Application of Precision Farming in Horticulture: A Comprehensive Review

Abstract: Precision farming, also known as precision agriculture, is a data-driven farm management system that aims to identify, analyze, and manage variability within fields for optimal profitability, sustainability, and land resource protection. It involves applying the right treatments at the right time and location within a field. In horticulture, precision farming plays a crucial role in resource-efficient management, including techniques like fertigation, greenhouse cultivation, soil and leaf nutrient-based fertilizer management, and more. This comprehensive review paper explores the application of precision farming in horticulture, emphasizing its potential impact on crop management, environmental health, and economic sustainability.

Key words: Precision farming, Horticulture, Resource-efficient and Sustainability.

Introduction:

Precision farming, sometimes known as precision agriculture (PA), represents a revolutionary paradigm shift in modern agricultural practices. Generally meticulous planning started with production and continuing through postharvest and processing, precision farming harnesses the power of information, technology, and management to enhance efficiency, productivity and sustainability in horticulture (Roberson, 1999). With the ever-increasing global population and diverse challenges caused by climate change, horticultural productivity must be increase in an ecofriendly and sustainable way. Precision farming offers a suitable solution with immense promises by integrating a comprehensive approach that integrates advanced technology, meticulous data analysis, and proper management strategies to optimize horticultural production across the entire crop cultivation cycle (Zarco-Tejada, 2016). Precision farming is grounded in recognition of information as the cornerstone of modern success of horticultural crop production. In a data centric age, precision farming leverages precise spatial and temporal insights into soil properties, crop conditions, agro-climatic patterns, disease and pest dynamics as well as topographical features. This rich source of information, ranging from historical archives to real-time data streams, forms the foundation of decision-making processes at every stage of production, harvesting and postharvest management.Integral to the success of precision farming is the sophisticated technology infrastructure that underlies its operations. From precision seeding and chemical application equipment to the integration of global positioning systems (GPS), geographic information systems (GIS), and advanced computing capabilities, technology serves as the backbone of this horticultural revolution. GPS facilitates precise geo-referencing of field features, while GIS enables the organization and analysis of spatially referenced data, empowering farmers with actionable insights and decision support systems.

However, technology alone is insufficient without effective management practices guiding towards implementation. Management in precision farming encompasses the strategic analysis of information and the judicious application of technology to maximize quality production. Through meticulous planning, resource allocation, and adaptive decision-making, management ensures that the full potential of precision farming is realized, driving increased productivity as well as profitability in an ecofriendlyand sustainable way.The advent of precision farming has emerged as a response to the growing challenges facing modern horticulture, including the intensification of production, environmental degradation, and resource constraints. Moreover, the application of precision farming principles extends beyond traditional crops to encompass horticultural commodities, where technologies such as robotics and sensor-based harvesting systems are revolutionizing harvesting practices and labor-intensive processes (Edan *et al*., 2009).As we stand on the cusp of the 21st century, precision farming stands poised to redefine the future of horticulture, offering a pathway towards sustainable intensification and enhanced food security (Umeda *et al*., 1999). However, like any transformative innovation, ongoing research and development are crucial to fully unleash the potential of precision farming, ensuring its adaptation to evolving horticultural landscapes and the ever-changing requirements of farmers and consumers.

Objectives:

The primary objectives of a comprehensive precision farming programme can be summarized as enhancing production efficiency, optimizing product quality, maximizing the effectiveness of pesticide and seed usage, conserving energy, and safeguarding surface and groundwater resources. The objectives of precision farming mostly revolve around two crucial aspects that need to be considered before implementing any production system:

i) It must be cost effective.
ii) It must be environmentally sound.

Application of Precision farming Techniques in Horticulture:

The application of mechatronics in horticultural crops has been mostly developed in last 15 years. Method of application for precision farming in horticulture are broadly divided into two arenas i.e.

A) Site specific management (SSM): Site- specific management is the field production phase of the system.
B) Postharvest process management (PPM):Postharvest process management begins after harvesting the crop and continues until final processing or consumption.

A. Site-specific management:

Site-specific management is distinct from the conventional approach of managing a whole field as a whole. Whole field management involves assessing the overall circumstances of a field or farm and implementing appropriate management strategies based on these factors. Site-specific management involves the division of fields into distinct management zones, sometimes referred to as grids. Each zone is then individually quantified and maintained.

In order to implement a comprehensive management strategy, producers must possess the requisite information and technology to engage in site-specific management. The spatial information needs encompass soil chemical and physical characteristics, field topography, pest populations, crop diseases, and moisture availability. Technology is essential for obtaining and utilizing this information. Essential technologies comprise GPS/GIS, control systems, and yield mapping systems. For this technology to be effectively utilized, it is necessary to integrate it with production equipment such as planters, sprayers, spreaders, harvesters, etc. that are capable of meeting the demanding standards of control and accuracy needed in precision farming. Any equipment that is unable to meet the performance requirements of traditional farming methods will not be deemed suitable for precision farming.

i) Advanced planting techniques in precision farming:

a. RTK-GPS Based Vegetable Transplanter-

The integration of RTK-GPS technology into vegetable transplanters is a noteworthy progression in precision agriculture, providing immense advantages for maximizing crop management efficacy and efficiency. Centimeter-level positional accuracy is provided by the tractor's Real-Time Kinematic (RTK) GPS technology. This accuracy is essential for charting the precise spots where the transplanter will plant the plants. Because of this high degree of accuracy, every plant's location is recorded almost exactly, which is essential for later care and management chores (Sun *et al.*, 2010). There are orientation sensors included in the mechanical hitch that connects the tractor to the transplanter. By monitoring the transplanter's angle and movement in real-time, these sensors provide an additional layer of information on the planting procedure. Robustly managing the input from these sensors and the RTK-GPS, embedded control system logs information about each planting event, the location of the tractor, and the odometry (movement data) of the transplanter. Every plant's complete data, including its exact location and planting time, is recorded by the system. With the use of this data, extremely detailed maps can be created to direct future precision agriculture practices like targeted irrigation,fertilization, pest management and harvesting (Sun *et al.*, 2009).

Plant spacing and arrangement are improved by precise planting control, which promotes improved crop growth and simpler upkeep. Precise planting maps minimize waste and environmental effect by enabling the application of inputs such as water, nutrients, and pesticides with accuracy. Plant damage during mechanical weeding or other interventions can be minimized by having a thorough understanding of plant locations, which improves following field activities. This system has some shortcomings, such as the initial setup costs for RTK-GPS systems and the possibly expensive cost of the necessary technology, which could prevent smaller enterprises from using it. For such sophisticated equipment to be used and maintained effectively, farm workers must possess a certain level of technical expertise. Precision in plant care chores can be further improved by integrating RTK-GPS data with other technologies, such as drones, robotic weeders, or automated sprayers. Utilizing the data gathered, sophisticated analytics and machine learning might be used to forecast problems with plant health, enhance growing environments, and boost yields (Norremark*et al.*, 2007). A prime example of how precision agricultural technology are transforming farming methods is the RTK-GPS based vegetable transplanter. These systems enable highly targeted management approaches by supplying extremely accurate data on plant locations, which may result in notable gains in crop yield, quality, and resource usage efficiency. It's possible that more farmers may use these creative methods as technology develops and becomes more widely available, which will cause a larger shift in agricultural practices (Lan *et al.*, 2009).

ii) Nutrient management inprecision farming:

a. Variable Rate Technology (VRT):

Use of variable rate technology (VRT) in agriculture shows how precision farming may greatly improve the efficacy of farm management techniques and the efficiency with which resources are used. GPS technology is used by variable rate applicators to precisely locate the tractor and applicator inside the field. Applying the right number of inputs at the right places requires precision. Prescription maps, which identify several management zones within a field, are made prior to application using soil samples, yield data, and other pertinent agronomic data. Additionally, some sophisticated systems make use of real-time data from sensors that keep an eye on things like crop health, nutrient levels, and soil moisture. These maps and sensor data are read by an onboard computer, which then calculates the necessary application rates for each zone. The spreader or sprayer settings are then automatically adjusted by the control system to apply the proper quantity of lime, fertilizer, insecticides, or other inputs in accordance with the prescription map (Bongiovanni and Lowenberg-DeBoer, 2004).

Lime and fertilizer inputs are not wasted in places that don't need them thanks to variable rate technology (VRT), which modifies application rates based on individual field zones. As a result, inputs are used more efficiently, which may raise crop output and quality. The environmental impact of farming activities can be reduced by reducing excess application, which also helps to minimize runoff and chemical leaching into surrounding water sources. From an economic standpoint, better returns on investment may result from inputs like lime and fertilizer being used more effectively even though their overall consumption may not reduce. VRT makes it possible to gradually alter application rates, which is essential for striking a balance between reaching the intended results and preventing needless overlaps. Prescription cells, or zones inside a field, can have their sizes changed according to the features of the application tools, enabling more accurate application and seamless transitions. VRT systems may be further improved by ongoing advancements in sensor technology, data analytics, and machine learning (Sishodia*et al.*, 2020). Preemptive management measures could be made possible by predictive analytics' ability to identify nutritional shortages or insect pressures before they manifest. Integration with additional smart agricultural technology, such drones or self-driving cars, may also improve data collecting and analysis procedures and streamline operations. One significant development in the direction of more accurate and sustainable farming methods is variable rate technology. Farmers might possibly increase crop productivity and profitability while also reducing their environmental impact and improving the efficacy of their inputs by customizing application rates to the unique requirements of various field zones (Saiz-Rubio and Rovira-Más, 2020).

iii) Water Management Strategiesin precision farming:

a. Wireless Sensor Networks (WSN)-

Wireless sensor networks (WSNs) present viable ways to improve agricultural water management, especially when it comes to real-time soil moisture level monitoring. Farmers may remotely access critical data on soil moisture by placing sensor nodes around a field, allowing for more accurate and effective irrigation techniques. WSN data integration improves crop output and water use efficiency by enabling site-specific control of water distribution in irrigation systems, such as precision irrigation systems. For smooth control of individual sprinklers or irrigation zones, this integration usually entails sending real-time soil moisture data across communication networks like 3G cellular or Asymmetric Digital Subscriber Line (ADSL). Although methods such as canopy temperature measurement can give useful information on water stress in plants, they might not give early warning signs of impending moisture stress. This restriction highlights how crucial the real-time soil moisture data from WSNs is, as it allows for proactive irrigation changes to minimize water stress and maximize crop health all through the growing season (Riquelme *et al.*, 2009).

In precision agriculture, wireless sensor networks (WSN) are becoming more and more important, especially when it comes to real-time data collecting and analysis for irrigation technique optimization. Through the integration of these networks with cutting-edge irrigation systems, farmers may significantly improve crop health and water efficiency. Networks of Wireless Sensors Improve Irrigation Systems This sensor allows for the Real-Time Soil Moisture Monitoring. Numerous environmental data are measured by sensor nodes positioned all across a field, with soil moisture levels being the main focus. These sensors continuously and instantly offer data that is necessary to make wise irrigation decisions (Chappell *et al.*, 2013). Sensor node data is wirelessly transferred to a central system for remote access and analysis. This is frequently done using 3G, 4G, or even ADSL networks. This makes it possible for farmers to keep an eye on field conditions without having to be there (Kumar *et al.*, 2022). When necessary, even the watering can be operated automatically. Precise control over water application is made possible by the integration of real-time soil moisture data with automated irrigation systems. By adjusting the water output of individual sprinkler nozzles based on the moisture data received, systems like as the automatic center-pivot may target regions that require the most watering while preventing over-irrigation. Considerable water savings can be obtained by making sure that water is only used when and where it is required. In areas where water scarcity is a significant issue, this is vital. Higher yields and improved crop health might result from ideal soil moisture levels. Irrigation done precisely can help avoid problems like over-watering, which can harm crops just as much as under-watering. The risk of overwatering is reduced with precision irrigation.Precision irrigation lowers long-term costs by reducing the possibility of overflowing water runoff, which can transport fertilizers and pesticides away from the intended region and perhaps harm the environment. Thus, utilizing WSN for irrigation aids in water conservation, improves crop production and quality, and decreases runoff and leaching. However, it necessitates periodic maintenance due to the technological difficulty and specialized knowledge required of the sensor network. Regular checks and calibrations are also necessary to guarantee the accuracy of sensors (Verma *et al*., 2010). Robust data management systems are necessary to handle the massive amounts of data produced by these sensors. Artificial intelligence and machine learning may also be used to do predicted analysis and automated changes. As Peters and Evett (2007) point out, combining different kinds of sensors—like infrared thermometers to track canopy temperature—can give early warning signs of water stress before it affects yield. Several sensing techniques together can provide a more comprehensive picture of crop health and water requirements. In summary, Wireless Sensor Networks (WSNs) are a game-changer in precision irrigation, allowing for more efficient use of water resources through automated systems and precise, real-time monitoring. Incorporating wireless sensor networks (WSNs) into agricultural operations enhances crop output and efficiency while also supporting environmental sustainability. The possibility for additional integration with sophisticated analytics and more all-encompassing sensing technologies holds promise for even greater advancements in agricultural water management as technology develops (Lamb, 2017).

b. Variable Rate Irrigation (VRI) system:

In-depth evaluations of the soil, topography, and crop health variations in the field are the first step in the VRI systems process. Numerous techniques, such as soil moisture sensors, aerial photography, and other remote sensing technologies, can be used to collect this data. An irrigation system outfitted with sophisticated control systems that may modify the water production over different areas of a field is combined with the data gathered. Mechanisms that can change the spray patterns and intensities, such as variable-rate sprinkler nozzles, are used to make these modifications. The majority of VRI systems are automated and managed by complex software that interprets data from sensors, weather stations, and plant-based indications using algorithms. The amount of water required in various fields' zones is determined in real time by this software. VRI drastically lowers water waste by distributing water according to the particular requirements of each area of a field.

Research such as those conducted by Hedley and Yule (2009) and Yule*et al.* (2008) have shown that water savings of between 10% and 25% are possible. Accurate water management promotes ideal plant growth conditions that can result in increased crop quality and production by preventing both under and over-irrigation. By lowering runoff and deep percolation, one can lessen the amount of nutrients and pollutants that leak into surrounding water bodies and groundwater, safeguarding the ecosystem from possible pollution. Over time, the substantial economic benefits from VRI technology are mostly offset by the reduction in water usage and the possibility for yield increases. Installing and maintaining VRI systems can be very difficult, which can be a major obstacle for small-scale farmers in particular. A significant amount of money must be spent on training and technology for the initial setup. Requiring strong data analytics capability is necessary to manage the massive amounts of data generated by VRI systems. More user-friendly and intuitive decision-support software that can streamline the challenges of data interpretation may be one of the future developments. The precision and efficacy of irrigation techniques can be improved by integrating VRI with other precision agriculture technology, such as soil sensors or drones for aerial photography. As proposed by Osroosh (2014), greater research into more responsive and adaptive irrigation algorithms can help improve irrigation schedules so they can react instantly to shifting crop requirements and meteorological conditions. The future of precision agriculture is largely dependent on variable rate irrigation, which emphasizes efficiency and sustainability. VRI could be used when technology develops and becomes more widely available.As VRI develops and becomes more widely available, it may be able to significantly contribute to the agricultural sector's ability to meet the growing need for food throughout the world while protecting one of our most valuable resources i.e. water.

iv) Herbicide application Techniques in precision farming:

Precision agriculture has made great progress with the invention and application of sophisticated herbicide application techniques like those detailed here, which use laser sensors and microcontroller-based devices. These strategies seek to increase overall farming efficiency, reduce environmental impact, and maximize the use of herbicides (Matthews *et al.,* 2014). There are two types of contact type herbicide applicators on the market: laser sensor-based and microcontroller-based. There is a laser sensor and an applicator system in the Laser Sensor-Based Herbicide Applicator. This part, which uses a laser sensor to detect green colour, recognizes weeds by comparing their colour to that of the mulch or soil. The precise colour threshold (in this case, +10% green) that is selected determines the sensor's capacity to distinguish weeds from other green materials. Although the applicator system's nozzles, solenoid valve, and controller all depend on information from the laser sensor (Tewari *et al.,* 2014). The device detects weeds and triggers the nozzles to accurately administer herbicide just where it is required. By limiting the application of herbicide to regions where weeds are found, these components lessen the chance of herbicide drift, which can have an adverse effect on non-target species and the environment. Although this technique is incredibly effective, how well it works depends largely on how accurate the weed detecting algorithm is. False detections result in wasted herbicide, while missed detections might leave weeds untreated. The technology might be more expensive and sophisticated than traditional applicators, which could prevent marginal farmers from using it (Tiwari *et al.,* 2019).

An efficient use of chemicals is made possible by the real-time processing of images taken of the field by a microcontroller-based contact type herbicide applicator that uses variable rate application and real-time image processing to calculate weed density and modify the amount of herbicide applied accordingly. Contact-type application (usually using a roller or similar device) minimizes drift by applying herbicide directly to the weeds, which is safer for surrounding crops and lowers environmental pollution. The pace of adaptive application optimizes the usage of herbicide and reduces waste and environmental impact. For this equipment, the measures of concern are its operational speed, durability, and maintenance, particularly in hard farming conditions (Tewari *et al.*, 2014).Similar to previous systems, they could be improved even more by combining them with other technology used in precision agriculture, such as robotic weed eaters or drones (Green and Owen, 2011).

Precision agriculture is embodied in the goals of both laser sensor-based and microcontroller-based herbicide applicators, which aim to apply inputs more intelligently and efficiently. To go beyond the obstacles we currently face and improve the sustainability of agricultural operations, more innovation and experimentation will be necessary. By putting AI algorithms to use, weed detection accuracy and herbicide application adaptability could both increase. These systems may even learn from each application and get better over time. As these technologies advance, it will be critical to concentrate on lowering their cost and simplifying their maintenance so that a wider variety of farmers may utilize those (Partel *et al*., 2019).

a. Precision Mechanical Weeding technology-

An important development in agricultural robotics is highlighted by precision mechanical weeding technology, such the robotic control systems you mentioned. This technology aims to efficiently control weeds and reduce the need for herbicides while increasing crop output. By directly applying herbicides to the weeds, these methods reduce the amount of chemicals that are exposed to both the crop and the surrounding area. Using a cutting mechanism to reveal the weed's vascular tissue, the approach applies herbicide directly to the affected area, making sure the chemical is used where it is most required (Tiwari *et al.*, 2019). Intra-row weeding and the Robotic Weeding System are two significant weeding systems. Sensors and mechanical components, including controllers, chemical applicators, circular saws, and micro-pumps, are integrated into robotic weeding systems. Together, these parts may identify weeds and treat them immediately, hence lowering the amount of herbicides required. While intra-row weeding machines are specifically made to work between plants in the same row, this is a difficult process because there is a chance that the crop could be harmed. Methods for precisely locating and eliminating weeds without damaging crops include those that use rotating discs or mechanical blades that are controlled by vision systems or other sensors. It has a number of benefits, including the ability to accurately distinguish between weeds and crops thanks to sophisticated sensors and imaging technologies. It also minimizes the amount of chemicals released into the environment by reducing the amount of herbicide used by sprayed on the area and only targeting weeds. These systems are adaptable instruments for a range of agricultural demands since they can be changed for different types of fields and plant densities. They are intended for specific crops and spacing (Hussain *et al.*, 2018).

The precision of the sensors and imaging technology is critical to these systems' efficacy. Issues like misidentification from errant foliage or speed constraints that prevent accuracy highlight the need for additional technical advancements. As you mentioned in your description, crop damage is more likely to occur at higher speeds. This problem can be lessened by improving the accuracy and speed of sensor processing, enabling speedier operation without sacrificing security. These devices' high cost and intricate technological design may prevent small-scale farmers or those in underdeveloped nations from using them. Accessibility could be improved by streamlining the technology and cutting expenses through economies of scale or more straightforward designs. These technologies should be simple to integrate with existing farming methods in order to maximize the benefits.These systems should be simple to integrate with other agricultural technology and practices, like crop monitoring systems and precision irrigation, in order to maximize their benefits. The identification procedures can be made better by including machine learning algorithms, which will enable the systems to grow and change with time. Current limitations may be addressed by creating more advanced sensors that can distinguish between crops and weeds in a range of situations. The development of models to enhance comprehension of the financial gains and operational effectiveness may promote the broader implementation of these technologies (Melander and McCollough, 2021).The development of precision mechanical weeders is a major advancement in the direction of sustainable agriculture. There is a significant deal of potential to further minimize the use of chemicals, boost agricultural yields, and support more ecologically friendly farming methods by developing and improving these technologies (Machleb*et al.,* 2020).

v) Horticulture Crop Disease identification in precision farming:

a. Spectroscopy-

As spectroscopy can examine how electromagnetic radiation interacts with plant tissues, it has become an important technique for diagnosing illnesses in horticulture crops. With the use of this technology, which measures plant samples' absorption, reflection, or transmission of light across a range of wavelengths, disease-related minor alterations can be found (Sankaran *et al*., 2010). Spectral signatures, which are distinct patterns of light absorption or reflection indicative of particular illnesses or physiological states in plants, are one popular method. Through the use of spectroscopy, it is possible to identify disease symptoms before they become evident to the unaided eye by comparing the spectral signatures of healthy and diseased plants (Couture *et al.*, 2018). Horticultural practitioners utilize a range of spectroscopic techniques, such as visible-near infrared (VNIR), mid-infrared (MIR), and hyperspectral imaging, to identify diseases. For example, MIR spectroscopy is frequently used to examine structural and compositional changes in plant tissues, while VNIR spectroscopy is useful for evaluating metabolic changes linked to the onset of disease. Plant samples can have their spectral and spatial information simultaneously acquired thanks to the combination of spectroscopy and spatial imaging known as hyperspectral imaging. This makes it possible to analyse disease symptoms in great depth down to the pixel level, which makes it easier to detect and map diseases in horticultural crops. All things considered, spectroscopy provides a quick, sensitive, and non-destructive method for detecting diseases in horticulture crops. This allows for early identification and focused management techniques to reduce crop losses and raise overall output. Spectroscopic methods are still vital to improving horticultural disease management strategies even as technology develops (Pandiselvam*et al*., 2022).These methods, which use imaging techniques like hyperspectral and fluorescence imaging to capture plant characteristics or stress indicators linked to the presence of illness, are indirect approaches to disease detection in horticulture crops. These methods have potential for early and non-invasive disease identification, allowing for prompt action to reduce crop losses.

Atherton *et al.* (2015)classified diseased and healthy leaves in horticultural crops using fluorescent imaging spectroscopy in conjunction with computer vision and machine learning approaches. Using normalized graph approaches, they segmented fluorescence images, and then used co-occurrence matrices to extract texture properties from the segmented images. The inputs used by a support vector machine classifier were these extracted features. Pydipati*et al.* (2006) used artificial intelligence and a machine vision control system in Florida to detect citrus diseases early. This technique made it easier to apply fungicides precisely where it was needed and detected infections.

vi) Pesticide application in precision farming:

a. Canopy Sensor based technology-

Precision agriculture has advanced significantly with the introduction of ultrasonic canopy sensor-based pesticide applicators, especially in the case of orchard crops where indiscriminate pesticide spraying might cause environmental problems (Skolik*et al*., 2018). An ultrasonic canopy sensor-based pesticide applicator was created at IIT Kharagpur. It only sprays pesticide when it detects the existence of the target plant's canopy. This automated system ensures that spraying happens just where necessary, saving a significant amount of insecticide/pesticide (about 45–50%) when placed on a tractor (Tiwari *et al*., 2019). In a similar vein, a sprayer that makes use of ultrasonic sensors—like the Prowave 400EP14D—was created overseas. These sensors allow for the real-time detection of canopy structures when combined with the right electronics and a personal computer. The exact administration of pesticides only where necessary is ensured by the solenoid-controlled spray nozzles, which open and close in response to signals from the ultrasound sensors (Chen *et al*., 2012). Hocevar *et al.* (2010) created a machine vision-based automated orchard sprayer prototype that uses an RGB camera to detect canopies. In order to adjust the pesticide spray flow to the apple tree canopy's shape, the system analyses the taken pictures in real time. With this method, chemical volume and liquid flow rate can be varied, and the spray can be adjusted via controlled electric valves.Modifying the spray to fit the contours of the canopy. Furthermore, to detect the features of the target canopy and enable optimized spray deposition on the leaves by adjusting the application rate to the size and density of the canopy, a Crop Identification System (CIS) based on ultrasonic sensors was created (Llorens *et al*., 2011).

b. Field scouting and mapping-

These developments in precision pesticide application not only lessen the negative effects of pesticide use on the environment, but they also lower costs and increase crop protection techniques' effectiveness. Precision agriculture relies heavily on field scouting and mapping, which provide georeferenced data on a range of characteristics. For example, georeferenced soil sample provides important information about soil variability within a field. Farmers can target problems at different points in the field by taking specific actions based on the identification of crucial soil or nutrient qualities. This focused strategy aids in maximizing crop output and resource efficiency. Additionally, field scouts have the ability to map different crop pests, which makes it possible to identify pest populations in certain fields (Zude-Sasse *et al*., 2016).With the use of this information, sites can be treated specifically, using pesticides or other management techniques only where needed. This minimizes the amount of chemicals used and its negative effects on the environment. Precision agriculture techniques are further enhanced by the development of real-time sensors. These sensors can continuously monitor vital indicators like plant stress, soil fertility, or pest populations and give farmers immediate feedback. Real-time sensor data can facilitate automated management decisions when combined with the right control technology and management algorithms (Cubero *et al*., 2020). For example, tailored pesticide spraying can be started automatically if insect numbers are found in particular fields beyond threshold levels. All things considered, field scouting, mapping, and real-time sensor technologies provide a thorough method of precision agriculture that enables farmers to make well-informed choices and carry out accurate management plans catered to the particular requirements of their fields.

c. Variable Rate Technology (VRT) based pesticide application-

Variable rate sprayers have the potential to significantly reduce pesticide use when integrated with IPM concepts. Utilization of pesticides can be reduced by 30% to 80% by spraying them only where pest populations above economic thresholds. This focused strategy lowers expenses and lessens the chance of environmental pollution and pesticide resistance (Pecenka*et al.,* 2021).

vii) Yield monitoring systems:

The integration of yield monitoring systems with other smart farming technology can yield significant advantages in terms of enhancing the productivity, sustainability, and financial gain of agricultural operations. In mechanized horticulture farming, there are two main technologies for yield monitoring: mass flow monitoring and mass accumulation monitoring. These technologies combine data with GPS information to create intricate yield maps (Longchamps *et al.,* 2022). Mass flow monitoring supports precision agriculture, since farmers may make informed decisions about planting, fertilizing, and irrigation to increase yields and decrease waste by using the comprehensive maps produced to comprehend production variability within a field. Accurately projecting crop production from different portions of the field allows farmers to optimize resource use, saving money on labor, seeds, and chemicals. Proper market planning is also facilitated by crop forecasting. On the other hand, load cells used in the mass accumulation monitoring method are positioned beneath a waggon or hopper used to gather harvested crops. These load cells gauge the crop's weight as it fills the hopper. A yield map is made using the weight change over a predetermined period of time and the associated GPS time and position data (Toscano *et al.,* 2019). Harvested crops in this technique are usually moved by means of a chain mechanism or conveyor belt. Load sensors are positioned carefully on the idler wheels and other belt support components. The weight of the material that is currently on the conveyor can only be determined with the help of these sensors. These sensors continuously log the material's weight as the crop travels along the belt. This information, when combined with GPS data that pinpoints the harvest's location at each spot, enables the production of an intricate, georeferenced yield map (Ruiz-Altisentand Ortiz-Canavate, 1999).It improves transportation and storage effectiveness, which lowers loss. Farm management systems that use yield data can make better decisions about crop rotation and field rest intervals. With the use of artificial intelligence to enable real-time analysis and predictive insights, the integration of other data types, such as soil moisture sensors, weather data, and crop health sensors, can further improve the accuracy and usefulness of yield maps, making yield monitoring an even more potent tool for precision agriculture.

a. Automated Yield Monitoring System-

A key element of precision agriculture is automated yield monitoring, which gives farmers real-time information on yield variability in their farms. Farmers can make educated decisions to save expenses, raise production, and enhance system efficiency by quantifying this variability (Khan and Hussain, 2019). For real-time mapping of fruit yield, such a system usually consists of colour cameras, a laptop computer installed on a Specialized Farm Motorized Vehicle (SFMV), proprietary software, and a real-time kinematics-global positioning system (RTK-GPS). With this configuration, farmers may map and precisely track the yield of their harvested fruits and vegetables (Farooque *et al.*, 2013). For example, Chang *et al.* (2012) created a yield monitoring system that measures the production of wild blueberries using optical sensors.This device proved how well optical sensors work for precise fruit yield estimation. While mechanized harvesting makes yield tracking of horticultural crops relatively simple, more study is required to create and improve yield mapping methodologies for harvesting fruits and vegetables. By advancing precision agricultural techniques, such research projects can help farmers optimize their harvesting procedures and increase yields (Rosa *et al*., 2011).

viii) Harvest Monitoring in precision farming:

a. Hand-Trak system-

The unique, creative method adapts yield tracking technology to hand-harvested crops in North Carolina by using portable GPS receivers and the Hand-Trak system. The method aims to maximize the productivity and efficiency of hand-harvested crop operations while addressing the particular problems presented by manual harvesting processes. It is a forward-thinking combination of traditional and modern agricultural approaches. It is powered by a system for data collection and monitoring. A Hand-Trak gadget, which logs each pick (a bucket of vegetables), is provided to each worker. Important information is recorded by this system, including the time, worker ID, crop kind, and quantity of picks. The Hand-Trak logs a pick when a worker pours their bucket into a trailer. A yield map, which indicates how much of the crop was harvested and where in the field, is created by combining the data from the GPS receivers and the Hand-Trak. These maps offer important insights into the spatial yield variability throughout the field, even if they are not as accurate as those made using mechanical harvesters fitted with yield monitors (Pandey *et al.*, 2021).

Farm managers can identify top achievers and places where training may be required by closely monitoring worker productivity. Precise documentation of every employee's selections guarantees equitable and accurate processing of payroll and facilitates the identification of high- and low-performing areas within the field, thereby directing focused interventions. However, compared to yield maps produced by automated methods, those produced by this method are less accurate. Errors could arise from the manual nature of data logging and picking. Combining data from several sources (such as GPS and Hand-Trak) calls for sophisticated software that must be verified for correctness. In order to improve the method's accuracy and efficiency, more precise GPS devices must be combined with Hand-Trak data. By interpreting the massive volumes of data using advanced analytics and machine learning, harvesting tactics may be more successfully optimized and yield patterns may be predicted. The accuracy and usefulness of yield maps for manually harvested crops can be greatly improved as technology advances by including increasingly complex sensors and data analytics technologies. Advances in sensor technology, in conjunction with the use of cloud computing and mobile apps, have the potential to enhance the efficiency and automation of data collecting and processing (Huang and Tsai, 2008).

b. Automated Harvesting System-

Harvesting fruits and other horticulture crops frequently involves labor-intensive techniques like handpicking. However, these approaches have limited large-scale scalability and cost-effectiveness. Since the 1960s, a number of mechanical harvesting techniques have been investigated as a solution to this problem. These techniques include limb shaking, air blasting, canopy shaking, trunk shaking, and the use of chemical agents to aid in the detachment of fruit. Although these techniques might boost productivity, they frequently have trouble preserving fruit consistency in terms of quality and size. On the other hand, mechanized harvesting methods present a viable substitute. These technologies identify fruits on trees using machine vision control, making precise targeting and harvesting possible (Yoshida *et al*., 2022). Usually, the vision control system has colour cameras that give the control information on the position and separation of fruits.These devices can maintain fruit quality and choose sizes by utilizing vision technology, which increases harvesting efficiency overall. Because of issues including low efficiency, limited intelligence, and expensive initial investment costs, automated harvesting systems are still in the research and development stage and have not yet achieved commercialization, despite their potential benefits (De Kleine and Karkee, 2015). Researchers are working to overcome these obstacles and create more effective harvesting robots that are suited to the requirements of horticulture crops. With continued development, automated harvesting systems could completely transform horticultural industry harvesting procedures by bringing about lower labour costs and greater efficiency (Pereira *et al*., 2017).

B. Postharvest process management:

Postharvest processing commences immediately after the crop is collected. Inadequate management of the crop at this phase might have a negative impact on its quality. Precision farming is applied in the management of postharvest processes by utilizing sensors to monitor conditions during curing or storage. The goal is to attain the best possible parameters and maintain the quality of the produce. Automated controls are employed to regulate temperature, humidity, and the flow of fresh air. Through constant monitoring of the curing or handling conditions, it is able to make adjustments that would not be feasible using the traditional way of manual control. The feedback control loop is a crucial component in precision farming, just like in other aspects of this practice. By consistently monitoring the state of the crop during storage or curing, and analyzing the data in real-time, it is possible to make adjustments to storage or curing conditions in order to maintain or improve the quality of the crop.

Conclusion:

Precision farming in India is capable of bringing next green revolution to produce food security as well as rural wealth. Although it is in dawning stage in India, but has lot of adoption opportunities. Scarcer inputs like labour, water, fertilizer and change of weather pattern affecting majority of the farms in India because they are rainfed and seek help of engineers, scientists and agriculturists together with government's intercession to take application of Precision farming forward. Progressive farmers in India have adopted mechanization, are identifying better crops to use the seed to be propagated further and likewise if they adopt Precision agriculture, it would help Indian horticulture in increasing yields and economic returns per field with minimized harm to environment. But Indian farmers will adopt Precision farming only if it brings more or at least similar profit as compared to conventional practices and supported by government and private sectors to volunteer in initial costs. Also training centers to train implementation of these technologies and guidance to use them is very much required. Therefore an organized structure of researchers, engineers, industries and growers can coordinate to implement Precision farming and achieve sustainable horticultural production.A significant portion of this technology is still in its early stages of development. Further study is required to enable the systems to achieve maturity. Although precision farming is theoretically possible, additional research is required to better understand the economic and environmental advantages of numerous elements of this practice.

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