and aquaculture, the word "crop monitoring" here refers primarily to monitoring for staple crops. Agroclimatic studies, crop condition and stress monitoring, and crop output forecasts are often included in crop monitoring operations. Certain systems further incorporate evaluations of food security, which provides an early warning of potential food insecurity. Crop monitoring, seen through the perspective of remote sensing, primarily concentrates on crop growth status and final yield. A significant amount of research has been conducted on crop mapping (Bégué *et al.,* 2018; Orynbaikyzy *et al.,* 2019), crop condition evaluations (Virnodkar *et al.,* 2020; Zhang *et al.,* 2019), crop yield projections and forecasting (Schauberger *et al.,* 2020; Elavarasan *et al.,* 2018; Klompenburg *et al.,* 2020), drought monitoring (Jiao *et al.,* 2021; Khanal *et al.,* 2017) and precision agriculture (Maes *et al.,* 2018; Berger *et al.,* 2020), according to recent studies in the field of crop monitoring (Weiss *et al.,* 2019; Meshram *et al.,* 2021; Kamilaris *et al.,* 2018). To measure and record information about a remote area, a remote sensing system consists of four fundamental parts. The power source, transmission line, target, and satellite sensor are some of these components (Singh *et al.,* 2014).

Developments in digital image processing and internal software development have been greatly aided by Indian researchers. A few examples of these applications are the development of watersheds for agriculture, mapping land resources, forecasting possible spots for fishing, precision agriculture, crop systems analysis, agricultural water management, drought assessment and monitoring, and many more. (Navalgund and Ray, 2000), (Panigrahy and Ray, 2006), and (Navalgund *et al.,* 2007).

6.1 Application of remote sensing in fruit crops

Orchard mapping and area of arable land estimation: (Sharma and Pangrahi, 2010) conducted research to create a block-by-block database on apple plantations in the Himachal Pradesh district of Shimla. High resolution remote sensing data from the most advanced Indian Remote Sensing (IRS) satellite P6 was used to map apple orchards. Using data from remote sensing, an accuracy of over ninety percent has been attained. Another study on the assessment of apple orchard area in the Kashmir valley's Pulwama district was carried out by (Mustaq and Asima, 2014) utilizing remote sensing and agro-metrology land-based observation.

Precision application of fertilizer: Apple orchard area was estimated and monitored using digital data from Landsat and AWIFS. The bulk of apple orchards (89.82%) were discovered to be clustered in the elevation range of 1500–2000 meters; those above 2000 meters represented 10% of the area, while those below 1500 meters of elevation filled 0%.

Abiotic stress detection: Remote sensing technologies can also be used to detect abiotic stressors like moisture deficit. Several methods, including thermal and high spatial resolution multispectral aerial photography, were used to track the Photochemical Reflectance Index (PRI) and crown temperature in peach orchards. To create stress, several irrigation regimes were used, such as controlled and persistent deficit irrigation techniques. According to the findings, there is a discernible variation in the reflectance pattern of stressed and well-irrigated plants (Saurez *et al.*, 2010).

Detection of Pest infestation: In orchards, remote sensing technology can lower the cost of insect monitoring. (Ludeling *et al.*, 2009) have measured the visible and near infrared reflectance of 1153 leaves and 392 canopies in 11 Californian peach orchards to assess the viability of detecting spider mite damage in orchards. Chlorophyll, carotenoids, and other photosynthetic pigments are altered by physiological stress in trees, and these changes are readily identifiable by shifts in spectral reflectance.

Disease incidence detection: Multispectral imaging is nevertheless useful for visual assessment because it provides real-time or almost real-time imagery, even with advancements in the spatial, spectral, and temporal resolution of satellite imagery. It is feasible to identify healthy trees and sick trees using this imaging technology. According to (Sindhuja *et al.*, 2013), there was a variation in average reflectance. The visible region's values of healthy trees were lower than the near-infrared regions, but the HLB-infected trees' values were higher. This might facilitate the adoption of prompt control measures, hence reducing the potential for disease transmission. By identifying susceptible plant areas, detecting changes in plant pigment, and detecting variations in pest-induced leaf bones, remote sensing is a valuable tool for managing nematodes and pests by early disease identification and detection (Usha *et al.*, 2013). A complex digital imaging system linked to reflectance and density of canopy under varying levels of phylloxera stress was developed by (Johnson *et al., 1*996). Using Cook and Cook's multiregional NIR cinematography, the seasonal growth of the soil fungal complex and the southern root-knot nematode (Meloidogyne incognita Chitwood) in kenaf (Hibiscus cannabinus L.), an affiliate, was seen.

Estimation of crop area: Horticultural crops typically experience significant fluctuations in production and demand, leading to a very unstable market and pricing. For market planning and produce export, accurate data on the area and output of horticultural items is crucial. In this case, remote sensing proves essential in analyzing the supply scenario. It is possible to predict the acreage and productivity of crops like potatoes, which are spread out over huge contiguous fields, with an accuracy of more than 90% (Nageswara Rao *et al.* 2004). It is easy to estimate the area under mango orchards when the trees are more than five years old, but overlapping spectral signatures make it difficult to estimate younger mango trees (Usha *et al.*, 2013). Mulberry yields spectral fingerprints that are comparable to other vegetable crops early in the season, but they later segregate independently (Nageswara Rao *et al.*, 2004).

Estimation of crop canopy: The estimation of the crop canopy in horticulture is crucial because it specifies how much fertilizer, insecticide, and other chemicals to be applied. In addition, crop health and predicted yield are indicated by canopy volume (Smart *et al.*, 2000; Schumann, 2008). Although there have been cases where large crops' canopy cover has been estimated using remote sensing techniques for years, most horticulture crops were ultimately left unaccounted for (Thomas *et al.*, 2008). The canopy cover of the main horticultural crops in commercial fields with different planting configurations and maturation stages is correlated with remotely sensed NDVI (Thomas *et al.,* 2008).

Estimation of crop yield: Utilizing remote sensing to predict the yield of various annual crops is a highly helpful technique, but its application to fruit trees and vegetables has been very restricted so far (Maja and Ehsani, 2010, Usha *et al*., 2013). Limited research has been conducted on the prediction of tomato processing yield using remotely sensed aerial images and a crop growth model (Koller and Upadhyaya, 2005a). Additionally, studies have examined the relationship between the modified normalized difference in vegetation index and leaf area index for tomato processing (Koller and Upadhyaya, 2005b). In 2008, Yang and colleagues used reflectance spectra and aerial photography to determine the physical properties of cabbage as well as its yield. Using an automated ultrasonic system and a sensor-based autonomous yield monitoring system, (Whitney *et al.,* 2002) and (Zaman *et al.,* 2006) mapped citrus plantations.

7. NUCLEAR TECHNOLOGY IN HORTICULTURE

The majority of people are aware of how nuclear technology contributes to the diversity of electricity generation. However, the majority are unaware of the fact that this technology has a greater impact on non-energy applications (Bagher *et al.,* 2014). Nuclear technology has several uses in horticulture, despite being mostly linked to nuclear energy and weapons. The advancement of horticulture methods has been greatly aided by these technologies, which have enhanced water quality, increased crop output, and controlled pests and diseases. These applications have made use of physical mutagens, such as electromagnetic radiation like gamma rays (emitted from radioactive cobalt-60), X-rays, UV light, and particle radiation like thermal and fast neutrons, alpha and beta particles. For instance, chromosomal breaks caused by ionizing radiation make it easier for DNA strands to cross-link and for nucleotides to be deleted or substituted (Oladosu *et al.,* 2016). Furthermore, the effects of gamma radiation released by 60CO on Gladiolus plants were examined in a study conducted by (Srivastava *et al.,* 2007). When compared to the control group, the exposed plants showed notable alterations. Plant height, leaf size, and general structure were all influenced by gamma radiation. Additionally, flowering patterns were altered, leading to variations in the size, color, and shape of the flowers as well as variations from the usual pattern of the flowers' symmetry. Apart from these, several additional radioisotopes, including Zn65, S35, and Rb86, have been employed in several investigations into the growth and absorption of nutrients by plants (Nirmal and Ajaib, 2019).

Seed Breeding Technique: The generation of radiation led to the development of improved yielding seed varieties. A well-known example of a crop that has become successful is "miracle" rice, which has substantially raised the cost of producing rice. Technologies for radiation-induced mutations have become a major component of plant breeding techniques. These are a few significant cultivars and verities with particular quality characteristics that were released from different research locations as shown in Table 1.

Table no. 1 Effect of radiations of horticultural fruits (Rai and Rai, 2018)

Fruit	Cultivar	Year	Mutagens	Improved fruit traits
Apple	Golden haidegg, Mcintosh	1966 1970	Gamma rays	Fruit size
Mango	Rosica	1966	Spontaneous	Large and good quality
Orange	Xuegen 9-12-1 Eureka 22	1983 1987	Gamma rays X-rays	Seedless Fruit quality
Peach	Magnif	1968	Gamma rays	Large, red skin
Loquat	Shiro-mogi	1981	Gamma rays	Fruit size
Banana	Novaria	1993	Gamma rays	Earliness
Papaya	Pusa nanha	1986	Gamma rays	Dwarfness
Plum	Spurdente-ferco	1988	Gamma rays	Earliness
Pomegranate	Karabakh	1979	Gamma rays	Fruit quality
Sweet cherry	Lapins	1983	X- rays	Larger size

8. VERTICAL FARMING TECHNIQUES

The production and development of crops/plants in regions that are steeply sloped and built vertically is known as vertical farming. The biggest issue facing the globe today is feeding its expanding population, which is about to explode. Vertical farms exist in a range of sizes and styles, from compact, wall-mounted, or two-story systems to massive, multi-story warehouses. All vertical farms, however, use one of the three soilless methods—hydroponics, aeroponics, or aquaponics to supply nutrients to their plants. These three expanding systems are explained in the following information:

8.1 HYDROPONICS

One sustainable technology that could be a superior substitute for conventional farming is "hydroponics." Thus, the actual meaning of the term hydroponics is "working water" Niu and Masabni, 2022). By providing the necessary nutrients as a nutrient-rich solution that goes straight to the roots of the plants and promotes their growth, this method helps do away with the need for soil. In addition to growing inert media like perlite, gravel, and mineral wool, plants can also be grown with their roots submerged in the nutrient-rich mineral solution (Sardare *et al.,* 2023) (Sonkar and Jain, 2024). According to the researchers there are most common three types of hydroponics system explained with their characteristics (Okemwa, 2015; Nguyen *et al.,* 2016; Lopes *et al.,* 2008)

Drip system: With the drip method, the nutrient solution is kept in a container while the plants are grown independently in a soilless media. Through nozzles, a pump distributes water or fertilizer solution to each plant root in the proper amount (Rouphael and cola, 2005). The gradual release of nutrients makes it possible to gather extra solutions and either circulate them again or release them. Plant varieties may be grown simultaneously with the Drip method.

Ebb and Flow: The flood and drain principle underlies the operation of the first commercial hydroponic system, Ebb and Flow. It is made up of a solution reservoir that is rich in nutrients and a grow tray. The grow tray is filled with the solution by a pump on a regular basis, and it then gently empties. This method may be used to cultivate a variety of crops, however problems like mildew, algae, and root rot are frequent (Nielsen *et al.,* 2006), so a modified system with a filtration unit is required.

Deepwater culture: In a hydroponic system known as deepwater culture (DWC), plant roots are suspended in nutrient-rich water with air delivered straight to the roots via an air stone. The Hydroponics buckets system, in which plants are cultivated in net pots with their roots submerged in a nutrient-rich fluid, is a prime example of this type of system. Monitoring salinity, pH, oxygen and nutrient concentrations is crucial in order to keep mold and algae from growing in the body of water (Domingues *et al.,* 2012). Larger fruit-producing plants, especially tomatoes and cucumbers, respond strongly to DWC.

Wick system: The most basic hydroponic system, the Wick System runs without the need for power, pumps, or aerators (Shrestha and Dunn, 2013). The roots of the plants are connected to a nutrient-rich fluid reservoir via a nylon wick in a porous media such as cocopeat, vermiculite, or perlite. Through capillary action, plants get water or nutritional solutions. It is appropriate to use this approach for tiny plants, spices, and herbs.

Nutrient film technique: In hydroponics, the nutrient film technique is one of the most often used techniques. In channels where the fertilizer solution is continually poured, plants are developed. A thin layer of the fertilizer solution feeds the roots of the plants (Khan *et al.,* 2020). There's no need for a growth media or timer because it's an ongoing activity. The nutrients are immediately absorbed by the roots from the film. The roots of the plants are maintained damp rather than completely buried in water, in contrast to deep water cultivation (Aires, 2018). In order to avoid system failure or stoppage, the power supply and pump system must be maintained (Solanki *et al.,* 2017).

8.2 AEROPONICS

An enhanced form of hydroponics known as aeroponics involves spraying a fertilizer solution directly onto plant roots that are only visible in the air (Elijah and IKRANG, 2022). Aeroponics involves keeping plant roots exposed to oxygen-rich air at all times. This allows for faster nutrient uptake at the root surface. The most sophisticated kind of hydroponic system is this one. Nutrient solutions are misted onto plant roots using a variety of nozzle designs, including pressured airless nozzles, high-pressure atomization nozzles, and ultrasonic atomization foggers. The static pressure is controlled and maintained by a computerized system; its range is 60 to 90 Psi. This frequency is dependent on the kind of crops grown, the time of year, the stage of plant growth, and the cultivation duration. Similar to other hydroponic system types, the aeroponic system is controlled by a timer that operates the nutrient pump for a few seconds every couple of minutes (Arjina, 2013). Aeroponics is a viable technique for space exploration even if it is costly and has demonstrated the most promising crop production returns (Lakhiar *et al.*, 2018).

8.3 AQUAPONICS

Fish and plants are combined into a single environment in aquaponic systems, as compared to hydroponic systems. The nutrient-rich stool generated by fish grown in inland ponds is supplied to the plants in vertical farms. The plants filter and purify the wastewater before reusing it as fish ponds. Even though some small-scale vertical farming systems use aquaponics, most vertical farming systems concentrate on producing certain vegetable crops that develop quickly rather than utilizing aquaponics. This maximizes efficiency by streamlining manufacturing and economics. Newly standardized aquaponic systems, however, have the potential to increase the prevalence of this closed-cycle system.

Automation in Hydroponics

In smartphone technology, the aim was to create a completely automated hydroponic system with cheap running expenses and a reasonable learning curve. (Palande *et al.,* 2018) The automated hydroponic system maintained the conditions required for the test plant to flourish while integrating an IoT network for remote monitoring and management. Titan Smartponics offers several advantages, such as complete control over the elements that allow a plant to thrive, customization according to the requirements of various plants, and independence from an outside atmosphere or environmental work.

9. CHALLENGES AND OPPORTUNITIES

Technology has the power to completely transform the agricultural industry, but one of the biggest obstacles to this progress is farmers' lack of technical expertise in operating technology-driven equipment. By keeping the farmers in mind while creating the systems, we can effectively address the issue. When creating digital products, designers must concentrate on the user interface; offering solutions in local languages is one method of possibly getting over this difficulty. A key barrier to small-scale farmers adopting modern technologies is the cost and quality of the equipment and sensors. Because IoT devices are diverse, interoperability is critical. Thus, effective device synchronization is required for improved performance. This is a challenging undertaking due to the numerous manufacturers and equipment involved. Because of the daily growth of data from IoT devices, horizontal scaling will ultimately become necessary (Villa-Henriksen *et al.,* 2020). Despite all of the challenges, they have the potential to help automate and improve horticulture in the future. These technologies have the potential to revolutionize agricultural practices. In the future years, the development of 5G technology will be essential to expanding the potential of the Internet of Things.

10. SUMMARY AND CONCLUSION

Artificial intelligence-assisted farming automation facilitates the transition to precision cultivation for increased crop output and better quality while using less resources. AI may help lower agriculture costs by controlling labor costs, using pesticides and fertilizers effectively, and minimizing crop losses through timely and mature harvesting. Furthermore, instead of discouraging the younger generations from migrating to metropolitan areas, technology advancements can encourage tech-savvy individuals to choose horticulture as their vocation.The technology information center documented impressive levels of technology adoption, but they also had significant drawbacks. For instance, it was challenging to measure the farmer's productivity and yield in relation to extension efforts, and each village received only one recommendation, regardless of the health of the soil. Additionally, the crop sub-sector received too much attention at the expense of the forestry, fisheries, livestock, and natural resources management sub-sectors (Giovannucci *et al.*, 2002). Moreover, in this system, farmers rely on the expertise of the village-level extension officers, who might not always be up to date. The potential applications of remote sensing and GIS are emerging quickly. These include the identification of crop biomass, soil parameters, including soil moisture and nutrient content, green fruit counts, agricultural yield estimation, damage caused by biotic and abiotic stressors, etc. Thanks to blockchain technology, horticultural supply chains have a fantastic chance to increase transactional efficiency, lower resistance, and foster traceability on a global scale (Zhang *et al.*, 2018). Blockchain technology can assist the food and horticulture sectors in managing recognized risks and preserving systemic affordability. Blockchain technology in horticulture makes it possible to connect different horticultural companies and see data on distributed ledger networks, from production to supply. Finding a middle ground where producers and engineers can communicate and understand each other's demands is necessary to accomplish this aim. Technologists must meet producers' expectations by offering greatly improved goods, services, and procedures that support efficient and sustainable food production in urban and peri-urban areas. Producers must understand the best uses of technology and demand innovations that address the actual needs of the food supply and value chains.

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