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IoT and Wireless Sensor Networks in Precision Agriculture: State-of-the-Art and Revolutionary Step out towards Future Directions - A Review

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Abstract

Automation of agricultural activities based on the Internet of Things (IoT) can trans the agriculture industry from static or manual to dynamic and intelligent. Additio IOT is a less labour intensive procedure decrease manpower involvement. Wir Sensor Networks (WSN), Precision Agriculture (PA) are the primary caus automation in the agricultural sector. PA involves in specialized sensors and algori which helps to receive the required amount of nutrients for maximizing the yield maintaining sustainability. PA involves obtaining accurate information about the sta the soil, crops, and weather from the sensors placed in the fields. High-resolution pl of crops are taken with manned or unmanned satellites or aerial platforms. The pl are processed to retrieve data for future decisions. A review of close-by and fa sensor networks in the field of agriculture is covered in this study, along with s issues and difficulties. This survey covers wireless communication technologies, ser and wireless nodes used to measure environmental behaviour in agriculture, as we the platforms used to obtain spectral images of crops, the spectral images and V applications are used to analysis the typical vegetation indices. A wireless se network-based system is the initial module, and it tracks the condition of crops in time. The multi-spectral imagery obtained in the second module by a low-altitude re sensing platform which processed to identify healthy and diseased crops. We emphasize the outcomes from a case study and indicate the difficulties and direction need to take moving forward.

Keywords: Precision farming, Spatial analysis, Remote sensing, Variable-Rate Technology.

Introduction

Global population growth raises concerns about future food security due to resource and food shortages, making it challenging to provide human civilization's basic demands in the near future (Mumtaz *et al*., 2017). To meet this problem, several cutting-edge technologies are being implemented in the agriculture sector to increase productivity. Precision agriculture (PA) uses IoT devices to monitor crop conditions at different growth phases using both close- and far-field sensing methods. Various factors like water level, temperature, nutrient contents are extremely crucial factors in plant health determination. A farmer can be benefitted by PA to precisely determine the conditions that must exist for a crop to be healthy, as well as the locations and dosages of these conditions period in question. In order to accomplish this, a massive amount of data from many sources and field locations must be collected, including soil nutrients, the existence of weeds and pests, the amount of chlorophyll in plants, and certain meteorological factors (Abbasi *et al*., 2014). The collected data needs to be examined in order to produce agronomic recommendations. As an illustration, a plant's amount of greenness (or chlorophyll content) can indicate the nutrients it needs based on its stage of growth. Together with the weather forecast, this data is merged with the properties of the soil where the plant is growing. The amount of a specific fertilizer that should be applied to that plant the following day is calculated using all of the information that has been gathered. The key to increasing yields is to provide agronomic information to farmers at the appropriate time and make sure they follow these suggestions. WSNs, a network of several wireless nodes linked together to monitor the physical parameters of the environment, are the primary source of power for PA. Each node comprises of a radio transceiver, a microcontroller, a sensor or sensors, an antenna, and additional circuitry for communicating with a gateway to send data gathered by the sensor(s) (Wang *et al*., 2006). The controller then sends the data to the cloud or a portable device after the controller receives it from the controller after sensors that have collected the data from the physical parameters. Many specifications are needed in the agriculture industry, including information on soil characteristics, crop varieties, weather patterns, types of fertilizers, and water requirements. Depending on the type of crop grown on a given plot of land and the plant itself grown in various climates, different crops may have varying needs (Srbinovska *et al*., 2015). These crop factors' changing behavior is tracked via sensors. Sensors may now be used in many different spheres of life, including agriculture, thanks to the rapid improvement of WSN technology in terms of sensor size and cost (Cambra *et al*., 2017). A WSN typically comprises one or more wireless nodes that are also linked by sensors. These nodes, which are very small machines, are in charge of data collection. There are two different kinds of nodes: source nodes that gather data and sink or gateway nodes that receive data from source nodes. In comparison to a source node, a sink node is more computationally powerful. When picking wireless nodes, there are restrictions on energy, memory, power, size, data rate, and cost. Throughout the last decade, numerous WSN applications for remote agricultural health monitoring have been proposed. A cyber-physical system for keeping tabs on a crop of potatoes was presented in (Rad *et al*., 2015). Cyber-physical systems are intelligent systems made up of hardware, software, and physical components that are integrated to perceive the changing conditions of the outside world. IoT-based systems face several difficulties when the number of devices grows exponentially. Each node communicates data to the distant cloud, as is customary in an IoT network, creating cloud Latency with minimal power consumption, better bandwidth utilization, and sporadic Internet access are the key issues that the IOT-based system faces. Congestion is another obstacle. Modern methods to solve these problems, which lessen the computational load on the cloud, include fog computing and edge computing. Fog computing's primary objective is to save bandwidth and energy, which contributes to an improvement in the end-user experience's service quality. The Fog of Everything was shown to have a six-layer, energy-efficient construction (Baccarelli *et al*., 2017). The first layer was an Internet of Everything (IOE) layer in which objects (which might be stationary, moving, or nomadic) operated under numerous spatially distributed clusters. The second was a wireless access network that enabled communication between objects in the fog and between objects themselves through a wireless channel (T2F and F2T). The Fog of Everything was shown to have a six-layer, energy-efficient construction. The connected fog nodes at the third layer exhibited characteristics of a virtualized cluster. The fourth layer contained an inter-fog backbone that was in charge of connecting fog nodes. The virtualization layer came next, giving each connected entity the capacity to expand its meager resource set by taking advantage of the virtual clone's computing power. Peer-to-peer (P2P) communication was made possible by the overlay inter-clone virtual network at the top layer. Then, a protocol stack for FOE was provided. This protocol stack was then evaluated by building a quick prototype called V-FOE and simulating it using the iFogsim toolkit. Strong proof of the usefulness of the proposed framework was supplied by the results, which also showed increased energy efficiency and a lower failure rate (Cambra *et al*., 2017).

Considering all of these concerns, our goal is to provide the industry and research communities with a study of communication technologies, measurements, and existing practices. Spectral pictures, IoT, and other data sources are monitored and analyzed by devices, sensors, and platforms utilized in environmental and agricultural applications (Skakun *et al*., 2018). PA is powered by an IoT-based architecture to track the health of the crops. The created system comprised two modules: one was a wireless sensor network-based crop health monitoring system that utilized several sensors to obtain the crop's current health status; the other was an NDVI-based analysis of spectrum photos taken by a drone to determine the chlorophyll content. It was additionally used to keep track of the crop's health (Daroya and Ramos, 2017; Fontana *et al*., 2015; Mahajan and Bundel, 2016).

2. Technologies Used in Precision Agriculture

Understanding cutting-edge technology and its applications is essential for anyone interested in perfection husbandry. Software and advanced operating techniques are only two among the many instruments available (Figure 1). The rulings that follow give a brief description of each of these.

(A) **MAPPING:** The most important and original stage in perfection husbandry is creation of charts for crop and soil attributes. These charts will measure geographic variability and serve as a frame for its operation. The process of gathering data is bettered by employing GPS to capture exact position coordinates both ahead and during crop product. Grid soil slice, yield monitoring, RS, and crop gibing are the technologies used for data collecting.

(B) **Global Positioning System (GPS) receivers:** Satellites that are part of the Global Positioning System (GPS) shoot signals that GPS receivers can use to determine various geographical locations. As this information is given in real-time, it's possible to admit nonstop position updates while moving. It's possible to collude measures of soil and crops when one always has access to precise position data. GPS can be used to track a misplaced device or help individuals to find their locations. Vehicle locations also tracked through the GPS receiver. GPS beacons can be used for emergency response to alert authorities to a person's position. At sea, GPS might be useful for search and rescue missions. GPS is necessary for precision farming methods in agriculture, which enable the use of field sensors, drones, and mapping software. GPS-enabled tracking gadgets can aid law enforcement in solving crimes and averting casualties and property damage. Additionally, when mapping projects like highways, crops, soil, power lines, and rivers, GPS mapping and surveying can assist save time and money.

(C) **Wireless Communication Technologies:** Due to the explosive growth of IoT devices and WSN technologies over the past few decades, numerous communication protocols have been developed. Each protocol has its parameters depending on the bandwidth, the number of available channels, data rate, battery timing, cost, and other variables (Al-Sarawi *et al*., 2017). In IoT-based agricultural applications, the following wireless communication protocols are most frequently used:

i. **Cellular:** The applications that need an exceptionally high data rate are best suited for cellular technology. Cellular device may use GSM, 3G, and 4G cellular connection capabilities to deliver dependable high-speed Internet connectivity while using more power. It needs the deployment of infrastructure, ongoing operational expenses, and backup personnel with a central management authority. Cellular technology is an excellent choice for subterranean wireless sensor networks, such as security systems in smart home projects and agricultural applications, although it uses more battery power (Zhang *et al*., 2017). In a smart irrigation system was described that used several soil moisture sensors that were placed in the field and connected to a ZigBee mesh network (Khelifa *et al*., 2015).

ii. **6LoWPAN:** An IP-based protocol called 6LoWPAN was the first one to be utilized for IoT communication. Because of its low bandwidth and low power requirements, 6LoWPAN is very inexpensive. There is an adaption layer between the network layer and the MAC layer to accommodate IPv6 and IEEE 802.15.4 interoperability (Al-Sarawi *et al*., 2017). Applications for 6LoWPAN include monitoring medical devices, environmental conditions, and home automation and security systems. A wireless sensor network with 6LoWPAN support was introduced by to track the soil characteristics of crops (Paventhan *et al*., 2012). The 6LoWPAN system design for applications in precision agriculture was covered in certain research, where it was also discussed how this protocol performed under various baud rates and power constraints (Suryady *et al*., 2011).

iii. **ZigBee:** ZigBee is a wireless communication standard that is frequently used in precision agriculture to track environmental factors that affect the health of crops

(Sarode and Chaudhari, 2018). It supports mesh, star, and tree topologies with multi-hop data transmission has a flexible network structure, has a long battery life, is simple to install, and supports big nodes. ZigBee is widely used in smart irrigation and greenhouse systems, among other smart agricultural applications (Chikankar *et al*., 2015; Zhou *et al*., 2007).

iv. **BLE:** BLE is a well-suited protocol for IoT applications, including agriculture, and is just as well-known as Bluetooth smart technology (Xue-fen *et al*., 2017). It is specially made for IoT applications that require low bandwidth, low latency, and short-range connectivity. It only has a 10-meter range, which is pretty short. However, its limitations on communication between devices, lack of security, and potential connection loss during communication are negatives. To gather the data from the sensors, a BLE-based architecture was proposed (Tanaka *et al*., 2018).

v. **RFID:** RFID systems are made up of a reader and a transponder with a very low radio frequency, or RF tag. The active reader tag system and the passive reader tag are the two tag technologies that are used in RFID. Passive reader tag systems are, however, weakly powered. Smart shopping, healthcare, national security, and smart agriculture applications are just a few IoT uses for RFID. A smart irrigation system for the Internet of Things based on RFID was presented in several studies (Wasson *et al*., 2019). The system used RFID communication protocols to gather sensor readings and send them to the cloud, where the user could regulate a water pump based on the amount of water in the soil. The system included soil moisture & soil temperature sensors as well as a water management system.

vi. **Wi-Fi:** The most popular protocol for enabling device connection over a wireless signal is called Wi-Fi. Millions of sites, including homes, offices, and public spaces like cafés, hotels, and airports, can connect to the Wireless Local Area Network (WLAN) via Wi-Fi at a fast speed. Wi-Fi is frequently utilized in Internet of Things (IoT) applications, such as smart irrigation, crop health monitoring, and greenhouses. An environmental monitoring infrastructure for greenhouse conditions, including temperature, light intensity, and soil moisture level, was described in some studies (Liang *et al*., 2018). This system had sensors that gathered information about environmental variation and wirelessly transmitted it to the cloud. Similar to this, a different Wi-Fi-based smart farm technology was unveiled (N-Usha, 2017).

vii. **LoRaWAN:** The LoRa network supports LoRaWAN. Long-distance communication is made possible by the physical layer of LoRa, which also defines the system architecture and communication protocol of the network. All devices' power consumption, data rate, and communication frequency are controlled by LoRaWAN. Because of its broad coverage area and low power requirements, LoRaWAN is frequently used in agricultural applications (Davcev *et al*., 2018).

D. Yield monitoring and Mapping:

Grain Inflow in the clean-grain elevator of a combine is continuously measured and recorded by grain yield observers in completely automated systems. The information demanded by yield charts can be attained from yield observers when connected to a GPS receiver. For applicable operation opinions, yield assessments are pivotal. Yet, while assaying a yield chart, it's also important to take into account the soil, terrain, and other environmental rudiments. When used effectively, yield data offers significant feedback for assessing the goods of managed inputs like seed, dressings, toxin emendations, and artistic ways like irrigation and tillage.

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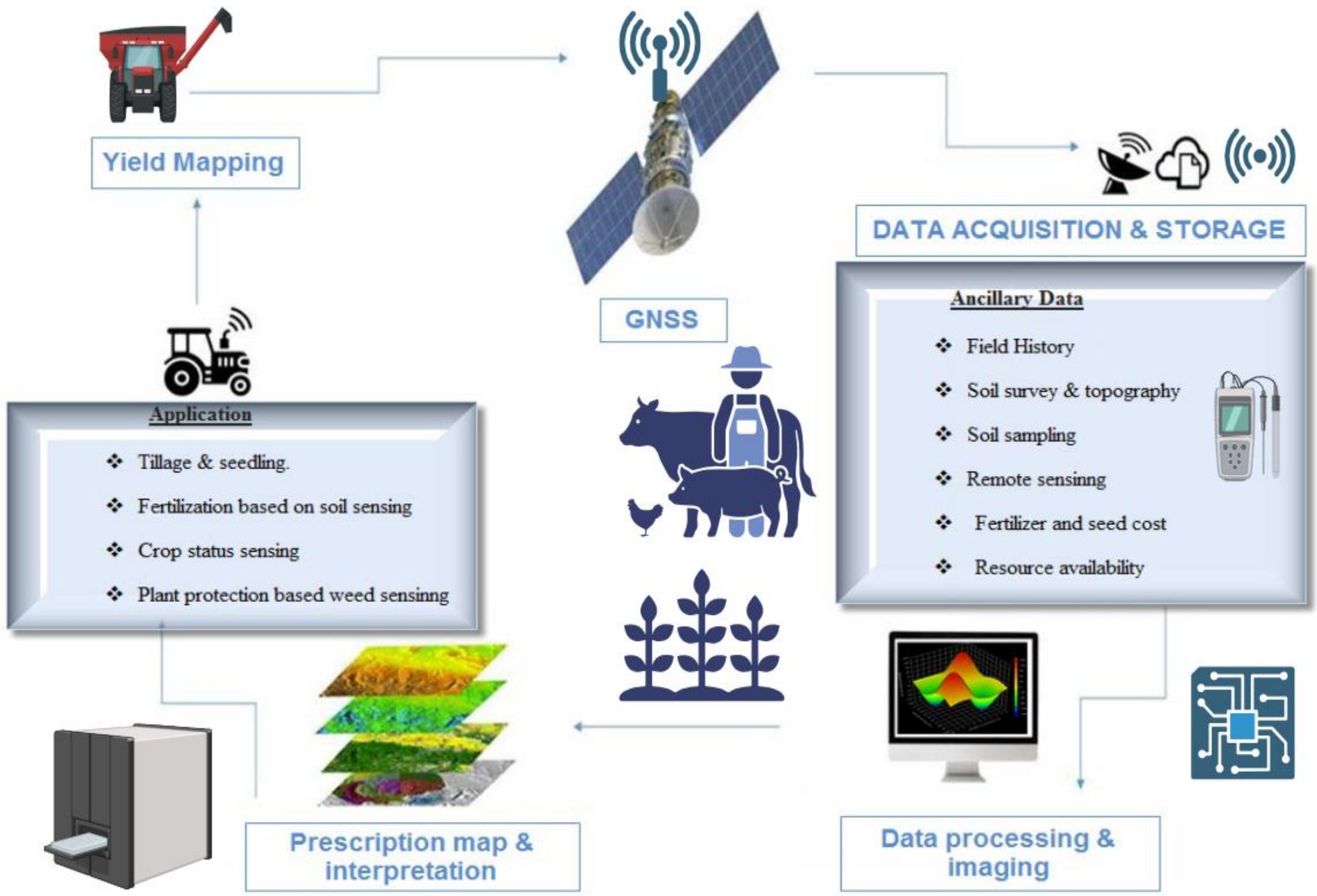

Fig 1: Schematic representation of Precision Agriculture

E . Grid soil sampling and variable rate fertilizer (VRT) application:

A group of soil cores collected at arbitrary spots within the slice region are encouraged to an installation for analysis. Using the results of the soil test, crop experts advise on toxin operation. The same generalities of soil slice are used in grid soil slice; still, slice intensity is increased. The creation of a chart of nutrient conditions is the end of the grid soil slice. A crop's nutrient conditions are interpreted for each soil sample after laboratory analysis of grid soil samples. A computer that's mounted on a variable-rate toxin spreader has the operation chart loaded into it.

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The computer instructs a product-delivery regulator to modify the quantum and/ or type of toxin produced by the operation chart using the operation chart and a GPS receiver.

F. Remote sensing:

The process of collecting data ever is called remote seeing. Data detectors might be simple hand-held widgets, aircraft mounts, or satellite-grounded systems in upstanding photos, factory stress performed from humidity, nutrients, contraction, crop conditions, and other issues with factory health are constantly visible. Near-infrared film land captured by electronic cameras has a strong correlation with healthy factory towels (Xue and Su, 2017). Crop stress can be located and measured using ever tasted photos. As saying these prints can help identify the root cause of specific crop stress factors. The process of collecting data ever is called remote seeing. Data detectors might be simple hand-held widgets, aircraft mounts, or satellite-grounded systems.

1. **Spectral image processing platforms:** Considerations for remote sensing platforms for spectral pictures include airborne, satellite, and unmanned aerial vehicle (UAV) platforms (Rudd *et al*., 2017). Each platform has a unique coverage area, which is based on three elements: (i) Ground Sampling Distance which is calculated using spatial resolution, (ii) the frequency or rate of data collection, and (iii) the typical separation between the object and sensor. Apart from coverage range, several factors (Toth and Jó´zków, 2016).
2. **Satellite-based image processing platforms:** The most stable platforms among all others for remote sensing are thought to be space-borne platforms. Satellites, rockets, and space shuttles are some examples of these platforms. High spatial resolution is one of the benefits of satellite-based remote sensing, making it promising for the extraction of large amounts of time-series data. The images obtained by satellite platforms are stable and free of noise, which is typically introduced during image capture owing to interference (Rudd *et al*., 2017; Zhong *et al*., 2018).
3. **Airborne-based platforms:** Compared to satellite platforms, airborne platforms are more adaptable yet still expensive. The revisit time is flexible and subject to human control. This platform's coverage area is significantly less than satellite-based ones but substantially more than UAV platforms (Rudd *et al*., 2017; Lottes *et al.*, 2017).

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G. Geographic information system (GIS):

To produce charts, geographic information systems (Civilians) use point attributes and position information. The capability to record layers of data, including yields, maps from soil checks, data from remote detectors, crop gibing reports, and measures of soil nutrients, is a crucial point for agrarian Civilians. By integrating and altering data layers to produce an analysis of operation scripts, the Civilians can be used to dissect present and indispensable operations in addition to data storehouse and display.

H. Soil Variation: A spatial variable is soil variation: Together with topography, factors like water-holding capacity or variations in organic matter offer an even more intriguing perspective on a field where a farmer has added inputs or disturbed the soil. The value of individual samples, which represent points, depends on their interpolation. Topographic maps can be used to gather information about topographic variation within fields, but their resolution is frequently insufficient to provide the necessary detail about these variations. For agricultural areas, it is not known how topographic changes affect water use, plant development, soil processes, yield, surface runoff, and groundwater hydrology.

I. Variability of soil water content: The fact that soil water content in a field change over time and space is well known, and these temporal and geographical variations in soil water content patterns may have significant ramifications for precision agriculture in general and water management in particular.

J. Time and Space scales: Understanding time and space scales are necessary for precision agriculture. Because operations take place when they will benefit the crop the greatest, time scales are important. Precision farming requires management that is implemented in a spatial and time context to completely realize its objectives. To accurately record the changes that are occurring organically within an area, it is crucial to take on the issue of monitoring in space and time. Yet it will take the planning and execution of trials in space and time to properly understand the potential influence of precision agriculture principles on environmental quality.

3. Impact of precision farming:

The "Green Revolution" of the 1960s made our nation food self-sufficient. Our farmers gathered nearly 72 million tonnes of wheat in 1999, moving the nation up to second place in the world's wheat production from just over six million tonnes in 1947.worldwide production of wheat. In the past 50 years, food grain production has expanded more than three times, while yields have

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increased more than twice as much. High input application, including increased fertilizer, irrigation, pesticides, higher usage of HYVs, increased cropping intensity, and increased mechanization of agriculture, has made all of this possible (Kirby *et al.*, 2017; Nawandar and Satpute, 2019).

4. Post-green Revolution transformation:

There was a significant contribution from the green revolution, of course. The productivity levels of several important crops, despite agriculture's amazing rise, fall short of expectations. The world's most productive nation has agricultural yield levels that are much higher than the upper limit of what Indian high-yielding varieties is capable of producing, whilst we have not even reached the lowest level of potential productivity for these types.

5. Natural degradation of various resources:

In India, land declination affects about 182 million ha of the country's total geographical area of 28.7 million ha. Of this, 141.33 million ha are caused by water corrosion, 11.50 million ha by wind corrosion, and 12.63 and13.24 million ha are caused, independently, by waterlogging and chemical deterioration (salinization and loss of nutrients). One of the primary causes of this state of Environment is the 2.2 population growth between 1970 and 2000. To turn this green revolution into an evergreen revolution, tilling techniques must be developed in a way that maximizes production from the available land, water, and labour resources without endangering the environment or society.

6. Basic components of precision farming:

The key elements of a precision farming system must manage variability because precision farming fundamentally depends on measurement and comprehension of variability. The components of precision agricultural technology include information-based, decision-focused, and technology-enabled. The components include Remote sensing (RS), geographic information systems (GIS), the global positioning system (GPS), soil testing, yield monitors, and variable rate technology are a few examples of (enabling technologies). A significant amount of spatial and temporal data must be collected, managed, analyzed, and produced to practice precision farming. All of these technologies are available in India, where they can be used by agriculture officers who have received the appropriate training from agricultural training facilities.

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7. Basic steps in precision farming:

We can control the variability that makes precision agriculture viable by providing site-specific agronomic recommendations and using the technology that is currently available to us to comprehend the variability. Each precision farming system must include evaluation as a crucial component.

1. **Assessing variability:**
   In precision farming, determining variability is a crucial first step. Precision agriculture's task is to quantify the variability of these components and processes and identify the specific times and locations when particular combinations are accountable for the spatial and temporal variance in crop production. Precision agriculture has made great use of techniques for evaluating spatial variability, which is easily accessible.
2. **Managing variability:** Farmers must match agronomic inputs to known conditions using management advice once variation has been sufficiently quantified. We can utilize a GPS device to make maintenance simple and cost-effective while enhancing site specificity. The idea of precision soil fertility management necessitates the existence, correct identification, and reliable interpretation of within-field variability, which affects crop yield, crop quality, and the environment. Inputs can therefore be used correctly.
3. **Evaluation:** There are three crucial considerations regarding the evaluation of precision agriculture. Economics, Environment issues, Technology transfer. The most significant finding in the analysis of precision agriculture's financial success is that the use of the data in applications rather than the usage of technology is where the value is found. The use of enabling technologies enhancing production efficiency or adding other types of value can make precision agriculture viable. It can also be made practical by agronomic principles and decision-making guidelines. Although using enabling technologies and agronomic principles in precision agriculture does include managing spatial and temporal variability, the essential word here is managed.

8. Challenges in technology transition:

i. **Cost of Hardware:** To evaluate numerous factors in real-time, PA mostly uses hardware, such as sensors, wireless nodes, drones, spectral imaging sensors, etc. These sensors have several drawbacks, such as expensive deployment, maintenance, and development costs. Certain PA systems are economical. smart irrigation systems that need inexpensive hardware parts and sensors are appropriate for small arable land. Unfortunately, due to their high installation costs, drone-based crop health monitoring systems are only practical for extensive arable land (Saha *et al.*, 2018).

ii. **Weather variations:** One of the main issues that have an impact on the accuracy of the data that sensors acquire is environmental variation. Field-installed sensor nodes are sensitive to changes in the environment, such as rain, temperature swings, changes in wind speed, sunlight, and so on. Because atmospheric disturbances can cause interference in wireless communication channels, communication between wireless nodes and the cloud may be interrupted. Platforms for drones, satellites, and aircraft are all susceptible to changes in the weather.

iii. **Data Management:** Data is continuously produced by the sensors in PA. The massive amounts of data that PA systems produce necessitate adequate resources for data analysis. The majority of the data is produced by real-time data gathered from sensors placed across the fields after a few minutes and spectral images obtained from high-altitude or low-altitude platforms

iv. **Literacy rate:** The adoption rate in PA is significantly influenced by literacy. Farmers in developing nations with high rates of illiteracy raise crops based on their knowledge. They don't use cutting-edge agricultural technologies, which leads to productivity loss. Farmers must receive education to comprehend the technology; otherwise, they must rely on a third party for technical assistance.

v. **Connectivity:** Future 5G networks may be 100 times faster than 4G ones, resulting in substantially faster communication between devices and servers. As 5G networks have a far higher data capacity than conventional networks, these devices which are essential technologies being tested in PA environments can transfer information from remote sensors and drones. In contemporary applications where safe and quick

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data transfer provides real-time data management and support for decision-making, the introduction of new communication networks based on 5G is essential.

vi. **Interoperability:** Due to many digital standards, equipment interoperability is one of the main issues PA has. The adoption of new IoT technologies and their expansion are being slowed down by this lack of interoperability, but it is also impeding the improvement of production efficiency through applications in smart agriculture. To fully realize the promise of effective machine-to-machine communication and data sharing between machines and management information systems, new methodologies and protocols to combine various machine communication standards are necessary (Mekala and Viswanathan, 2019).

9. Global Scenario and comparative Indian roadmap on application & uses of IoT and Wireless Sensor Networks in Precision Agriculture:

In numerous research institutes across India, the study of precision agriculture has already begun. To research the role of remote sensing in mapping the variability about place and time, the Space Application Centre (ISRO), Ahmedabad has begun an experiment in the Central Potato Research Station farm at Jalandhar, Punjab. NABARD in cooperation with the Chennai-based M S Swaminathan Research Foundation village in Tamil Nadu's Dindigul district has been accepted for the application of variable rate input. T conduct precision farming experiments on the institute's farm, the Indian Agricultural Research Institute has developed a plan. Variable rate input application was also started in several cropping systems by the Project Directorate for Cropping Systems Research (PDCSR), Modipuram and Meerut (UP), in partnership with the Central Institute of Agricultural Engineering (CIAE), Bhopal. Indian farmers may be able to reap the benefits of cutting-edge technologies in the next few years with the aid of precision farming without sacrificing the quality of the soil.

In the ever-evolving realm of agriculture, the integration of cutting-edge technologies has become instrumental in enhancing efficiency, productivity, and sustainability. One such technological frontier that has gained significant traction globally is the amalgamation of the Internet of Things (IoT) and Wireless Sensor Networks (WSNs) in precision agriculture. This dynamic duo is reshaping the agricultural landscape by providing farmers with real-time data, actionable insights, and automated control over various aspects of crop cultivation, livestock

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management, and resource utilization. The foundation of this transformative synergy lies in the deployment of wireless sensor networks across agricultural fields. These networks consist of small, smart devices equipped with sensors that gather a plethora of data related to soil conditions, weather patterns, crop health, and more. Leveraging these networks, farmers can monitor and manage their operations remotely, reducing the need for manual intervention and optimizing resource utilization.

One of the primary applications of IoT and WSNs in precision agriculture is precision crop monitoring. Through the deployment of sensors that measure soil moisture, temperature, and nutrient levels, farmers can gain precise insights into the conditions that affect crop growth. This data is then transmitted in real-time to a centralized system accessible through the internet, enabling farmers to make informed decisions about irrigation schedules, fertilizer application, and other critical factors. This not only improves crop yield but also conserves water and minimizes the environmental impact of agricultural practices. In addition to soil monitoring, weather conditions play a pivotal role in agricultural success. IoT devices equipped with weather sensors can provide real-time information on temperature, humidity, wind speed, and precipitation. By integrating this data with advanced analytics, farmers can anticipate weather patterns and plan their activities accordingly. For example, in the face of an impending storm, farmers can take preventive measures to protect their crops, thus mitigating potential losses. This proactive approach to weather-related challenges is revolutionizing the way farmers manage risk and make strategic decisions. Livestock management is another facet of agriculture benefiting from the integration of IoT and WSNs. Smart collars equipped with sensors can monitor the health, location, and behavior of individual animals. This not only allows farmers to detect signs of illness or distress early on but also enables precise tracking of livestock movements. Such insights contribute to efficient feeding strategies, disease prevention, and overall improvement in animal welfare. Additionally, the real-time data generated by these sensors can be analyzed to optimize breeding programs, enhancing the genetic traits of livestock for better productivity.

The global adoption of IoT and WSNs in precision agriculture is witnessing an upswing, driven by the quest for sustainable and resource-efficient farming practices. Developed countries, in particular, are at the forefront of this technological revolution. In the United States, for instance,

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the Midwest's expansive corn and soybean fields are increasingly dotted with smart sensors, drones, and automated machinery. These technologies work in harmony to gather and process data, allowing farmers to make data-driven decisions that optimize yields while minimizing inputs. Europe, too, has embraced precision agriculture with open arms. The European Union's push for sustainable farming practices aligns seamlessly with the capabilities offered by IoT and WSNs. Countries like the Netherlands, known for their progressive approach to agriculture, have implemented precision farming techniques to maximize the productivity of their limited arable land. The integration of sensors and IoT devices has not only increased efficiency but has also contributed to the region's commitment to reducing the environmental impact of agriculture (Ando, 2012). Asia, home to a significant portion of the world's agricultural land, is witnessing a rapid surge in the adoption of precision agriculture technologies. Countries like China and India, grappling with the challenge of feeding large populations, are turning to IoT and WSNs to optimize food production. In China, precision agriculture technologies are being deployed to address concerns such as soil degradation and water scarcity. Similarly, in India, where agriculture is a vital component of the economy, the government is actively promoting the use of IoT devices to empower farmers with real-time information and improve overall agricultural practices. The benefits of IoT and WSNs in precision agriculture extend beyond individual farms to entire agricultural ecosystems. Agricultural supply chains are becoming more interconnected and data-driven, fostering collaboration among farmers, suppliers, and distributors. This interconnectedness allows for better coordination in managing the production, storage, and distribution of agricultural products. For example, by monitoring the condition of crops during transportation using IoT-enabled sensors, stakeholders can ensure that produce reaches its destination in optimal condition, reducing waste and maximizing the economic value of the harvest (Mittal *et al.*, 2018).

Challenges, however, accompany the widespread adoption of IoT and WSNs in precision agriculture. One significant hurdle is the initial cost of implementing these technologies. The deployment of sensors, connectivity infrastructure, and data analytics systems requires a substantial investment, which may pose a barrier for small-scale farmers or those operating in regions with limited resources. Governments and private stakeholders need to collaborate to create incentives and support mechanisms that make these technologies accessible to a broader spectrum of farmers, ensuring that the benefits of precision agriculture are inclusive. The issue of data privacy and security looms large in the era of interconnected agricultural systems. The vast amount of data generated by IoT devices, ranging from soil moisture levels to livestock health records, is a valuable asset. However, safeguarding this data from cyber threats and unauthorized access is imperative. Governments and technology providers must work hand in hand to establish robust cybersecurity frameworks and regulations that protect the interests of farmers and stakeholders involved in precision agriculture. The global scenario of using IoT and Wireless Sensor Networks in precision agriculture is evolving at a rapid pace, reshaping the way we approach food production (Naranjo *et al.*, 2017). The integration of smart technologies offers a holistic solution to the challenges faced by the agricultural sector, from optimizing resource utilization and increasing productivity to promoting sustainable and environmentally friendly practices. As the world grapples with the imperative to feed a growing population while minimizing the ecological footprint of agriculture, the marriage of IoT and WSNs emerges as a beacon of hope, heralding a new era of precision and efficiency in farming practices. It is imperative for governments, industries, and farmers to collaborate, addressing challenges and fostering the widespread adoption of these transformative technologies for a more sustainable and food-secure future (Candiago *et al.*, 2015).

10. Conclusions and Prospects:

Farmers can use crop inputs like fertilizers, insecticides, tillage, and irrigation water more efficiently because of precision agriculture. Increased crop yield and/or quality can be achieved without harming the environment by using inputs more efficiently. Determining the cost-benefits of Precision Agricultural management, however, has proven to be challenging. Several of the technologies currently in use are still in their infancy, making it difficult to determine the cost of goods and services. This could render our existing economic analyses of a certain technology obsolete. Today's production agriculture is surrounded by economic and environmental problems that can be solved through precision agriculture. Although there are still concerns regarding cost-effectiveness and the best uses for the technological instruments we now have, the idea of "doing the right thing in the right place at the right time" has a strong intuitive appeal. The ability and speed with which the information required to direct the new technology may be discovered will ultimately determine how successfully and fast Precision Agriculture will succeed. The strategy that must be used by policymakers to encourage Precision Agriculture at the farm level: 1. Encourage the use of precision farming technology by specific progressive farmers who have the

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necessary ability for risk-taking, as this technology may need capital investment. 2. Determining niche markets for organic farming of particular crops. 3. Urge farmers to implement water accounting procedures on their properties. 4. Encourage the adoption of water-saving methods and micro-level irrigation systems. 5. Promote the use of primary data collected at the field level to analyze the geographical and temporal variability of the input parameters. 6. Develop a strategy for the effective dissemination of technology to farmers. 7. Provide the farmers full technical help so they can create large-scale replicable pilot programs or models. 8. Governmental support for setting procurement prices, cooperative group or self-help group formation. 9. Establishment of export promotion zones with the required infrastructure, such as cold storage, processing, and grading facilities. The integration of IoT and Wireless Sensor Networks (WSNs) in precision agriculture has emerged as a transformative force, revolutionizing traditional farming practices. The deployment of interconnected sensors and devices has enabled farmers to monitor and manage their crops with unprecedented precision, leading to increased efficiency, reduced resource wastage, and improved yields. The real-time data collection and analysis capabilities provided by these technologies empower farmers to make informed decisions, optimizing resource allocation and enhancing overall agricultural productivity. Additionally, the ability to remotely control various aspects of the farming process, such as irrigation and pest control, contributes to sustainable and environmentally friendly farming practices. The holistic approach of IoT and WSNs in precision agriculture not only enhances crop yield but also fosters economic viability and environmental sustainability. The concept of a smart farm ecosystem, where multiple interconnected devices communicate seamlessly, is likely to become more prevalent. This interconnectedness will extend beyond individual farms, creating collaborative networks where data can be shared for the benefit of the entire agricultural community. Collaborative efforts can lead to the development of standardized protocols and interoperable systems, fostering a more unified and efficient agricultural sector. This collaborative approach is especially crucial in addressing global challenges such as food security, where the exchange of data and best practices can lead to more resilient and sustainable agricultural systems worldwide. Security and privacy concerns, however, remain significant challenges that need to be addressed in the future development of IoT and WSNs in precision agriculture. As these systems become more widespread and interconnected, the potential for data breaches and unauthorized access increases. Robust cybersecurity measures and standardized protocols are essential to safeguard sensitive agricultural data and ensure the integrity of the entire ecosystem. Moreover, efforts to bridge the digital divide in rural areas and provide adequate training for farmers to leverage these technologies will be crucial for widespread adoption and success. The integration of IoT and Wireless Sensor Networks has already begun to revolutionize precision agriculture, providing farmers with unprecedented insights and control over their operations. The future holds even greater potential as advancements in AI, machine learning, and collaborative networks promise to further enhance efficiency, sustainability, and productivity in the agricultural sector.

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