

Precision Agriculture Technologies for Sustainable Crop Production: A Review**Ashok Kumar¹, Arvind Kumar², Jagdish Grover³, S.R. Singh⁴, M.C. Yadav⁵, and Vijay Kumar Yadav⁶**

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The population has always been a major factor that has led to the growing need for improvements in the field of agriculture. Precision agriculture (PA) encompasses a set of technologies that allow farmers to collect data on variations within fields and manage crops at a more granular level. PA technologies include sensors, satellite imagery, information management tools, and variable rate application systems. Together, these enable data-driven, site-specific decision-making to optimize productivity while minimizing environmental impacts. This review examines recent advances in PA technologies and their role in supporting sustainable crop production. Key developments reviewed include remote sensing platforms and techniques, proximal soil sensors, variable rate systems, robotics and automation, and decision support tools powered by artificial intelligence and machine learning. Challenges and future directions are also discussed. Widespread adoption of PA technologies has the potential to increase yields and profitability for farmers while reducing use of inputs such as water, nutrients, and

pesticides. However, barriers to adoption exist, including costs, technical complexity, and integration challenges. The application of PAT contributes significantly to environmental sustainability by promoting practices that conserve water, reduce chemical usage, and enhance soil health.

Keywords: Precision agriculture, technology, remote sensing, sensors, automation, sustainability.

1. Introduction: Demand for food and agricultural commodities in India is growing far faster than the country's population. As a result of the sole pursuit of high productivity in order to meet ever-increasing demand for agricultural products, indiscriminate resource utilization has resulted in the neglect of the critical linkage between agriculture and the environment, posing a threat to the future of Indian agriculture on a sustainable basis. Farmers and government officials are looking for innovative ways to boost resource efficiency, decrease expenses, and subscribe to sustainable agriculture in these days of rising input costs, falling commodity prices, and environmental concerns. Agriculture production is currently facing substantial obstacles, such as rising production costs, a scarcity of irrigation water, and greater public awareness about the environmental implications of agricultural production. The focus on enhancing productivity during the green revolution, coupled with total disregard of proper management of inputs without considering the ecological impacts, has resulted in environmental degradation (Singh 2010). Precision farming is a farm management approach that uses information and technology to discover, analyze, and manage variability within a field for maximum profitability, sustainability, and land resource protection. PF differs from traditional agriculture in that instead of managing the entire field as a single unit, management is customized for tiny regions within the field. In the semi-arid tropics, PF has emerged as a promising option for enhancing and sustaining yield.

It is founded on the notion of heterogeneity within homogeneity and necessitates precise data on the degree of variability in field management. The goal is to change the agricultural inputs in response to changing field conditions. PF also features as one of the main research agendas in the tenth five-year plan (Ashish et al., 2003). According to Robert et al. (1995), precision farming is defined as information and technology based agricultural management system to identify, analyze and manage site soil, spatial and temporal variability within fields for optimum profitability, sustainability and protection of the environment. Precision farming approach is required to ensure that the requisite resources for crop growth are

available and crop protection needs are met without deficiency or excess at each point in time during the growing season (Patil and Shanwad, 2009). Precision management can be applied based on the requirement to the field at right time, right place, right quantity and by right method. Globally, adoption level of precision farming technologies was estimated based on the various technologies adopted. Daberkow et al. (2006) showed the adoption rate of the precision agriculture technology in the US. For example, yield monitors were adopted by 36.5 percent of corn farmers and 28.7 percent of soybean farmers in the early 2000s. Variable Rate Applicators (VRA) were adopted by 5 percent to 10 percent of these farmers in the same period.

2. Precision Farming in India

Adoption and success of PF in India will be determined by whether or not adoption initiatives are appropriately designed. Before applying PF to Indian agriculture, a planned number of experiments and analyses are required. To enter PF, there are three stages: present, intermediate, and future. According to (Mondal and Basu, 2009), the current stage involves uniform crop and soil management, the development of specialist manpower and institutions for PF, the popularisation of the PF concept through mass media communication, seminar, workshop, and so on, whereas the intermediate stage will involve stratified random sampling within zone, the delineation of management zones throughout the country, the validation of computer models with zone specific data, and the future stage will involve fine grid sampling. Precision farming technologies are still in their nascent stage in India. Because of the small size of holdings and the diversity of planting patterns, applying basic precision farming methods in India is difficult. Precision farming is unquestionably need for an hour and relevant to Indian agriculture (Dwivedi et al., 2002).



Figure 1: Recent trends of nanotechnology in precision agriculture.

For a developing country like India, integrating farmer expertise, precision agriculture tools, and crop simulation

modeling to assess management choices for underperforming spots in crop fields may be a great choice. Applications of "single Precision agriculture technology," "precision agriculture technology package" (for the user to choose one or a combination), and "integrated precision agriculture technology" will be the important compositions of the strategies of precision agriculture in the future for developing countries. Single precision agriculture technology might be beneficial for tiny farms. As a result, modest machine-based variable rate technology, single, low-cost, low-level precision agriculture technologies, and other such tactics are used in small-scale farming (Mondal and Manisha, 2009).

3. Principles of Precision Farming: The principles of precision farming are centered on the fundamental ideas of site-specific management, data-driven decision-making, and ongoing monitoring and modification. The deployment of precision farming methods and technology is guided by these principles, which allow farmers to maximize agricultural productivity while reducing inputs and environmental consequences. The following are the fundamental tenets of precision agriculture:

Site-Specific Management: • Site-specific management recognizes that agricultural fields exhibit spatial variability in soil properties, topography, and other factors that influence crop growth and productivity. • Instead of treating the entire field as uniform, precision farming identifies and manages small zones or management units within the field based on their unique characteristics. • By tailoring management practices, such as planting, fertilization, and irrigation, to the specific needs of each zone, farmers can optimize resource use and maximize yield potential.

• **Data-Driven Decision-Making:** Precision farming relies on accurate and timely data to inform decision-making processes. This data may include information on soil properties, crop health, weather conditions, and historical yield data. • Advanced technologies, such as GPS, GIS, remote sensing, and sensor networks, are used to collect, analyze, and interpret data from the field. • By integrating data from multiple sources and applying advanced analytics techniques, farmers can gain insights into spatial variability and make informed decisions about crop management practices.

Continuous Monitoring and Adjustment: • Precision farming involves ongoing monitoring of crop conditions, soil moisture levels, nutrient status, and other relevant parameters throughout the growing season. Monitoring may be conducted using remote sensing technologies, sensor networks, and on-the-ground observations. Based

on real-time data and feedback, farmers can make timely adjustments to management practices, such as adjusting irrigation schedules, applying additional inputs to areas of deficiency, or implementing pest control measures. Continuous monitoring and adjustment enable farmers to respond quickly to changing conditions and optimize crop performance throughout the growing season.

4. Scope of Adoption of Precision Farming in India

Precision farming is divided into two types, according to Nowak (1997): 'soft' PF and 'hard' PF. 'Soft' PF relies heavily on visual crop and soil monitoring, as well as management decisions based on experience and intuition, rather than statistical and scientific analysis. 'Hard' PF, on the other hand, makes use of all modern technologies such as Geographical Positioning System, Remote Sensing, and Variable Rate of Technology. In India, land fragmentation is seen as the most significant impediment to large-scale agricultural mechanisation. However, these fragmented lands are cultivated under a family responsibility system, and all small farmers have consciously followed 'soft' PF technology for millennia through the widespread adoption of High Yielding Variety (HYV) crops. According to Mondal and Basu (2009) and Siddiq (2000), comprehensive soil testing followed by adequate NPK fertiliser application can raise productivity levels by 2-3 times in most Indian states. However, one explanation for this poor fertiliser application is the expensive cost of traditional soil sampling. So, in these states, inexpensive dynamic soil sampling technologies, as well as nutrient status analysis on a broad scale by Recognisance Soil Survey, can make a significant difference. By predicting intermediate conditions, the use of a precisely validated zone-specific computer simulation model can increase the time between two successive soil samplings. The nutrient maps, combined with simple fertiliser recommendations for each management zone within the field, can be disseminated using large-scale mechanisation and high fertiliser and pesticide doses. According to Kalkat (2000), the state of Punjab accounts for 1.5 percent of India's entire geographical area but consumes 1.38 million tonnes (almost 10% of total India fertiliser use) of NPK fertiliser and 60% of India's herbicides.

Key of precision farming:

1) Data Collection: Precision farming relies on the collection of accurate and timely data about soil properties, crop health, weather conditions, and other relevant factors. This data can be obtained through various means, including satellite imagery, drones, ground-based sensors, and manual sampling.

2) Data Analysis: Once collected, data is analyzed to identify patterns, trends, and spatial variability within the

field. Advanced analytics techniques, such as spatial interpolation, statistical modelling, and machine learning, are often employed to derive actionable insights from the data.

3) Decision Support Systems: Based on the analysis of data, decision support systems provide farmers with recommendations and guidance for optimizing farm management practices. These systems may include software tools, mobile applications, and online platforms that integrate data from multiple sources and provide real-time monitoring and decision-making support.

4) Precision Application Technologies: Precision farming relies on technologies that enable the precise application of inputs, such as variable rate application equipment, GPS-guided machinery, and automated irrigation systems. These technologies allow farmers to adjust input rates and application timing based on site-specific conditions, maximizing efficiency and minimizing waste. Precision farming is a comprehensive concept that incorporates various technologies and scientific knowledge, such as computer science, electronics, and geoprocessing. These technologies and knowledge are applied in agriculture to optimize production by accounting for variability and uncertainties within agricultural systems. Precision farming involves the use of sensors, information systems, enhanced machinery, and informed management to adapt production inputs site-specifically within a field and individually for each animal.

5) This approach allows for better resource utilization, reduces the need for fertilizers, and improves water efficiency. By utilizing technology such as satellite positioning, internet-of-things, and data analytics, precision farming enables farmers to monitor and manage the quantity and quality of agricultural produce, while also maintaining the quality of the environment and improving the sustainability of the food supply.

5. Decision-Making Platforms for Precision Farming

A variety of new soft computing technologies has been proposed and adopted for monitoring and making precise decisions based on field data collected from sensors. An AI based intelligent control system has been proposed by Pahuja et al. (2013) for development and synthesis of a smart climate controller for precision farming in greenhouses. The system proposed employs Artificial Neural Networks (ANN) for control of humidity and temperature in artificially weather conditioned green houses. The intelligent controller proposed by Pahuja et al. (2013) presents a unique approach of applying artificial intelligence in regards to precision based farming within a greenhouse. Lamorski et al. (2013) performed a comparative study to estimate soil water requirements

from quantified soil properties using Support Vector Machined (SVM) and Artificial Neural Networks (ANN) for precision farming. The outcome of the research showed that the three variable SVM's were more effective with the same level of accuracy as the eleven variable ANN's. However, the correlation between the measured and the predicted soil water content was relatively lower using SVM due to the presence of high soil matric potentials resulting mainly from relative errors. In another study related to precision-based farming, Karim et al. (2014) employed remote hyperspectral image analysis using SVM and ANN as instruments for detecting and classifying weeds on a cornfield with the aim of intelligently controlling the amount of nitrogen application for weed management. In their research, the SVM technique achieved low misclassification rates and high generalization ability in comparison to the ANN. In this research a conclusion is arrived at that SVM is best suited for the effective detection and control of weeds. A Precision crop management system using a fuzzy controller was proposed by Jones and Barnes (2014). In their work, two expert models were applied by employing Fuzzy Logic (FL) rule base system. In one expert model physical and chemical traits of the soil were measured and integrated with local weather data as crisp inputs whereas in the other model, soil parameters in terms of water use, runoff and drainage were approximated through prediction analysis and their effect on the crop yield as shown. A comparison was then performed between the model estimated and measured yields for the fields tested. The results obtained from this research verify that the predicted yields obtained using the Fuzzy based decision support system was more accurate in comparison with the measured yields (Jones and Barnes, 2014).

The implementation of agricultural data with visual data mining technology are depicted by Yash et al. (2015) whereby high dimensional agricultural field data mined is reduced to smaller dimensions with the purpose of deriving important knowledge related to yields in precision farming such as fertilizer and water application. Self-organizing maps and Sammon's mapping technique is used to disintegrate the large data base into smaller interpreted data for quick and intuitive decision making. The conclusion derived from this research paper is that Sammon's mapping technique is only suitable for small data sets whereas Self organizing maps are conducive for large data. A Guelph Intelligent Greenhouse Automation System (GIGAS) for greenhouse-based precision agriculture has been proposed by Halimi and Moussa (2015). The Guelph Intelligent Greenhouse Automation System presented in this research is an intuitive robotics

system with outstanding functional capacity for greenhouse applications. The system proposed uses a machine vision system consisting of a number of cameras which are used to take a variety of real time images of plants. A plant data base is created to track the development of all the plants within the greenhouse to enable the intelligent system to make intuitive decisions and resource planning for the plants (Halimi and Moussa, 2015).

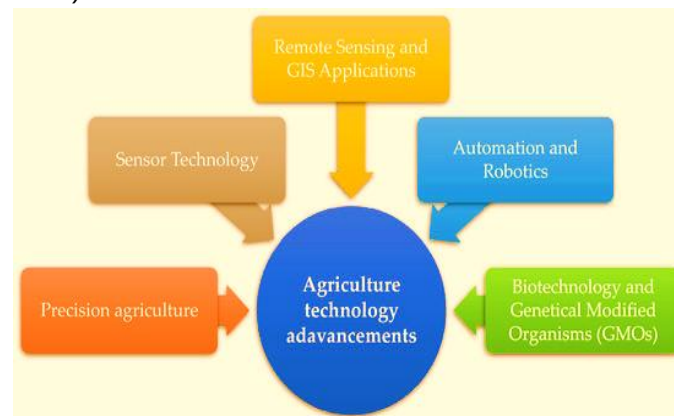


Figure 2: More technology advancements in agriculture.

The intuitive decisions made by the intelligent system are sent to the robot for execution purposes. Results from this research indicate that 92.3% production efficiency is achieved using GIGAS whereby a 63.2% increase in yields was achieved. Thalheimer and Rakesh (2015) present a system for continuous analysis and measurement of plant growth using a microcontroller and an optoelectronic reflex sensor. The principle of operation of the proposed system is reliant on the detection of contrasting black and white bars visible of a roll of adjustable tape that allows for continuous measurements to be made. Plant growth is measured in terms of the changes observed in the fruit of the plant and overall perimeter of the stem thus providing a sustainable data base for monitoring plant growth and allowing the farmer to intuitively allocate resources to the plant. It also enables timely harvesting of the plant as soon as maturity is reached. Lee et al. (2016) and Twarakavi et al. (2015) make a comparative research study of classification algorithms and their application in yield prediction in precision farming systems. The algorithms implemented in this research have been assessed for a period of several years for yield prediction in soya beans. The algorithms assessed and evaluated in this research for yield prediction include Support Vector Machines (SVM), Neural Network (NN) and Bagging. The conclusion drawn during evaluation of the systems is that Bagging is considered as the most suitable and accurate algorithm in relation to yield prediction for precision farming since the

error deviation realized is low with a mean absolute error of 18985.7864 as shown in Figure 3 (Lee et al. 2016). Yield prediction is used in this research to enable the farmer to effectively plan for harvesting, resource allocation for present and future planting seasons. In Ambarish and Saroj (2016) prediction of hourly soil moisture requirement is presented using two algorithms based on neural networks i.e. Scaled Conjugate Gradient (SCG) and Quasi newton BFGS for WSN based precision farming. The performance of the two algorithms proposed was tested and studied on a 50m by 100m Bermuda grass field in terms of their ability to predict soil moisture content for every hour by putting into consideration unique environment, soil parameters, and the actual soil moisture content at the given time. According to Ambarish and Saroj (2016), the Scaled Conjugate Gradient (SCG) neural network pattern produced better results in comparison to the Quasi-Newton BFGS based on the Mean Square Error and Root Mean Square Error.

6. Precision farming process

The precision farming process consists of three steps. They are: 1. Assessing variability: The first and most crucial step in any precision farming system is the measurement of variability. Precision farming requires inputs to be applied in accordance with the existing variability. Hence, evaluating in-field variability is a critical step in precision farming. Tools for assessing variability include remote sensing, global positioning systems, geographical information systems, and yield monitoring. 2. Managing variability: The second phase in precision farming is the management of field variability through site-specific allocation of available crop production inputs. 3. Evaluation of precision farming: The efficacy of any specific technology is mostly determined by its evaluation in terms of economics, environmental protection, and technology dissemination. The economic feasibility of the product is determined by its market return. The environmental feasibility is determined by maintaining soil, water, and crop environments. Technology dissemination is determined by its adoption at the field level. Tools of precision farming Precision farming is characterized by a distinguished set of advanced tools that aid in the monitoring of variance and the management of inputs. These comprises of:

1. Remote Sensing (RS): RS is a technological tool which helps to acquiring spectral, spatial, and temporal information about an object without coming into physical contact with the object. It helps farmers in crop condition assessment, monitoring of pest and diseases, mapping of soil characteristics and management practices, diseases and stress detection, crop yield estimation etc.

2. Geographic Information System (GIS): The GIS contributes significantly to precision farming by allowing spatial data to be shown as a map. GIS may provide farmers with valuable information about crop results, soil-plant interactions, and field variability.

3. Global Positioning System (GPS): The right thing is in the right place and in right time-which is where GPS comes into play. Doing the right thing begins with good operators and management using standard tools like planters, fertilizer applicators, harvesters, and other necessary equipment. For the field implementation of variable rate technology, GPS technology provides a precise positioning system.

4. Yield Monitoring (YM): Yield monitors are agricultural yield measurement devices installed on harvesting equipment. The yield data from the monitor is taken and data obtained from the GIS unit.

5. Variable Rate Technology (VRT): VRT refers to machines that can modify their application rates automatically in response to their situation. It integrates GPS technology with variable input controllers mounted on farm equipment to optimize crop input application rates based on crop or field variability. Fields are typically divided into 'management classes' or 'zones' based on soil and nutrient maps obtained.

6. Sensor technologies: To measure humidity, vegetation, temperature, texture, structure, physical character, humidity, nutrition level, vapor, air, and so on, various technologies such as electromagnetic, conductivity, photo electricity, and ultra sound are utilised. Data from remote sensing is used to differentiate crop species, locate stress situations, identify pests and weeds, and monitor drought, soil, and plant conditions. Sensors allow for the capture of massive amounts of data without the need for laboratory examination. (Chen et al., 1997).

7. Rate controllers: Rate controllers are devices that regulate the delivery rate of chemical inputs such as fertilizers and pesticides, which can be liquid or granular. These rate controllers monitor the speed of the tractor/sprayer as it travels over the field, as well as the flow rate and pressure (if liquid) of the material, making real-time delivery changes to achieve a desired rate. Rate controllers have been around for a while and are routinely utilised as stand-alone systems.

8. Precision irrigation in pressurized systems: Recent improvements in sprinkler irrigation are being launched for commercial use by regulating the motion of the irrigation equipment with GPS-based controls. In addition to motion control, wireless communication and sensor technologies are being developed to monitor soil and ambient conditions, as well as irrigation machine

operation parameters (such as flow and pressure), in order to achieve higher water application efficiency and crop utilisation. These technologies have tremendous potential, but further development is required before they can be commercialised.

7. Brief review

The recent rapid use of machine vision methods in fruit and vegetable farming enables growers to grade products and monitor food quality and safety, with automation systems recording metrics linked to product quality. Colour, size, form, exterior faults, sugar content, acidity, and other internal attributes are examples (Njoroge et al., 2002). Furthermore, surveillance of field operations such as chemical spraying and fertilizer use may be possible in order to give complete fruit and vegetable processing procedures. The development and adoption of PA technologies and methodologies in viticulture (termed Precision Viticulture, PV) is more recent than in arable land. However, driven by the high value of the crop and the importance of quality, several research projects already exist in wine production areas of the world (Ojeda et al., 2005 and Ferreiro-Arman et al., 2006). According to Shibusawa Sakae (2002). Precision farming denotes a management method that considers variability within and across fields in order to maximise production and economic returns while minimizing environmental effect. Precision farming's major technologies are variability description, variable-rate technology, and decision support systems. Precision farming on a regional scale is one method for small-farm agriculture. It may not only improve farm management, but it may also boost rural development.



Figure 3: Precision Agriculture and How Drones Contribute to Farming.

Diaz et al. (2012) suggested a smart irrigation management system based on data collected and recorded from a humidity sensor with the help of an intelligent low power wireless trans-receiver. The irrigation management data obtained from the sensor and trans-receiver network is monitored using a computer. The researchers then use the retrieved processed data to

calculate soil moisture requirements for the plants as well as predict/modify the irrigation timetable for increased yields. Yang et al. (2014) looked at a weed detection and eradication system based on image processing whereby a Fuzzy logic-based decision support system was used to establish and deduce where and what quantity of pesticide to be applied on the plant field. The fuzzy logic controller was primarily used to communicate spray commands to farmers based on the number of weeds detected in a certain area of the field. Based on the crisp data collected from the image sensors and FL rules, the findings of this study demonstrate that a fuzzy logic system has the capacity to facilitate a high degree of precision.

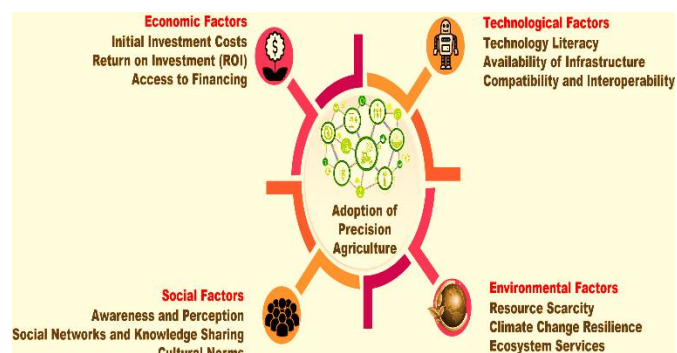


Figure 4: A systematic review on the factors governing precision agriculture adoption among small-scale farmers

Tangang et al. (2014) proposed a machine vision system for field weed detection based on natural lighting. A fuzzy cognitive map was employed to construct the image-based real-time processing algorithm, and hue-saturation colour space conversion was used to separate the weeds from the crops from the overlapping background of rock and soil residue. The precision-based system's outputs were primarily employed for selective mapping and pesticide administration for maximum weed eradication. Ratasuk et al. (2016), Cancela et al. (2015), Rani and Kamalesh (2014), the system architecture proposed in is developed to monitor humidity and soil moisture parameters for precision agriculture. A number of tests are carried out to ensure the accuracy of the humidity and temperature monitoring systems in closed and open green houses. The researchers discovered that the position estimate of sensor nodes in the Wireless Sensor Network (WSN) had certain flaws, with the average localization error decreasing with the coefficient related to signal propagation. Furthermore, the researchers concluded that a terrible environment has a negative impact on the system's robustness. Pydipati et al. (2015) and Tan employed a crop pest management system based on colour textural analysis to extract classification

algorithms that may be used in the identification of disease-infested citrus leaves. In this study, the ANN classification technique was examined using Radial Basis Function (RBF) networks with Fuzzy outputs for strength indication. According to Irmak et al. (2015), a Precision Agriculture Sensing System (PASS) based on a network of wireless multimedia sensors is presented to meet the needs of an adaptive modern precision agricultural system. On a big farm, the suggested technology is intended to reduce the need for human monitoring and interaction. Bulky data transmission is accomplished on the farm using a bitmap index transfer mechanism and dedicated monochip sensors for the wireless multimedia sensor network. Facial et al. (2016) suggested an adaptable unmanned aerial vehicle (UAV) for crop pest management in dynamic terrain course correction approaches used by UAVs for precision-based pest eradication by applying an evolving evolutionary algorithm to map the most appropriate course correction based on dynamic weather and terrain conditions. The technology suggested in this study provides a framework for unmanned aerial vehicles (UAVs) used for pest eradication to intelligently alter their navigation behavior based on cognitive vision and real-time weather data obtained from sensors. Boissard et al. (2016) a cognitive vision-based technique for prior pest identification and eradication in green houses was proposed. The researchers' cognitive vision system uses image processing and a machine-based learning algorithm to detect peers in real time. The suggested method is based on early detection of the pest (whitefly) during its life cycle before and after maturity, using characteristics derived from pest photos using grey type co-occurrence matrices, histogram equalisation, binary operation, and neighbourhood linked properties.

8. Overview

Precision Agriculture is an international journal that publishes innovative research on resource use efficiency, productivity, quality, profitability, and sustainability of agricultural production.

- Addresses within-field natural resources variability, including soil and crop variability and characteristics.
- Explores engineering technology, focusing on sensor systems, computational techniques, positioning systems and control systems.
- Present content on Managing variability, including sampling techniques and methods, nutrient and crop protection chemicals recommendation and crop quality
- Covers topics on engineering technology, focusing on sensor systems, computational

techniques, positioning systems and control systems for site-specific application

- Encourages submissions on measurement, management, technology and impact of spatial variability at the within-field scale.
- Prioritizes environmental coverage including sediments, leaching, runoff and drainage related to within-field spatial variability.

9. Evolution and significance in modern agriculture-

Precision farming in contemporary agriculture represents a significant change technique to from conventional agricultural data-driven and technology-enabled approaches, with profound implications for the industry. In the past, agriculture mostly used broad methods, applying fertilizers, insecticides, and water equally over extensive areas, without considering differences in soil qualities, terrain, or crop needs. Nevertheless, the introduction of precision farming has completely transformed this way of thinking by using sophisticated technology to customize agricultural methods according to the unique requirements of each field or even tiny areas within fields. Precision farming originated in the late 20th century, with the early use of technology like Global Positioning Systems (GPS) and Geographic Information Systems (GIS) in agriculture. These technologies allowed farmers to precisely delineate field borders, evaluate soil properties, and evaluate the condition of crops from a spatial standpoint. With the advancement and affordability of processing power, precision farming solutions have broadened to include remote sensing technologies like satellite images and drones, along with sensor-based monitoring systems for collecting real-time data.

Precision farming is very important in contemporary agriculture because to its capacity to optimize resource utilization, improve crop productivity, and limit negative effects on the environment. Farmers may enhance efficiency and output while minimizing waste by accurately directing inputs such as fertilizers, herbicides, and water to specific regions of the field where they are most required. This focused strategy not only enhances economic benefits for farmers but also reduces environmental hazards linked to excessive pesticide use and fertilizer runoff. Furthermore, precision farming enables farmers to make decisions based on data, enabling them to closely monitor the development of crops, identify pests and illnesses at an early stage, and take proactive measures to adapt to changing circumstances. Precision farming utilizes the integration of diverse data sources and sophisticated analytics to help farmers optimize planting schedules, improve irrigation management, and anticipate crop yields with enhanced accuracy. This improved decision assistance

enables farmers to reduce risks and maximize profits in a climate that is becoming more uncertain and varied. Precision farming not only provides advantages at the farm level, but also plays a vital role in tackling wider issues that contemporary agriculture faces, including food security, sustainability, and climate change adaptation. Precision farming enhances resource efficiency and resilience, hence promoting the sustainable sustainability of agricultural systems and safeguarding food security for an expanding global population. Precision farming promotes the shift towards sustainable and eco-friendly agricultural techniques by decreasing greenhouse gas emissions, limiting soil erosion, and protecting water quality.

10. TECHNOLOGIES ENABLING PRECISION

FARMING Global Navigation Satellite Systems (GNSS): Global Navigation Satellite Systems (GNSS) play a crucial role in enabling precision farming by providing accurate positioning and navigation information to agricultural machinery and devices. GNSS technologies, such as GPS (Global Positioning System), GLONASS (Global Navigation Satellite System), and more recently Galileo and BeiDou, offer farmers precise location data, which is essential for implementing site-specific management practices and precision agriculture techniques. Here's how GNSS technologies facilitate precision farming: **Accurate Positioning:** GNSS receivers installed on agricultural equipment and devices receive signals from satellites orbiting the Earth, allowing them to determine their precise position in real-time. This accurate positioning is essential for guiding farm machinery during field operations, such as planting, spraying, harvesting, and soil sampling, ensuring that operations are carried out with high precision and efficiency. **Guidance Systems:** GNSS-based guidance systems provide farmers with visual or audible cues to follow predefined paths or patterns in the field, such as straight-line rows or curved contours. By guiding agricultural machinery along precise paths, guidance systems help reduce overlaps and skips in input application, minimizing input wastage and optimizing resource use. **Auto-Steering:** Auto-steering systems use GNSS data to automatically steer agricultural vehicles, such as tractors and sprayers, along predefined routes with high accuracy. These systems eliminate the need for manual steering by the operator, reducing fatigue and allowing for more consistent and precise field operations. **Mapping and Georeferencing:** GNSS technology enables the creation of accurate field maps and georeferenced data layers, which are essential for site-specific management and decision-making. Field boundaries, soil sampling points, crop health assessments, and yield maps can be precisely

georeferenced using GNSS data, facilitating spatial analysis and management. Integration with Precision Farming Technologies: GNSS receivers are integrated with other precision farming technologies, such as variable rate application (VRA) systems and data management software. By combining GNSS positioning data with information on soil properties, crop performance, and input requirements, farmers can implement targeted input application strategies tailored to the specific needs of different areas within a field. **Role of GPS, GLONASS, and other satellite Systems;** - Global Navigation Satellite Systems (GNSS), including GPS (Global Positioning System), GLONASS (Global Navigation Satellite System), and other satellite systems like Galileo and BeiDou, play a critical role in precision farming by providing accurate positioning, navigation, and timing information to agricultural applications. Here's how each of these satellite systems contributes to precision farming:

1. GPS (Global Positioning System): GPS is a satellite-based navigation system developed and operated by the United States government. GPS provides global coverage and accurate positioning information to users equipped with GPS receivers. In precision farming, GPS technology enables farmers to precisely determine the location of agricultural machinery, equipment, and sensors in the field. GPS receivers are integrated into various precision farming applications, such as auto-steering systems, guidance systems, and yield monitors, allowing farmers to conduct field operations with high accuracy and efficiency.

2. GLONASS (Global Navigation Satellite System): GLONASS is a satellite-based navigation system developed by Russia, which provides similar positioning and navigation capabilities to GPS. GLONASS complements GPS by offering additional satellite coverage and redundancy, particularly at high latitudes and in urban environments where GPS signals may be obstructed or degraded. In precision farming, GLONASS receivers can be used alongside GPS receivers to improve positioning accuracy and reliability, especially in challenging environments. ISSN: 2456-1878 (Int. J. Environ. Agric. Biotech.) <https://dx.doi.org/10.22161/ijeab.92.27>.

3. Galileo: Galileo is the European Union's global satellite navigation system, designed to provide independent, reliable positioning and timing services to users worldwide. Galileo aims to offer higher positioning accuracy, integrity, and availability compared to existing GNSS systems like GPS and GLONASS. In precision farming, Galileo satellites can augment GPS and GLONASS signals, enhancing the overall accuracy and

robustness of positioning information for agricultural applications.

4. BeiDou: Bei Dou is China's satellite navigation system, which provides regional and global positioning services similar to GPS and GLONASS. BeiDou offers improved accuracy, coverage, and signal availability in the Asia-Pacific region, where it is being increasingly used for precision farming and other applications. In precision farming, BeiDou receivers can provide additional satellite signals to complement GPS, GLONASS, and Galileo, further enhancing positioning accuracy and reliability in diverse environments.

11. Precision agriculture applications of GNSS technology- Global Navigation Satellite Systems (GNSS) technology, such as GPS (Global Positioning System), GLONASS (Global Navigation Satellite System), Galileo, and Bei Dou, offers a wide range of applications in precision agriculture. These applications leverage GNSS capabilities to enhance efficiency, accuracy, and productivity in various farming operations. Here are some precision agriculture applications of GNSS technology:

1. Field Mapping and Boundary Definition: GNSS technology enables farmers to accurately map field boundaries and delineate management zones within fields. GPS receivers integrated with mapping software allow farmers to create detailed field maps, which serve as a basis for precision agriculture practices such as variable rate application (VRA) and site-specific management.

2. Auto-Steering and Guidance Systems: Auto steering systems use GNSS signals to automatically steer agricultural vehicles, such as tractors, combines, and sprayers, along predefined paths or guidance lines. By maintaining accurate positioning and guidance, auto-steering systems reduce operator fatigue, minimize overlaps and skips in field operations, and ensure precise implement placement.

3. Variable Rate Application (VRA): GNSS technology enables variable rate application (VRA) of inputs such as fertilizers, pesticides, and irrigation water based on spatial variability within fields. By integrating GPS data with soil maps, yield maps, and other spatial information, farmers can apply inputs at varying rates according to the specific needs of different areas within a field, optimizing resource use and crop yields.

4. Yield Monitoring and Mapping: GNSS-equipped yield monitors installed on harvesters collect real-time data on crop yields as they are harvested. GPS positioning data is integrated with yield data to create detailed yield maps, which provide insights into spatial variability in crop performance and guide future management decisions.

5. Soil Sampling and Precision Soil Management: GNSS technology facilitates precise soil sampling by accurately recording sample locations in the field. GPS-guided soil sampling allows farmers to collect soil samples at predetermined locations, ensuring representative sampling and enabling site-specific soil nutrient management strategies.

6. Irrigation Management: GNSS technology supports precision irrigation by providing accurate positioning for irrigation equipment and sensors. GPS-guided irrigation systems can adjust water application rates based on spatial variability in soil moisture levels and crop water requirements, optimizing water use efficiency and minimizing water waste.

7. Remote Sensing Integration: GNSS data can be integrated with remote sensing technologies, such as satellite imagery and drones, to monitor crop health and growth patterns. By combining GNSS positioning with remote sensing data, farmers can identify areas of stress, disease, or nutrient deficiency in crops and target management interventions accordingly.

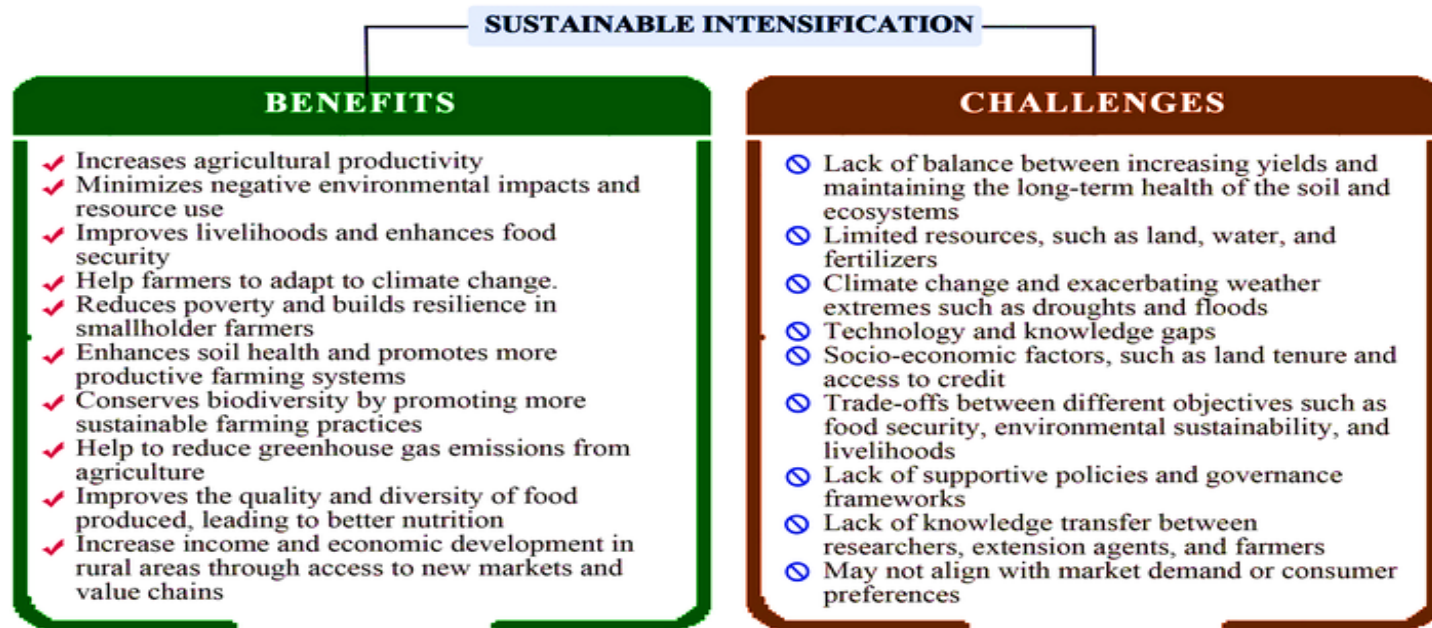
12. Geographic Information Systems (GIS): - Geographic Information Systems (GIS) are powerful tools that play a crucial role in precision farming by enabling farmers to manage, analyze, and visualize spatial data related to agricultural operations. GIS technology integrates geographic data, such as maps, satellite imagery, and field observations, with attribute data, such as soil characteristics, crop types, and yield data, to provide valuable insights for decision-making. Here's how GIS is utilized in precision farming:

1. Field Mapping and Management: GIS allows farmers to create detailed maps of their fields, including boundaries, management zones, and infrastructure such as irrigation systems and drainage ditches by digitizing field boundaries and other features, farmers can accurately delineate management zones based on factors such as soil type, topography, and historical yield data.

2. Soil Mapping and Analysis: GIS enables farmers to create soil maps that depict spatial variability in soil properties, such as texture, pH, organic matter content, and nutrient levels. By overlaying soil maps with other data layers, such as yield maps and crop health imagery, farmers can identify areas of nutrient deficiency or soil compaction and implement targeted management practices, such as variable rate fertilization or soil remediation.

3. Yield Monitoring and Analysis: GIS is used to analyze and visualize yield data collected from precision agriculture equipment, such as yield monitors on harvesters. By creating yield maps that display spatial variability in crop yields across the field, farmers can

identify patterns, trends, and areas of underperformance or overperformance, informing future management decisions and crop planning.



4. Precision Application of Inputs: GIS-based prescription mapping allows farmers to create application maps for variable rate application (VRA) of inputs, such as fertilizers, pesticides, and irrigation water. By integrating GIS data with agronomic models and soil test results, farmers can generate prescription maps that specify optimal input rates for different areas within the field, optimizing resource use and maximizing crop yields.

5. Remote Sensing Integration: GIS facilitates the integration of remote sensing data, such as satellite imagery and aerial photographs, into precision farming workflows. By overlaying remote sensing data with GIS layers, farmers can monitor crop health, detect pests and diseases, assess vegetation vigor, and track changes in land cover and land use over time.

6. Decision Support Systems: GIS-based decision support systems provide farmers with tools for spatial analysis, scenario modelling, and risk assessment. By combining GIS capabilities with advanced analytics techniques, such as spatial interpolation, suitability analysis, and multi-criteria decision-making, farmers can make informed decisions about crop management practices, land use planning, and resource allocation.

Remote Sensing: Remote sensing, using satellite and aerial imaging, is essential in precision farming since it provides vital data for monitoring crops, estimating yields, detecting diseases, and analysing soil. Remote sensing is used in precision farming to get accurate results Crop monitoring: - It is the use of satellite and aerial imaging to observe and assess the progress, advancement, and

condition of crops over the whole period of growth. Satellites and drones acquire high-resolution images that offers farmers precise information on crop conditions, such as the extent of canopy cover, the amount of biomass accumulated, and the various phases of plant development. Through the examination of changes in the patterns of light reflected by crops over a period of time, farmers are able to evaluate the overall condition of the crops, identify elements that may be causing stress (such as lack of nutrients, insufficient water, or infestations of pests), and pinpoint regions where there is a risk of reduced crop output. Crop yields are estimated using remote sensing data, which involves assessing crop biomass, vegetation indices, and other indications of agricultural production. Farmers may use remote sensing data, in conjunction with ground-based measurements and historical yield data, to calibrate and establish models that can accurately forecast crop yields at various development stages and across diverse fields. Remote sensing-based yield prediction enables farmers to evaluate crop performance, make prompt choices about harvest timing, and strategize for grain storage and sale.

Disease Detection: Crop diseases and pest infestations are detected and monitored using satellite and aerial images. Remote sensing data may be used to detect spatial patterns of disease outbreaks, enabling farmers to identify regions with high disease prevalence and prioritize management actions. By combining remote sensing data with disease models and on-site observations, farmers may use specific control measures, such as pesticide usage or crop rotation, to reduce

disease transmission and limit decreases in agricultural output.

13. Soil analysis: - It involves the use of remote sensing methods, such as hyperspectral imaging and soil moisture mapping, to evaluate soil qualities and conditions. Satellite and aerial images may be used to accurately monitor soil moisture levels, soil texture, organic matter content, and soil salinity over extensive agricultural regions. Through the examination of regional heterogeneity in soil parameters, farmers may enhance irrigation scheduling, customize nutrient management tactics, and pinpoint regions susceptible to soil deterioration or erosion.

14. Sensor Technology: Sensor technology plays a vital role in precision farming by enabling real-time data collection and monitoring of various environmental and crop-related parameters. Here's how sensor technology contributes to precision farming:

1. Deployment of Sensors for Real-Time Data Collection: Sensor networks are deployed across agricultural fields to collect real-time data on soil, weather, crop, and environmental conditions. These sensors are strategically placed throughout the field to capture spatial variability in parameters such as soil moisture, temperature, nutrient levels, and crop health. Sensors may be installed in the soil, on weather stations, on drones, or mounted on agricultural machinery to continuously monitor field conditions during the growing season.

2. Monitoring Soil Moisture: Soil moisture sensors are used to measure the moisture content of the soil at different depths and locations within the field. These sensors provide real-time information on soil moisture levels, allowing farmers to assess soil water availability and make informed decisions about irrigation scheduling. By monitoring soil moisture continuously, farmers can optimize irrigation timing and volume, reduce water use, and minimize the risk of overwatering or underwatering crops.

3. Monitoring Soil Temperature: Soil temperature sensors measure the temperature of the soil at various depths to assess soil thermal properties and conditions. These sensors help farmers monitor soil temperature fluctuations throughout the day and across different seasons, which is critical for crop growth and development. By tracking soil temperature, farmers can optimize planting schedules, manage crop emergence and growth stages, and mitigate the risk of frost damage or heat stress.

4. Monitoring Nutrient Levels: -Nutrient sensors are used to monitor soil nutrient levels, such as nitrogen (N), phosphorus (P), potassium (K), and other essential

nutrients. These sensors provide real-time data on soil nutrient concentrations, allowing farmers to assess nutrient availability and make informed decisions about fertilizer applications. By monitoring nutrient levels continuously, farmers can implement precision nutrient management strategies, adjust fertilizer rates, and reduce nutrient losses through leaching or runoff.

5. Monitoring Other Environmental Parameters: Sensor technology is also used to monitor other environmental parameters, such as air temperature, humidity, wind speed, solar radiation, and atmospheric pressure. These sensors provide valuable data for assessing microclimate conditions, predicting weather patterns, and optimizing agronomic practices such as pest management, crop spraying, and harvesting operations.

15. Precision Farming Applications: Precision farming encompasses a variety of applications aimed at optimizing agricultural practices, improving efficiency, and enhancing sustainability. Here are some key precision farming applications:

1. Variable Rate Technology (VRT): Variable Rate Technology (VRT) is a precision farming practice that involves the adaptive application of agricultural inputs, such as fertilizers, pesticides, and irrigation water, based on spatial variability within fields. Instead of applying inputs uniformly across the entire field, VRT allows farmers to tailor input application rates to match the specific needs of different areas or zones within the field. Here's how VRT works and its benefits: **Spatial Variability Assessment:** VRT begins with the assessment of spatial variability within the field, which may include variations in soil properties, topography, crop health, and yield potential. Farmers use tools such as soil maps, yield maps, satellite imagery, and soil sensors to identify spatial patterns and zones of high and low productivity within the field. **Prescription Map Generation:** Based on the spatial variability assessment, farmers generate prescription maps that specify optimal input rates for different zones or management units within the field. Prescription maps are created using specialized software that integrates data from various sources, such as GIS, GPS, remote sensing, and soil sampling, to generate recommendations for input application rates.

II. Adaptive Input Application: Using VRT-enabled equipment, such as variable rate fertilizer spreaders, sprayers, or irrigation systems, farmers apply inputs at variable rates according to the prescription maps. VRT equipment is equipped with GPS guidance systems and controllers that adjust input application rates in real-time as the equipment moves through the field. Input rates may vary based on factors such as soil fertility, crop nutrient

requirements, historical yield data, and environmental conditions.

16. Benefits of Variable Rate Technology (VRT):

1. Optimized Resource Use: VRT allows farmers to apply inputs more precisely, matching input rates to the specific needs of different areas within the field. By applying inputs where they are most needed and reducing inputs in areas with lower requirements, farmers can optimize resource use efficiency and minimize input wastage.

2. Increased Yield Potential: Tailoring input application rates to match crop requirements can help maximize yield potential by addressing nutrient deficiencies, optimizing soil fertility, and mitigating yield-limiting factors within the field.

3. Cost Savings: VRT helps farmers reduce input costs by avoiding over-application of inputs in areas with sufficient nutrient levels and minimizing input expenditures in low-yield or unproductive areas. By optimizing input use efficiency, farmers can achieve cost savings while maintaining or improving crop yields and profitability.

4. Environmental Benefits: VRT promotes environmental sustainability by minimizing nutrient runoff, reducing soil erosion, and mitigating the risk of groundwater contamination associated with excessive fertilizer and pesticide use. By targeting inputs to areas of need, VRT helps minimize environmental impacts and improve the overall sustainability of agricultural practices.

Variable rate technology involves the application of inputs, such as fertilizers, pesticides, and irrigation water, at variable rates based on spatial variability within fields. By integrating data from soil maps, yield maps, and other sources, farmers can create prescription maps that specify optimal input rates for different areas of the field. VRT allows farmers to tailor input applications to match the specific needs of crops, optimize resource use, and maximize yield potential while minimizing environmental impacts.

5. Precision Irrigation: Precision irrigation involves the precise application of water to crops based on real time monitoring of soil moisture levels and crop water requirements. Sensor technology and automated irrigation systems enable farmers to apply water only when and where it is needed, reducing water waste and improving water use efficiency. Precision irrigation helps optimize crop growth, minimize water stress, and mitigate the risk of over-irrigation, soil erosion, and nutrient leaching.

6. Crop Monitoring and Management: Crop monitoring and management applications utilize remote sensing, satellite imagery, and sensor technology to monitor crop health, growth, and development. Farmers can use aerial

imagery, drones, and satellite data to assess crop conditions, detect pest infestations, diseases, and nutrient deficiencies, and identify areas of potential yield variability within fields. By monitoring crops continuously and responding to changes in real-time, farmers can implement timely management interventions, such as pest control measures, nutrient applications, and irrigation adjustments, to optimize crop performance and minimize yield losses.



Figure 5: Importance of Precision Farming in Agriculture

7. Data Analytics and Decision Support Systems: Data analytics and decision support systems integrate data from multiple sources, such as GPS, GIS, remote sensing, and sensor networks, to provide farmers with insights and recommendations for informed decision-making. These systems analyze historical data, predict future trends, and generate actionable recommendations for optimizing agronomic practices, input applications, and resource allocation. By leveraging advanced analytics techniques, such as machine learning and artificial intelligence, farmers can improve yield prediction accuracy, optimize resource use efficiency, and enhance overall farm management.

8. Precision Livestock Farming: Precision farming techniques are also applied to livestock management, including animal health monitoring, feed management, and environmental monitoring. Sensor technology, GPS tracking, and data analytics enable farmers to monitor animal behavior, health status, and performance metrics in real time. Precision livestock farming helps optimize feed efficiency, reduce disease risks, improve animal welfare, and enhance overall productivity and profitability in animal agriculture.

Precision Irrigation: Precision irrigation is a key component of precision farming that focuses on efficient water management through the use of sensor-based irrigation systems. These systems leverage technology to optimize water application,

minimize water waste, and reduce the environmental impact of irrigation practices. Here's how precision irrigation works and its benefits:

1. Sensor-Based Irrigation Systems: Precision irrigation systems utilize sensors to monitor soil moisture levels, weather conditions, crop water requirements, and other relevant parameters in real-time. Soil moisture sensors are installed at various depths within the root zone to continuously monitor soil moisture content. Weather stations or sensors measure environmental factors such as temperature, humidity, wind speed, and solar radiation.

2. Adaptive Water Application: Based on data collected by sensors, precision irrigation systems adjust water application rates and timing to match crop water requirements and soil moisture levels. Automated controllers and actuators regulate irrigation equipment, such as drip irrigation systems, sprinklers, or center pivots, to deliver precise amounts of water only when and where it is needed. By dynamically responding to changing conditions, precision irrigation systems ensure that crops receive the right amount of water at the right time, optimizing water use efficiency and crop productivity.

3. Reduction of Water Waste: Precision irrigation minimizes water waste by avoiding over-irrigation and runoff, which can occur with conventional irrigation methods. By applying water directly to the root zone and avoiding surface runoff, precision irrigation systems reduce water losses due to evaporation, deep percolation, and surface runoff. Soil moisture sensors prevent irrigation when soil moisture levels are adequate, avoiding unnecessary water application and conserving water resources.

4. Environmental Impact Reduction: Precision irrigation helps reduce the environmental impact of agriculture by minimizing water use, nutrient leaching, and soil erosion. By conserving water resources and reducing nutrient runoff, precision irrigation systems protect water quality and aquatic ecosystems. Reduced energy consumption associated with pumping and distributing water also contributes to lower greenhouse gas emissions and environmental sustainability.

III. Benefits of precision irrigation

1. Improved Water Use Efficiency: Precision irrigation optimizes water use efficiency by delivering water directly to the root zone of crops, minimizing losses due to evaporation, runoff, and deep percolation. By matching water application rates to crop water requirements, precision irrigation systems ensure that water is used more efficiently, maximizing crop yields per unit of water applied.

2. Enhanced Crop Performance: By providing crops with optimal moisture levels, precision irrigation systems promote healthy root development, balanced growth, and improved crop vigor. Consistent soil moisture levels help reduce water stress, increase nutrient uptake, and enhance crop resilience to environmental stresses such as drought and heat.

3. Cost Savings: Precision irrigation systems help farmers reduce water, energy, and labor costs associated with irrigation. By optimizing water use efficiency and minimizing input wastage, precision irrigation systems can lead to significant cost savings over time, improving the profitability of agricultural operations.

4. Environmental Sustainability: Precision irrigation contributes to environmental sustainability by conserving water resources, minimizing water pollution, and reducing greenhouse gas emissions. By adopting precision irrigation practices, farmers can minimize their environmental footprint and contribute to the long-term sustainability of agricultural production systems. Precision irrigation involves the use of sensor-based irrigation systems to achieve efficient water management, minimize water waste, and reduce the environmental impact of irrigation practices. Here's how precision irrigation accomplishes these goals: Efficient Water Management: Sensor-based irrigation systems utilize various sensors to monitor soil moisture levels, weather conditions, crop water requirements, and other relevant parameters in real-time. Soil moisture sensors are installed at different depths within the root zone to continuously monitor soil moisture content. Weather stations or sensors measure environmental factors such as temperature, humidity, wind speed, and solar radiation. Based on data collected by sensors, precision irrigation systems dynamically adjust water application rates and timing to match crop water requirements and soil moisture levels. Automated controllers and actuators regulate irrigation equipment, such as drip irrigation systems, sprinklers, or center pivots, to deliver precise amounts of water only when and where it is needed. By optimizing water application rates and timing, precision irrigation systems ensure that crops receive the right amount of water at the right time, maximizing water use efficiency and crop productivity.

5. Reduction of Water Waste: Precision irrigation minimizes water waste by avoiding over-irrigation and runoff, which are common with conventional irrigation methods. By applying water directly to the root zone and avoiding surface runoff, precision irrigation systems reduce water losses due to evaporation, deep percolation, and surface runoff. Soil moisture sensors prevent irrigation when soil moisture levels are adequate, avoiding unnecessary water application and conserving water

resources. Additionally, precision irrigation systems can incorporate technologies such as drip irrigation, which delivers water directly to the root zone of plants, further minimizing water waste. Environmental Impact Reduction: Precision irrigation systems help reduce the environmental impact of agriculture by conserving water resources, minimizing water pollution, and reducing energy consumption. By optimizing water use efficiency and minimizing nutrient runoff, precision irrigation systems protect water quality and aquatic ecosystems. Reduced energy consumption associated with pumping and distributing water also contributes to lower greenhouse gas emissions and environmental sustainability. Moreover, precision irrigation systems can help mitigate the impacts of climate change by promoting resilience to drought and other extreme weather events through efficient water management practices.

6. Crop Monitoring and Management: Crop monitoring and management are crucial components of precision farming, and remote sensing plays a significant role in assessing crop health and detecting pests, diseases, and nutrient deficiencies. Here's how remote sensing is utilized for crop monitoring and management in precision farming: 1. Remote Sensing for Crop Health Assessment: Remote sensing technologies, such as satellite imagery, aerial photography, and drones, are used to assess crop health and vigor. These remote sensing platforms capture multispectral or hyperspectral images of agricultural fields, which can reveal subtle variations in crop reflectance associated with different health conditions. By analysing spectral signatures and vegetation indices derived from remote sensing data, farmers can assess crop health, monitor growth dynamics, and identify areas of stress or decline within fields. Crop health assessment using remote sensing helps farmers make informed decisions about management interventions, such as irrigation scheduling, nutrient application, and pest control. 2. Early Detection of Pests, Diseases, and Nutrient Deficiencies: Remote sensing enables the early detection of pests, diseases, and nutrient deficiencies by identifying spatial patterns and anomalies in crop reflectance. Changes in crop reflectance patterns, such as discoloration, chlorosis, or leaf wilting, may indicate the presence of pests, diseases, or nutrient imbalances. Remote sensing data can be processed using machine learning algorithms and image analysis techniques to detect and classify crop stress factors based on spectral signatures. By detecting pests, diseases, and nutrient deficiencies early, farmers can implement timely management strategies, such as targeted pesticide applications, disease control measures, and foliar nutrient

sprays, to mitigate yield losses and minimize economic impacts.

17. Component/tools or techniques of precision farming/geo informatics:

The major components of precision farming are; Geographical information system (GIS), Geographical positioning system (GPS), Remote sensing, Variable rate technology, NDVI, SSNM, DRIS approach, Soil testing and yield monitoring etc.

1. Global Positioning System (GPS) Global Positioning System as a satellite-based radio navigation system (with a complete set of at least 24 satellites orbiting the earth in a designed pattern) maintained by the US Department of Defence which provides accurate 3-dimensionals location data viz., latitude, longitude, and elevation, worldwide at any time, in any weather. There are two modes of GPS performance; single receiver mode which collects the timing information, timing is processed into position; and differential GPS mode (DGPS) using two receivers of which one receiver is mounted in a stationary position and the other is on the machine (Kumar et. al., 2017). The field boundaries, acreage estimation, roads, irrigation systems, distances between points and weed and disease affected areas could be generated by examining the agricultural land Geographical Information System (Yousefi et. al. 2015).

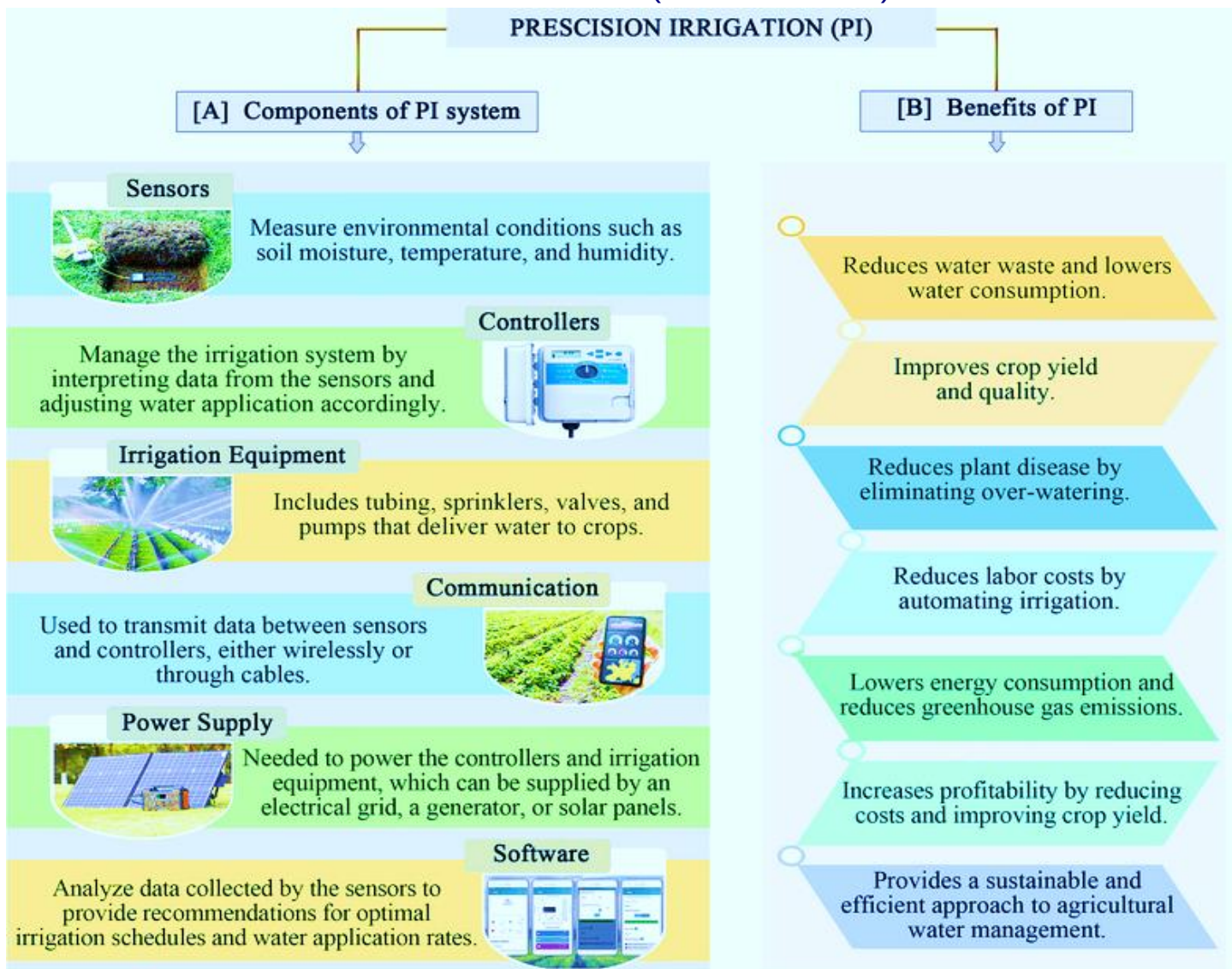
2. Geographic information system (GIS): Roger Tomlinson's pioneering work to initiate, plan, and develop the Canada Geographic Information System resulted in the first computerized GIS in the world in 1963. Geographic information system (GIS) is considered as the brain of PA (Kumar et.al.,2017) . GIS is a computerized mapping system to acquire, store, analyze and display information that is specially referenced to the earth. It is software that imports, exports and processes spatially and temporally geographically distributed data. GIS system provides a way to overlay different layers of data, these data used for land use, irrigation management, the study of the crop, soil and environment etc. this system comprises hardware, software and procedures designed to support the compilation, storage, retrieval and analysis of feature attributes and location data to produce the map. Ojo and Ilunga (2018) stated that the GIS database provides information about soil types, nutrient status, irrigation, topography, surface and subsurface drainage, quantity of application chemicals and crop production and it also establish the relationship between elements that affect a crop on a particular farming. 3. Remote sensing Remote sensing (RS) is the science of obtaining information about objects or areas from a distance, typically from aircraft or satellites or sensors mounted on aircraft, by detecting the energy that is reflected from

Earth. In another word, RS means to collect the information of an object without its physical contact. Remote sensors can be either passive or active. Passive sensors respond to external stimuli, most commonly the reflected sunlight from the earth's surface and records this natural energy while, active sensors use internal stimuli projected by the instrument itself to collect data about Earth. Yin et al. (2019) has divided the remote sensing system in to three broad categories viz., spatial foundation system, ground base system and remote sensing data storage system which overall include remote sensor, control and positioning system, carrier platform, data transmission and data preprocessing systems. The interaction between electromagnetic radiation with vegetation or soil is detected by capturing the reflected radiation emitted by either an active or passive sensor and measuring this captured radiation presents the status of the soil or vegetation attributes. The electromagnetic radiations used are usually visible, near-infrared (Mulla DJ., 2013), infrared or microwaves. According to Castro Gomez MG (2017) remote sensing system can be classified into two main classifications: optical and SAR (Synthetic Aperture RADAR). Usually, Landsat and SPOT satellite images have commonly been used for agricultural applications over large geographic areas since the 1970s. Airborne multispectral imagery has been widely used in precision agriculture for assessing soil variability, mapping crop growth and yield variability, detecting crop insect infestations and disease infections and mapping water status. Remote sensing has the ability to monitor the dynamic conditions of soil, plant, area under cultivation (with 95% accuracy), single crop cultivation area (within 10 days with 90% accuracy). For producer community in making decisions, the digitalized and georeferenced recorded observations are imported into the GIS workspace according to those delineations, maps, management zones are prepared (Tayari et.al. 2015). Remote sensing techniques play vital role in assessing crop condition and yield forecasting, acreage estimates of specific crops, detection of crop pests and diseases, disaster management, wild life management, water supply information and management, weather forecasting, range land management, and livestock surveys (Patil and Chetan 2017).

3. Variable rate technology (VRT) Chen et.al. (2013) stated that the application of inputs precisely in variable type and quantity in different pieces of land according to the present status and requirement is the practice of variable rate technology (VRT) in precision agriculture. Variable-rate technology (VRT) allows fertilizer, chemicals, lime, gypsum, irrigation water and other farm inputs to be applied at different rates across a field.

Variable-rate application (VRA) can range from the simple control of flow rate to the more complex management of rate, chemical mix and application pattern. VRA can match changes in crop yield potential with specific input rates resulting in a more efficient system and minimizing potential environmental impacts. VRT can be used to deal with spatial variability between management zones. There are two types of VRT 1. Map-based control: a map of application rates is produced for the field before the operation. 2. Real-time control: decisions about what rates to apply in different locations are made using information gathered during the operation. This requires sensors to detect necessary information on 'on-the go' and is usually designed for a specific job such as herbicide application. The variable rate applicator has three components which include control computer, locator and actuator. The application map is loaded into a computer mounted on a variable-rate applicator. In variable rate technology and variable rate application, programmable machines attached with sprayers (Chen et.al., 2012 & Shen et.al., 2017) are available to deliver the correct amount of chemicals depending up on crop growth stage, crop condition and previously collected crop growth data. According to Hakkim et al. (2016). A high degree of variation, it means higher variable rate application of inputs with more economical and environmental benefit in comparison with uniform management.

4. Normalized difference vegetation index (NDVI): NDVI value given by Green Seeker. The NDVI is a common and widely used remote sensing index (Bhandari, Kumar & Singh, 2012). It is one of the earliest remote sensing analytical products used to simplify the complexities of multi-spectral imagery, now it is the most popular index used for assessment of vegetation. Studies have shown that NDVI is effective to differentiate savannah, dense forest, non-forest and agricultural fields and to determine evergreen forest versus seasonal forest types (Pettorelli et.al. 2005), and it is used to estimate various vegetation properties like the leaf area index (Tian et.al. 2017) [23], biomass (Zhu and Liu 2015), chlorophyll concentration in leaves (Pastor Guzman et al. 2015), plant productivity (Vicente Serrano et.al. 2016), fractional vegetation cover (Dutrieux et al. 2015) and plant stress (Chavez et.al. 2016). Such types of estimations are often derived by correlating remotely sensed NDVI values with ground-measured values of these variables. Butt B. (2018) reveals that the reliability of NDVI directly determines the robustness of NDVI related models. NDVI is calculated as the ratio between top of atmosphere reflectance of a red band (pred) and a near-infrared (NIR) band (pnir).



The NDVI of a densely vegetated area will tend toward positive values, whereas water and built-up areas will be represented by near zero or negative values. It provides a crude estimate of vegetation health and means of monitoring the change in vegetation over time. 6. Site-specific nutrient management (SSNM) Site Specific Nutrient Management (SSNM) is an approach of supplying plants with nutrients to optimally match their inherent spatial and temporal needs for supplemental nutrients by using different tools of SSNM such as remote sensing, GPS, GIS systems, VRT, yield monitoring. SSNM approach is based on feeding crops with nutrients when needed. SSNM relies on 5R's i.e. Right source, dose, time, place and method. The SSNM provide an approach for need based 'feeding' of crops with nutrients. The SSNM approach aims at increasing farmers' profit by achieving the goal of maximum economic produce of the crops. The main features of Site-specific nutrient management were stated by Tiwari K.N., 2007. The site-specific application of primary (nitrogen, phosphorus &

potassium) and secondary and micronutrients based on soil tests are followed. It further provides guidelines for selection of the most economic combinations of different nutrients. Optimal utilization of existing indigenous nutrient sources such as crop residues and manures. The recent development in microprocessor and other electronic technologies for monitoring yields and sensing soil related variables are new tools available to make site specific farming a success. When measuring soil characteristics such as the harvest data, moisture and nutrients availability in the soil, satellite-based positioning system, namely, geographical positioning system (GPS) can be used to identify the locations where the data are taken. 7. Diagnosis and Recommendation Integrated System (DRIS) approach. The nutrient diagnosis of crops is done with the help of chemical fertility analysis of soils, using the nutrient requirements of the studied species and frequently the interpretation of nutrient concentrations in leaf tissue by using widely used methods viz., critical levels and sufficiency ranges (Bangroo et al., 2010 and

Savita et al., 2016). DRIS, which is the acronym for "Diagnosis and Recommendation Integrated System", was proposed by Beaufils (1973), based on studies on physiology and plant nutrition, initially in rubber trees cultivated in Vietnam and then in maize and sugarcane in South Africa. The diagnosis norms have been determined for several extensive forage, fruit, vegetable and timber (Bangroo et al., 2010; Savita et al., 2016). RIS indices can be calculated for the identification of deficiencies, excesses, or ideal values of nutrients in a crop. Furthermore, DRIS indices develop the nutritional balance index that represents the global balance of the nutrients involved in the nutrition of the plant (Bangroo et al., 2010; Chacon et al., 2013).

18. CHALLENGES OF PRECISION AGRICULTURE TECHNOLOGY

Fakhruddin, states 15 challenges and issues of precision agriculture: The first is Interoperability of different standards. Various technologies and tools do not follow the same operational standards. The second the steep learning curve it presents for the average farmer. The third is the unavailability of a strong internet connection in rural areas. The fourth is making sense of big data as it is impossible to monitor and manage every data point daily and weekly over all the growing seasons. The fifth is non-awareness of varying farming functions. For the fact you apply a certain amount of fertilizer on a particular soil, it does mean another soil with the same plant needs the same amount of fertilizer as the nutrient amount in the soil may differ. The sixth is the size of management zones. There is not much reference to use when dividing the management zones concerning soil sampling requirement. The seventh is barriers for entry for new firms. Precision agriculture is still new, so there are not a lot of companies in the market with this technology. This low competition can prevent new firms from entering the market. The eighth is lack of scalability and configuration problem. The same used for commercial sizes should also be used for small farms. However, this is not the case. The ninth is energy depletion risk. PA should be about conserving energy but when using all these technologies, in the long run it consumes a lot of energy using data hubs/ data centres, sensors and other gadgets. The tenth is that it poses a challenge for indoor farming. Most of the PA methods are optimized for outdoor farming. The eleventh is a technical failure and resultant damages. If there is a breakdown in the gadgets, it could lead to low crop yield or even crop failure. The twelfth is mounting e-waste. Regular updates of gadgets are making the older one's obsolete dumping them causes a landfill hence land pollution in the long run. The thirteenth is the loss of manual employment. With the

introduction of PA which reduces the need for much of the manual labour, those that were required for that job will not be needed since they have been replaced by technology. The fourteenth is the security factor. As long as a system is connected to the internet, security concerns will be an issue as it is in the conventional world. The last is benefits are not imminent. Like every good thing takes time, the benefits of PA are not immediate thus making the farmer not wanting to risk it financially in the beginning. In the aspect of livestock farming, the use of robots could reduce the human to animal interaction thus disallowing the farmers to familiarize themselves with the animals as in the conventional manner. The usage of technology increases the mental workload of the average farmer (Houstiou et al, 2017). Lack of national infrastructure such as power in outskirts where the farm is located could pose as a challenge for the enablement of precision agriculture.

18.1. PRECISION AGRICULTURE AND SUSTAINABLE FARMING:

Currently, technology is regarded as a major support pillar in almost all fields of human activity, including agriculture, where it has a significant impact on the quantity and quality of agricultural production. Precision agriculture management systems are evolving at a rapid pace. They allow farmers to find solutions to a variety of problems. Growers must become proficient with a variety of precision agriculture instruments in order to maximize output.

18.1.1. What is Precision Agriculture?

Dr. Pierre Robert, the father of modern precision farming, proposed precision agriculture in the 1980s. He developed the idea in college and spent many years researching and pioneering precision farming principles. The agricultural Fourth Industrial Revolution has resulted in a number of innovations known collectively as "agriculture." Modern technology allows for the precise, efficient, and effective processing of all data, among other things that will propel agriculture to new heights. The term "precision agriculture" implies accuracy and correctness in any production. The primary goal of precision farming is to adapt operations to the local environment by following the guiding principle of carrying out interventions at the appropriate time, place, and intensity.

GPS, drones, and satellite imagery are just a few of the smart farming technologies that can be integrated into such a system. Based on this data, farmers receive information on a wide range of topics, including crop status, weather forecasts, environmental changes, and so on. Another significant difference between precision farming and traditional agriculture is the ability to manage fields by dividing them into different zones rather than

managing them as a continuous block. This type of zoning allows for different management options for specific field components, such as adjusting the amount of fertilizer, maximizing method movement, and using fuel more efficiently. According to market research, the smart agriculture market is expected to be worth USD 36.24 billion by 2030, with a CAGR of 10.80%." in 2022(Straits research).

18.1.2. Why is precision agriculture important?

The ultimate goal of precision farming is to increase output with lower resource usage and maintain high quality standards.

for agricultural operations that can increase land production while optimizing efforts and resources and reducing consumption and waste.



Fig 6: AI Technology used in Agriculture

The task becomes more profitable for farmers and contractors as procedures are controlled more quickly and effectively, resulting in lower hourly expenses. They increase productivity while decreasing human resource fatigue for the environment, as more efficient resource use results in less fertilizer and herbicide waste, pollutants, and soil compaction.



Fig 7: Precision Farming

18.1.3. Benefits of Precision Agriculture

Farmers are only now realizing the advantages of precision farming with IoT. Agricultural business owners see the use of technology in crop and cattle management as a way to improve decision-making, increase return on investment (ROI), and improve overall site security. Here are a few advantages of smart farming technology:

18.2. Improved decision-making efficiency

When farmers use precision agriculture sensors to monitor soil moisture, crop health, and nutrient levels, they gain long-term access to priceless real-time data. In this manner, a site manager will be able to identify patterns and forecast adjustments, potential hazards, and yields, both during harvest and the growing season.

18.3. Access to farm records

When farmers use precision agriculture sensors to monitor soil moisture, crop health, and nutrient levels, they gain long-term access to priceless real-time data. In this manner, a site manager will be able to identify patterns and forecast adjustments, potential hazards, and yields, both during harvest and the growing season.

18.4. Access to farm records

Using technology to manage farms increases data accessibility. Precision agriculture allows team members to work outside of the office. Because of cloud-based technologies, all relevant information is freely accessible at any time from any device.



Fig 8: AI Tools used in Precision Farming

18.5. Improved crop protection

Pesticide overuse is one of the causes of high crop and soil pressure. Farmers frequently use excessive amounts of nitrogen to protect their crops from insect pests. Chemical use is costly and reduces the site's environmental sustainability. Precision agriculture (PA) can assist in the environmentally friendly management of

crop production inputs. PA can target fertilizer, seed, and chemical rates for soil and other conditions by using site-specific knowledge. One of the primary benefits of using Internet of Things-based smart farming technology is that it allows agriculture to better manage pests, apply chemicals only when necessary, and protect crops.

18.6. Irrigation management

Crop irrigation system based on real-time microclimate parameter data obtained from Digi Plant and the weather station. Detect soil moisture and automate the irrigation system to provide adequate amounts of water as needed. (For more information, visit here)

18.7. Smart Monitoring

Senz Argo's acoustic sensors provide real-time monitoring of climate parameters such as temperature, humidity, soil moisture, electric conductance, light, rain, and wind pattern.

18.8. Technologies used in Precision Agriculture

1.Yield monitoring and mapping

Grain yield monitors continuously measure and record grain flow in a combine's clean-grain elevator. Yield monitors connected to a GPS receiver can provide the data required for yield maps. Yield assessments are critical for making appropriate management decisions. However, when analysing a yield map, it is also necessary to consider the soil, terrain, and other environmental factors. When used correctly, yield data provides valuable feedback for evaluating the effects of controlled inputs such as fertilizer, lime, seeds, herbicides, and cultural techniques such as irrigation and tillage.



Fig 9: AI Tools used in Agriculture

2.Soil sampling and analysis.

Data about soil type, fertility, moisture content, and other factors can be collected using mobile apps. This data can be used to make irrigation, fertilization, and other crop management decisions.

3.Weather monitoring

Users can use hyperlocal weather data to determine when to plant, how much water to give crops, and when to harvest.

4.Equipment management.

Because agricultural equipment is expensive, farmers must keep track of it, schedule maintenance, and plan for repairs.

5.Remote sensing

Remote sensing is the process of collecting data from a distance. Sensors in agriculture can range from simple handheld devices to aircraft mounts and satellite-based systems. Remote sensing technologies are an important tool for site-specific crop management. Remote sensing has the potential to provide real-time analysis of a growing crop's attributes, which can aid in making timely management decisions that affect the crop's outcome.

18.9. How is GPS technology used in precision agriculture?

Satellites in the Global Positioning System send signals that allow GPS receivers to determine their location. Because this information is provided in real time, you can receive continuous position updates while moving. When precise location data is available at all times, it is possible to map soil and crop measurements. Using GPS receivers, which can be carried into the field or installed on tools, users can return to specific locations to sample or treat specific areas. GPS can be used for the following tasks:

18.20. Mapping of irrigation systems, fields, and roads.

Detection of areas with problem plants; soil testing in specific field areas. The tractor being driven with a parallel steering system.

18.21. Precise seed and fertilizer application.

Due to the widespread use of GPS and GNSS systems, high-precision positioning systems held a dominant share of more than 27% of the precision farming market in 2018, as seen below:



18.22. Most Important technique in Precision Agriculture

Farmers use precision farming in a variety of ways in their farming operations to make resource management decisions based on in-field, real-time data collection.

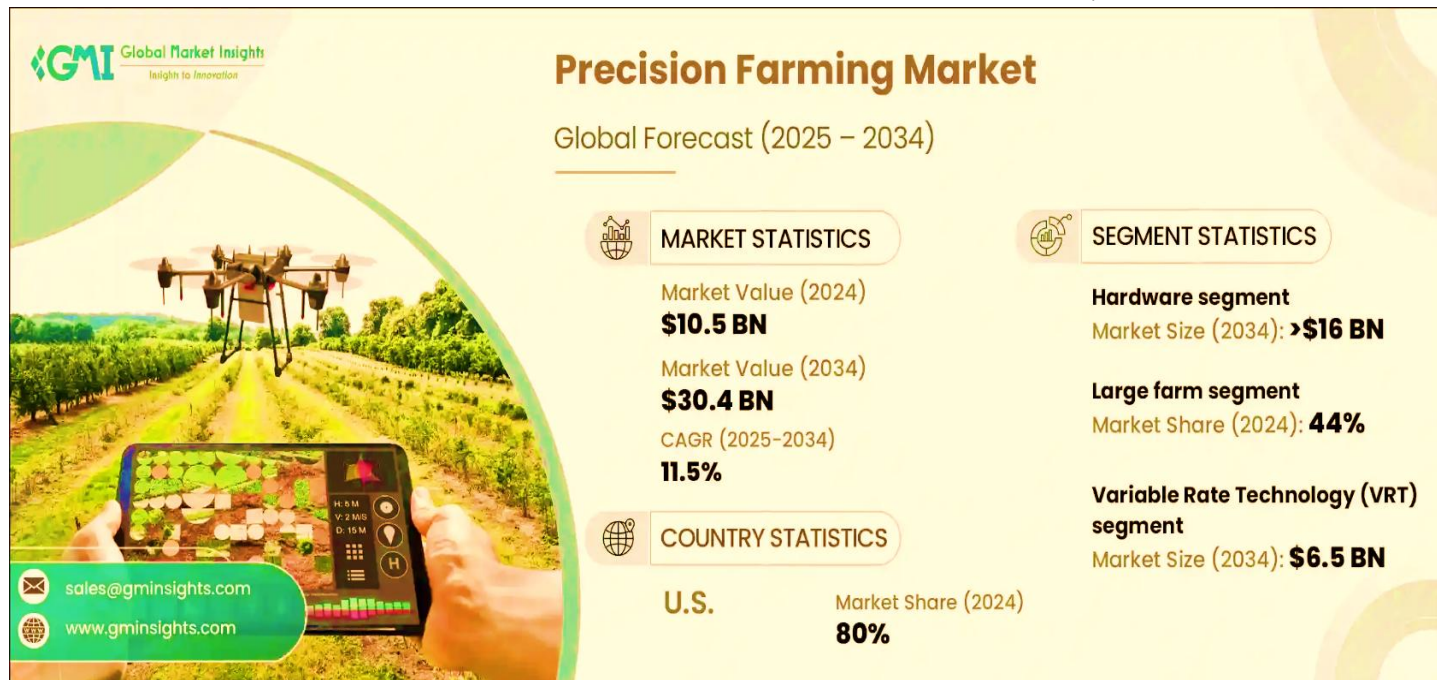
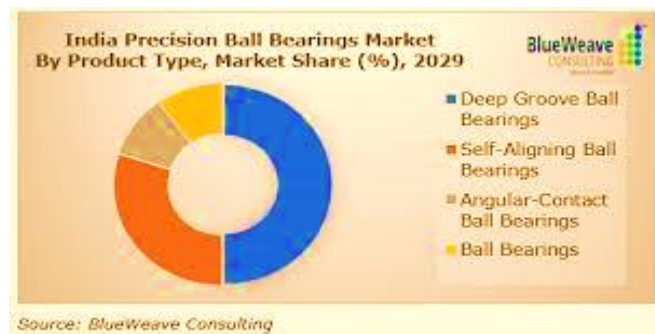


Fig 10: Precision Global Market (2025-2034)

The earliest and most widely used precision agriculture technique exists for variable-rate input applications. Growers can use VRT technology to apply fertilizer, chemicals, seeds, and other products to different parts of a field based on their needs. Farmers can also test the soil for nutrients such as nitrogen and feed only the areas that are deficient in those nutrients.



A group of soil cores collected at random locations throughout the sampling region is pooled and analyzed in a lab. Crop consultants recommend applying fertilizer based on the results of the soil test for the 20-acre area. Grid soil sampling uses the same concepts as soil sampling, but the sampling intensity is increased. Unlike traditional sampling methods, a 2-acre grid sampling technique would yield 10 samples from a 20-acre sampling area. The geographic location of soil samples collected in a systematic grid allows the data to be plotted. The end result of grid soil sampling is a map of nutrient requirements known as an application map. After

laboratory analysis of grid soil samples, the nutrient requirements of a crop are interpreted for each soil sample. The entire collection of soil samples is then used to create a fertilizer application map. The application map is loaded into a computer mounted on a variable-rate fertilizer spreader. Using the application map and a GPS receiver, the computer instructs a product-delivery controller to change the amount and/or type of fertilizer product in accordance with the application map. Precision agriculture can address the environmental and economic concerns that now surround production agriculture. It is clear that a large number of farmers have reached a management level where precision management can benefit them.



The concept of "doing the right thing at the right time" has a strong intuitive appeal, but questions about cost-effectiveness and the best uses of the technological tools we now have persist. Finally, the ability and speed with which the information required to direct new technologies

can be discovered will have a significant impact on precision agriculture's success.

19. Agriculture Automation Control System Market Size

Agriculture Automation Control System Market was valued at USD 4.38 billion and is anticipated to grow at a CAGR of over 10% between 2024 & 2032. A shortage of workforce and increasing costs for labor force are forcing the farmers to continue production and to manage the costs, leading to a significant increase in the demand for agricultural automation control systems.

19.1. To get key market trends

Farm operations monitoring & management are becoming efficient due to the availability of robots, Artificial Intelligence (AI), and sensors present in the contemporary world. For instance, in May 2024, NEC X made scalable investments in Verdi Expeditions Inc., marking the first-ever venture in farm automation and personalized plant health management.

19.2. What are the growth opportunities in this market?

Another evolution that is adopted within farms is the implementation of Internet of Things (IoT) and networking with the aid of data analytics in agro automation solutions. One potential enhancement in farmer decision-making is the use of analytical information from devices that provide real-time data on crop status, weather, and soil conditions. Predictive analytics enables the prediction and prevention of potential issues, leading to a more robust and sustainable farming system. A major challenge in the market is the high fixed costs. Automation technologies may provide long term gains of improved efficiency & productivity; however, the costs associated with implementing them may be extremely high, especially for the smallholder farmers. This arises from the cost of purchasing automation equipment, including the cost of installation and personnel training for automation systems operation & management. Hence, the cost of automation becomes one of the key factors that owners should consider when investing in automation solutions. Technological advancements of the automated systems and the concerns with relation to its maintenance pose another problem for the agriculture automation control system market. To non-technical oriented farmers, automation systems appeared to be rather mysterious as such systems often rely on rather complicated software algorithms, sophisticated sensors and highly elaborate pieces of equipment. Installation, calibration, and the integration of these systems are also more complex as it requires expert staff. In addition, the day-to-day functioning as well as the optimization of automation systems requires constant updates and technical support.

19.3. Agriculture Automation Control System Market Trends

In the contemporary structure of the agriculture automation control system industry, several trends are emerging to reinvent the management of farming operations. These technologies help farmers make better decisions by predicting the likely results of their actions, especially in managing crop resources and estimating yields. Furthermore, the integration of IoT into agriculture has enhanced the process of monitoring and controlling farms. IoT devices collect data from various sensors installed in fields through real-time transmission, assisting farmers by monitoring soil moisture levels, weather conditions, and crop health. In January 2024, Trimble introduced the Connected Climate Exchange, carbon marketplace, to join and integrate verified data during the agriculture supply chain for a better environment tomorrow. In line with this, the buyers of emission reductions and removals, such as Trimble's Connected Climate Exchange, ease the process of compiling data from farm organizations and verifying them. This platform enables access to carbon markets and sustainability programs, which were formerly too time-consuming and complicated, by connecting farmers, agronomists, Ag retailers, and carbon purchasers.

19.4. Agriculture Automation Control System Market Analysis

19.4.1. Learn more about the key segments shaping this market

Based on technology, the market is divided into sensor technologies, robotics and automation equipment, connectivity solutions, data management and analytics platforms, control systems, and others. The sensor technologies segment is expected to reach a value over USD 2.5 billion by 2032. In the rapidly expanding field of Agri-tech, sensor technologies have emerged as a pivotal segment experiencing the highest growth and transformation. Automation includes the use of sensors and these increase chances of farming since they relay useful information, such as soil moisture, temperature, humidity, and general health of crops, to farmers. Innovations in sensor technology have enabled farmers to monitor their fields with unprecedented accuracy, making decision-making and resource management more efficient. These sensors are becoming more advanced today as they offer wireless connections, remote control, and monitoring, helping farmers control the irrigation time and techniques, easy identification of pests that may be affecting the crops, and determination of the exact crop nutrition requirements. Therefore, sensor technologies are transforming conventional farming methods, improving production rates, and encouraging

environmentally friendly farming.

19.4.2. Learn more about the key segments shaping this market

Based on application, the market is divided into crop monitoring & management, livestock monitoring & management, soil & field analysis, climate control & management, and supply chain optimization. The livestock monitoring & management segment is the fastest growing segment with an anticipated CAGR of over 10% between 2024 & 2032. The dominance of the crop monitoring & management segment in the global market underscores its critical role in modern agriculture. Technologies in crop monitoring allow farmers to monitor their crops for any signs of diseases, development and progress throughout the seasons. With different sensors, drones & satellite images, one can obtain real-time data on parameters such as moisture and nutrient content, pests and diseases, and even stress indicators in plants. This wealth of information enables farmers to make sound decisions regarding irrigation, fertilization, and pest control, thereby achieving high yields with minimal resources and environmental impacts. Further, the collected data is processed through the advanced analytics platform, which helps the farmers to use precision agriculture technology to suit the needs of the crop and the fields.

19.4.3. Looking for region specific data?

North America dominated the global agriculture automation control system market in 2023, accounting for a share of over 30%. Farmers in North America, focused on increasing efficiency, boosting crop production, and addressing labor shortages, are highly receptive to automation technologies in farming. They adopt a range of solutions, from precision farming equipment to robotic farming and data analytical platforms. Similarly, favourable government policies, robust research programs, and the involvement of agribusiness & technology companies support the development of the agricultural automation market in this region.

The U.S. market is steadily expanding as the focus on technological advancements in agriculture increases. Automation systems are benefiting from the increased use of R&D and government incentives for using precision farming technologies. The trend toward improving productivity to meet the living standards of a growing population, coupled with the problem of labor scarcity, is driving the growth of agricultural automation in the U.S. The agricultural automation control system market in China is emerging due to rising labor costs, increasing production expenses, and governmental programs aimed at improving agriculture. China's drive for mechanization has resulted in the use of intelligent farming techniques

inclusive of AI, drones and robots. Due to government support of agriculture & food security, coupled with sustainable farming technologies, China has scaled up the use of automation, making it a global hub in the use of agricultural technologies. The South Korean agriculture automation control system market is also growing as the country is actively adopting rising smart farming technologies due to its aging agricultural workforce and a lack of accessible arable land. The government now supports automation through subsidies and research funding, encouraging the use of AI, IoT, and robots in agriculture. South Korea is actively adopting technology in farming to boost production, achieve food self-sufficiency, and reduce reliance on food imports. The market is experiencing a steady growth in Japan due to the country's developed technological network and the issues of depopulation in rural areas, and the deficiency of labor force in the country. Smart agriculture is supported by Japan government with policies & subsidies, to apply robotics, AI & IoT into agriculture. These technologies enhance crop productivity and resource utilization, positioning Japan among the world's leaders in agricultural innovations and sustainability.

19.4.4. Agriculture Automation Control System Market Share

AGCO Corporation, CNH Industrial N.V., and Trimble Inc. hold a significant share of over 25% in the agriculture automation control system industry. AGCO Corporation, a major player in agricultural machinery production, has integrated fully automated solutions under its brands such as Fendt and Massey Ferguson. It ensures that the respective gadgets that are used in the work of the firm's equipment are newer technology-effective tools such as precision planting systems, telemetry solutions, and farm management software, ensuring enhanced farmer productivity globally. In addition, AGCO participates in R&D projects to create new automation technologies for the effective development of modern farming, which makes the company one of the market's key contractors.

CNH Industrial N.V., through its brands Case IH and New Holland Agriculture, is a market leader in providing farmers worldwide with automation solutions. These include GPS guidance system, auto-steer, and sophisticated harvesting technologies designed to improve farm productivity and output. This allows CNH Industrial to always focus positively on innovations & sustainability. When developing its products, the firm effectively utilizes modern technologies to address challenges such as labor shortages and environmental pollution in the agricultural sector.

19.4.5. Agriculture Automation Control System Market Companies

Major players operating in the agriculture automation control system industry are:

- AGCO Corporation
- CNH Industrial N.V.
- Trimble Inc.
- Robert Bosch LLC
- Bayer AG
- Ag Leader Technology
- DICKEY-john
- CropX Inc.

19.4.6. Agriculture Automation Control System Industry News

In November 2023, AGCO Power unveiled a range of solutions from alternative fuels to electric systems at the Agrotechnical trade fair held in Germany in November 2023. AGCO Power showcased the fuel-cell-based e100 Vario Range Extender Concept, which doubled the operating time of the existing Fendt electric tractor from four to eight hours. The system transformed fossil-free green methanol into hydrogen, which was then converted into electricity to charge the tractor batteries while in operation.

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24. References

1. Ashish Mishra, Chidambara Raj P, Balaji D. Operationalization of precision farming in India. Department of Civil Engineering, Anna University, Chennai; c2003.
2. Boissard P, Martin V, Moisan S. A cognitive vision approach to early pest detection in greenhouse crops.

Journal of Computers and Electronics in Agriculture. 2016;2(3):81-93.

3. Cancela J, Fandango M, Rey B, Martinez, E. Automatic irrigation system based on dual crop coefficient, soil and plant water status for precision agriculture. Journal of Agricultural Engineering Research. 2015;12(4):150-157.
4. Chen F, Kissel DE, Clark R, West LT, Rickman D, Luval J, et al. Determining surface soil clay concentration at a field scale for precision agriculture, University of Georgia, Huntsville; c1997.
5. Daberkow SG, Morehart M, McBride WD. Information technology management. Economic Research Service, USDA; c2006.
6. Díaz S, Pérez J, Mateos A, Marinescu M, Guerra B. A novel methodology for the monitoring of Precision agricultural production process based on wireless sensor networks. International Journal of Science, Engineering and Technology Research (IJSETR). 2012;7(6):252-265.
7. Dwivedi RS, Wani LD, Bhattacharya A, Navalgund A. Space technology inputs for precision farming: resource and environmental monitoring. The Int. Archives of the Photogrammetry, Remote Sensing & Spatial Inf. Sci. 2002;34(7):319-321.
8. Faical B, Larson J, Roberts B, Kennedy G. An adaptive approach for UAV-based pesticide spraying in dynamic environments. Journal of Computers and Electronics in Agriculture. 2016;13(8):210-223.
9. Ferreiro-Arman M, Da Costa JP, Homayouni S. Hyperspectral image analysis for precision viticulture, In Image Analysis and Recognition, Springer Berlin Heidelberg; c2006. p. 730-741.
10. Irmak A, Jones J, Batchelor W, Irmak S, Boote K. Artificial neural network model as a data analysis tool in precision farming. International Journal of Precision Agriculture. 2015;9(6):227-237.
11. Kalkat GS. Agriculture in India - II, Punjab faces post green Revolution problems Tribune, Chandigarh India; c2000. p. 7-8.
12. Mondal Pinaki, Manisha Basu, Adoption of precision agriculture technologies in India and in some developing countries: scope, present status and strategies. Progress in Natural Science. 2009;19(6):659-666.
13. Mondal P, Basu M. Adoption of PA Technologies in India and Some Developing Countries: Scope, Present Status and Strategies. Prog. Nat. Sci. 2009; 19:659-666. 14. Njoroge JB, Ninomiya K, Kondo N. Automated fruit grading system using image processing, In Proceedings of the 41st SICE Annual Conference; 2002. p. 1346-1351.

14. Nowak P. A sociological analysis of site-specific management. In: The state of site-specific Management for Agriculture. American society of Agronomy, Madison, WI; c1997. p. 397-422.
15. Ojeda H, Carrillo N, Deis L. Precision viticulture and water status II: Quantitative and qualitative performance of different within field zones, defined from water poten. p. 741-748.
16. Patil VC, Shanwad UK. Relevance tial mapping, in XIV International GESCO Viticulture Congress, Geisenheim, Germany; c2005 of precision farming to Indian agriculture. Second National Conference on Agro-Informatics and Precision Farming, Raichur, Karnataka, India; c2009.
17. Pydipati Y, Burks F, Lee S. Statistical and neural network classifiers for citrus disease detection using machine vision. 2015;8(5):320-324. Transactions of the ASAE.
18. Rani M, Kamalesh S. Energy efficient fault tolerant topology scheme for precision agriculture using wireless sensor network. In Proceedings of the International Conference on Advanced Communication Control and Computing Technologies (ICACCCT). Ramanathapuram, India; c2014 May. p. 1208-1211.
19. Ratasuk R, Vejlgard B, Mangalvedhe N, Ghosh A. IoT system for M2M Wireless sensor communication for smart farming. In Proceedings of the IEEE Wireless Communications and Networking Conference. Doha, Qatar; c2016. p. 1-5
20. Robert PC, Rust RH, Larson WE. Site specific
21. management for Agriculture system. Proc. Site Specific Management for Agriculture System, Miniports; c1994.
22. Shibusawa Sakae. Precision Farming Approaches to Small-Farm Agriculture, Faculty of Agriculture, Tokyo University of Agriculture and Technology, 3-5-8 Saiwai Cho, Fuchu, Tokyo 183-8509, Japan, -08-01; c2002.
23. Siddiq E.A. Survey of Indian agriculture. The Hindu; c2000. p. 43.
24. Singh AK. Precision farming, Water Technology Centre, IARI, New Delhi; c2010. 25. Tang L, Tian L, Steward L. Colour image segmentation with genetic algorithm for in-field weed sensing. Transactions of the ASAE. 2014;43(4):1019-1027.
25. 26. Yang C, Prasher O, Whalen J, Goel P. Development of an image processing system and a fuzzy algorithm for site specific herbicide applications in Precision Agriculture. Journal of Computers and Electronics in Agriculture. 2014;3(5):112-116.
26. 27. B Ashwin Kumar and K Nirosha, Precision farming: Emerging technology in Indian agriculture-brief review, The Pharma Innovation Journal 2023; SP-12(7): 579-583.
27. Bangroo SA, Bhat MI, Tahir A, Aziz MA, Bhat MA, Wani MA. Diagnosis and Recommendation Integrated System (DRIS). A Review. J. Curr. Res,2010:10:084 097.
28. 2. Basavaraj Patil, Chetan HT. Role of Remote Sensing in Precision Agriculture Marumegh,2017:2(4):34-37.
29. 3. Bhandari Kumar, Singh. Technology,2012:6(12):612-621. Procedia 4. Butt B. Environmental indicators and governance. Curr. Opin. Env. Sust,2018:32:84-8.
30. Castro Gomez MG. Joint use of Sentinel-1 and Sentinel-2 for land cover classification: A machine learning approach. Lund University GEM thesis series, 2017.
31. Chacon Pardo E, Camacho-Tamayo JH, Arguello O. Establishment of DRIS norms for the nutritional diagnosis of rubber (*Hevea brasiliensis* Muell Arg.) clone RRIM 600 on the Eastern Plains of Colombia. Agron. Colomb.,2013:31(2):215-222.
32. Chavez RO, Clevers JGPW, Decuyper M, De Bruin S, Herold M. 50 years of water extraction in the Pampa del Tamarugal basin a Prosopis tamarugo trees survive in the hyper-arid Atacama Desert (Northern Chile)? J Arid Environ,2016:124:292-303.
33. Chen Y, Ozkan HE, Zhu H, Derksen RC, Krause CR. Spray deposition inside tree canopies from a newly developed variable rate air-assisted sprayer. Transactions of the ASABE,2013:56:1263-1272.
34. Chen Y, Zhu H, Ozkan, HE. Development of a variable rate sprayer with laser scanning sensor to synchronize spray outputs to tree structures. Transactions of the ASABE,2012:55:773-781. DOI: 10.1109/SoSE50414.2020.9130481.
35. Dutrieux LP, Verbesselt J, Kooistra L, Herold M. Monitoring Forest cover loss using multiple data streams, a case study of a tropical dry forest in Bolivia. ISPRS J Sensing,2015:107:112-125. Photogram Remote
36. Gyarmati G, Mizik T. The present and future of the precision agriculture. IEEE 15th International Conference of System of Systems Engineering (SoSE), 2020, 593-596.
37. Hakkim VA, Joseph EA, Gokul AA, Mufeedha K. Precision farming: the future of Indian agriculture. Journal of Applied Biotechnology,2016:4(6):0-7. Biology and 13. Kumar S, Karaliya SK, Chaudhary S. Precision farming technologies towards enhancing

- productivity and sustainability of rice-wheat cropping system. *International Journal of Current Microbiology and Applied Sciences*,2017:6(3):142-151.
38. Mahendra Kumar Gora, Uttam Shivran, Vinay. Precision Farming: An Introduction Agri Articles,2022:02(02):94-98. (MAR-APR, 2022).
 39. Mulla DJ. Twenty-five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps. *Biosystems engineering*,2013 2022:114(4):358-371.
 40. Ojo OI, Ilunga MF. Geospatial Analysis for Irrigated Land Assessment Modeling and Mapping. In *Multi-Purposeful Application of Geospatial Data*; Rustamov, R.B., Ed.; Intech Open: London, UK, 2018, 65–84. <https://doi.org/10.5772/intechopen.73314>.
 41. Pastor Guzman J, Atkinson P, Dash J, Rioja-Nieto R. Spatiotemporal variation in mangrove chlorophyll concentration using Landsat Sens,2015:7(11):14530–14558. 8. Remote
 42. Pettorelli N, Vik JO, Mysterud A, Gaillard JM, Tucker CJ, Stenseth NC. Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends Ecol. Evol*,2005:20(9):503–510.
 43. Savita S, Krishnappa R, Bidyapati M, Devi T, Mishra G, Rawat D, Srivastava PC. Diagnosis and Recommendation Integrated System (DRIS) approach on nutritional diagnosis in fruit crops. A Review. *J. App. Nat. Science*,2016:8(4):23372345.
 44. Sharma Y, Ashoka P. Precision farming and use of sensors in Horticulture. *Progressive Research–An International Journal Society Development*,2015:10:3244-3248. for Scientific
 45. Shen Y, Zhu H, Liu H, Chen Y, Ozkan E. Development of a laser-guided embedded-computer controlled air assisted precision sprayer. *Transactions of the ASABE*,2017:60:827-1838.
 46. Tayari E, Jamshid AR, Goodarzi HR. Role of GPS and GIS in precision agriculture. *Journal of Scientific Research and Development*,2015:2(3):157-162.
 47. Tian J, Wang L, Li X, Gong H, Shi C, Zhong R, Liu X. Comparison of UAV and WorldView-2 imagery for mapping leaf area index of mangrove forest. *Int J Appl Earth Obs Geoinf*,2017:61:22–31.
 48. Tiwari KN. Breaking yield barriers and stagnation through site-specific nutrient management. *Journal of Indian Society of Soil Science*,2007:55:444-454.
 49. Vicente Serrano SM, Camarero JJ, Olano JM, Martín Hernandez N, Pena-Gallardo M, Tomas-Burguera M, Gazol A, et al. Diverse relationships between forest growth and the normalized difference vegetation index at a global scale. *Remote Sens Environ*,2016:187:14
 50. 29. 26. Yin N, Liu R, Zeng B, Liu N. A review: UAV-based Remote Sensing. In *IOP Conference Series: Materials Science and Engineering*, 2019, 490(6).
 51. Yousefi MR, Razdari AM. Application o of GIS and GPS in precision agriculture (a review). *International Journal of Advanced Biological and Biomedical Research*,2015:3(1):7-9.
 52. Zhu X, Liu D. Improving forest aboveground biomass estimation using seasonal Landsat NDVI time-series. *ISPRS J Photogramm Remote Sensing*,2015:102:222 23.
 53. Ravindra A Daspute, Rohit Baburao Umbarkar, Rahul R Vikhe. Precision agriculture: Tools and techniques- A review. *International Journal of Agriculture and Plant Science*, Volume 5, Issue 2, 2023, Page No. 25-28.
