Chapter 13

Precision Agriculture and Digital Innovations in Soil Management

Anshu
Department of Soil Science
College of Agriculture
CSKHPKV Palampur,
Himachal Pradesh, India.
anshusharotri97@gmail.com

Suresh Kumar
Department of Soil Science
and Water Management
Dr. Y S Parmar University
of Horticulture and
Forestry Nauni Solan
Himachal Pradesh, India.

Abstract

The application of digital technology represents the beginning of a smarter, more sustainable agriculture industry and the fourth agricultural revolution. Technological advances include data-driven strategies for efficient farming methods and resource management. Precision agriculture is considered an essential aspect of new agricultural management technology, which focuses on increasing productivity by improving input efficiency while minimizing the number of inputs required for farming. Data-driven precision agriculture is a key technology that gives the ability to analyze data in depth to extract vital information and help farmers understand long-standing agricultural practices and make accurate decisions. Detecting variations in crop and soil characteristics to encourage the production of higher-value goods is the first step towards putting precision agriculture into practice. To map spatial variation and prescribe precise applications, a variety of tools are used, including yield monitors, proximate soil sensors, geographic information systems (GIS) hyperspectral imaging based on satellites and unmanned aircraft (UAV) and variable flow systems. Furthermore, the area of cultivated land is not increasing, the groundwater level is decreasing, and soil quality is not improving. Therefore, for sustainable agricultural production, data-driven agriculture using these technologies seems to be the most promising solution to the current problems and in the future. However, the widespread adoption of data-driven precision agriculture still poses some challenges. Therefore, special attention needs to be paid to increasing knowledge and improving access to the latest Big Data applications in precision agriculture to ensure that these advanced agricultural practices deliver expected benefits

Keywords: Precision agriculture, big data technology, GPS, GIS, UAV

I. INTRODUCTION

The key components of the latest agriculture 4.0 sector, which supports precision agriculture and smart agriculture, are data-based management, production based on new tools, sustainability and professionalization. To feed the world's growing population, projections from food and agriculture organizations indicate that agricultural production must increase by 70% by 2050.The use of "Big Data" in agriculture, prescription farming, smart agriculture and sustainable farming with the use of GPS and sensors used in field farming are some of the applications where digitalization has found the need for attention to address these challenges. These practices involve automated farm management activities for long-term improvement and environmental protection. These types of technological advancements are known to help agricultural sectors and their applications range from farming and irrigation operations to plant protection and harvesting systems. Crop failures, soil quality degradation, changing weather conditions, changing irrigation patterns, as well as natural vagaries also require technological solutions that can provide farmers and research scientists with more information to help them make sustainable decisions and also encourage farmers to not solely rely on previous experiences and lessons. Additionally, digital agriculture is said to create highly productive systems that are predictable and responsive to changes, especially those caused by climate change. When it comes to more efficient and effective digital agriculture technologies and processes, precision agriculture is becoming increasingly important. The idea of precision agriculture first emerged in the United States and Europe in the early 1980s and early 1990s, and it has been introduced in India over the past decade to map geographic variation, soil health and monitor productivity, as well as local agricultural development technology solutions. However, the level of knowledge and the availability of financial resources present some obstacles that still need to be overcome in order to significantly close the gap in the implementation of modern agricultural technologies. Small farmers are particularly disadvantaged in this manner since they have limited access to networks, infrastructure, and technologies in remote locations. The availability of electronic government services and the regulatory frameworks governing connectivity and data protection are also lacking in information. Therefore, it's important to solve these issues and concentrate on thorough analysis when using big data and artificial intelligence, especially with regard to precision agriculture.

II. PRECISION AGRICULTURE

Precision agriculture was first introduced by the United States House of Representatives in 1997, and many sources have since described it. It is defined as an integrated information-based and production-based agricultural system that improves overall, long-term and site-specific agricultural production, efficiency, productivity and profitability, and has minimal environmental impact (Tan *et al.*, 2022). It is widely acknowledged that the adoption of precision agriculture is revolutionizing agriculture and has greatly enhanced the cooperation between humans and machines. Through the use of modern information and communication technology, precision agriculture is recognized for redefining agriculture and delivering benefits in terms of profitability, productivity, sustainability, and crop quality, and environmental protection. The use of precision agriculture is also known to help farmers adapt to changing field conditions, crop needs and soil conditions. This smart farming technology is said to be different from conventional farming techniques because it is a long-term strategy based on accurately identifying crop variation and linking spatial and time with ground activities. It essentially focuses on data-driven digital systems and is used to enhance growers 'expertise through the integration of AI and drones, which can also help farmers to achieve " environmental" productivity and growth goals.

III. IMPORTANCE OF PRECISION AGRICULTURE

The abundance of precise measurements that systems using precision agriculture technology or practices collect and use to monitor their operations is perhaps their most important advantage. To monitor agriculture, improve decision-making, create an accessible agricultural register, improve investment and crop protection, and simplify irrigation management, integration of deeper statistics is followed in precision agriculture. Data are systematically available for comparison or evaluation, regardless of scale or location, and multi-layered analysis can provide insight into the complex relationship between soil chemistry and nutrients crop, soil light and yield, water input and drainage inefficiencies. To create farming systems that respond to real-time updates on all aspects of precision farming operations, IoT networks, API integrations, and smart devices are all known to work together, so decisions can be made almost instantly and all the data needed to make those decisions are available at the touch of a button. The adoption of precision agriculture allows farmers to stay proactive and minimize the risks associated with their work by integrating contingency planning, risk assessment and crop protection into the software to provide continuous monitoring changes and threats to soil productivity. For instance the application of variable rate irrigation in precision agriculture involves utilizing information from geospatial data analysis, weather monitoring, and soil moisture sensors to irrigate crops with the appropriate amount of water taking into account consequence of factors like slope and flow that affect the utilization of water absorbed by the ground. This type of agriculture thus promotes a greater appreciation of the diversity and small differences that exist in the landscape by providing the opportunity for a deeper understanding of a particular territory.

IV. COMPONENTS OF PRECISION AGRICULTURE

To create, implement and disseminate precision agriculture, information, technology and management are essential elements described below:

1. Information

It is important to compile several maps of the farm and area that include detailed information on different soil types, groundwater, pest and weed prevalence, geography, environmental pollution school, etc. To use local information at each decision-making stage for different farms, farmers can rely on these geographical proxies.

2. Technology

Farmers can identify nutrient-deficient areas and receive advice for applying integrated management measures for soil quality using remote sensing and geographic information systems (GIS), computer automated analysis, sensors, computers as well as appropriate software, etc

3. Management

An extensive management system is created using all the information collected along with available technology. To integrate, synthesize and process information as well as create computer-simulated agricultural production models that can help farmers conduct agricultural activities at specific locations, user-friendly technologies with users and cost savings have been created.

V. TECHNOLOGIES INVOLVED IN PRECISION AGRICULTURE

Technology is used in precision agriculture in a variety of ways, including the use of automated machines with embedded computers for precision ground positioning devices (GPS receivers), for sensing location, sends data from crop fields to monitoring stations for decision-making and presents results to growers through an app. To increase the efficiency of precision farming systems, several techniques are described below.

1. Big data

It is based on a decision support system that stores data collected at each stage of agricultural production in regional databases and cloud servers, maintains data records, and relates crops to their needs, relevant demand, while also preventing farmers from over-harvesting crops according to expected demand.

2. Remote Sensing

Using images captured by orbiting satellites, manned aircraft, and unmanned aerial vehicles (UAVs), remote sensing techniques rely on machine learning algorithms to remotely analyse physical and chemical properties of soil through aerial monitoring or for fertilization in precision agriculture. It is also a non-invasive and destructive way to study various elements using intensity, spectral and volume data provided by visible and near-visible spectrum sensors.

3. Drones

Unmanned aerial vehicles (UAVs) have a proven track record of high-quality remote viewing capabilities through spectral identification and the combined use of different onboard cameras to determine reflectivity in Different wavelengths for soil mapping as well as production mapping, along with their application even in complex terrains.

4. Wireless Sensors

To collect information about various weather and soil conditions, precision agriculture uses wireless sensors. Information collected through different types of sensors, whether drone-based or camera-integrated, is transmitted to the cloud via a wireless sensor network. The different types of wireless sensors are discussed below:

- **Optical sensors:** These devices use light refraction to obtain data related to color, humidity, temperature, location, height, size, shape and amount of chlorophyll in soil and vegetation. These captured image data are then processed using photometric methods.

- **Electrochemical sensors:** These types of sensors collect data through wires and work by detecting specific ions in the soil. Some of these include voltammetry or amperometry measurement, which determines the change in electrical current to electrochemical interactions through an applied voltage to evaluate pH levels and nutrient content in the soil. Additionally, examples include conductometry, which determines the change in conductivity, impedance measurement, which measures the change in resistance, and potentiometry, which measures the change in membrane potential.

- **Location sensors:** These sensors can accurately determine an object's longitude, latitude and altitude to within a few meters using GPS satellite signals. Their sources furnish geographical data about the object's position. Using GPS satellite signals, they can determine the location of an object within a few meters by calculating its latitude and longitude. They also offer spatial insights into the position of an element.

- **Ground sensor:** The information they monitor closely includes airflow, seasonal precipitation (such as October and November), wind speed, humidity, solar radiation and atmospheric pressure etc.

5. Satellite Imagery

Information about location, farmland, crop health, soil moisture, water consumption, crop yield and crop stress levels is collected by climate observation satellites. For example, satellite data is also confirmed on the ground using mobile sensors such as Green-Seeker.

6. Mapping

Map-based applications are used to monitor agricultural production and nutrient variation across space. Computer programs called geographic information systems (GIS) are often used to create maps that serve as site-specific management guides.

7. Variable Rate Technology

This real-time process is performed by mechanical devices under the control of a computer system, allowing and adjusting the input application almost instantaneously. To apply the correct amount of input at each location, the decision support system sends signals to the applicator at variable rates and gives a prescription for the specific fertilizer or agrochemical to spray up each unit.

8. Artificial Intelligence

Using computer-generated information machines can learn, understand, and respond to events. Machine learning techniques, advanced learning, natural language processing (NLP), swarm intelligence (SI), expert systems, fuzzy computing and computer vision are some of the elements of artificial intelligence. AI (AI) is used to extract knowledge from data. These elements form a structure for making intelligent predictions or choices

VI. DIGITAL INNOVATIONS IN PRECISION AGRICULTURE FOR SOIL MANAGEMENT

Crop selection, soil preparation, seed selection, crop yield determination, fertilizer and fertilizer selection are all influenced by the soil, which is an important factor. The impact of conventional agricultural practices and human activities has had a significant impact on soil quality, which is closely linked to the geographical and climatic conditions of the mined land. To make informed and correct decisions in land management, IOT technologies used in precision agriculture must be applied. The creation of mobile soil sensors has been shown to increase the effectiveness of precision agriculture (Pierce and Nowak, 1999). These sensors provide the ability to monitor soil parameters at a reasonably low cost due to increased measurement density (Sonka *et al.*, 1997). Accuracy and precision have been used to evaluate sensor performance, typically referring to the ability of a sensor to repeat its own measurements at the same time and place as well as the correlation between sensor measurements and real soil properties determined using traditional measurement techniques (Vaughan, 1999). Therefore to determine soil quality different types of sensors are described below:

1. Proximal Sensors

These sensors, when in close proximity or even in contact with the ground, directly or indirectly evaluate ground parameters. The most widely used techniques for close-range ground sensing are electromagnetic induction, resistivity, and reflectometry (Rossel *et al.*, 2011).

Table 1: Proximal sensors used in precision agriculture (Botta *et al*., 2022)

Soil Depth	Ground-penetrating Radar Electromagnetic induction
Soil Structure	Electrical Resistivity
	Magnetic Susceptibility
Soil Composition	X-ray Fluorescence Reflectometry
Water Content	Optical Reflectance
	y-ray Spectroscopy
Soil Compaction	Mechanical Interactions Ion Potentiometry
Mechanical properties	Seismic

2. Electrical and Electromagnetic Sensors

Sensors are used as the most practical method for mobile land mapping due to their fast response time, low cost, and excellent durability. Maps generated by these sensors can show correlations between soil texture, salinity, organic matter, moisture and other soil parameters.

3. Ground Penetrating Radar

Two antennas make up this sensor: a transmitter emits pulses of high-frequency electromagnetic waves, and a receiver monitors the reflected electromagnetic waves as a function of time (Davis and Annan, 2002). According to various studies, it can be used to map soil properties, such as soil texture. and organic matter, soil thickness and depth, and water table (Johnson *et al*., 1982; Truman *et al*., 1988; Doolittle and Collins, 1995; Freeland *et al*., 1998). Additionally, it can be used to detect changes in soil compaction due to the development of ploughed fields.

4. Optical Sensors and Radiation Measurements

A non-invasive way to assess the properties of soil is provided by these sensors. Soil reflectivity is influenced by a variety of factors such as moisture, organic matter, grain size, iron oxides, mineral composition, soluble salts and parent material. The reflection, absorption, or transmission properties of materials reflected from a ground surface in varying wavelengths can be determined by measuring multiple effects with essentially the same sensor response.

5. Mechanical Sensor

A detection device that indicates the resistance of the ground simply by rotating it vertically from a horizontal probe. Following the development of the maps, different ploughing depths are then prescribed for different field areas (Raper and Hall, 2003).

6. Sound and Pneumatic Sensors

The sensor device mentioned above uses a hollow rod with a rough surface and a microphone to capture the sound emitted when the rod comes into contact with the soil. The frequency of the recorded sound is then used to distinguish between different types of soil

7. Electrochemical Sensors

In such systems, the concentration of specific ions (H+, K+, NO3-, etc.) is determined by measuring the voltage (potential difference) between the sensor and reference components of the system with an ion-selective electrode (glass or polymer). membrane) or ion selective field effect transistor (ISFET). These types of sensor systems are used in commercial soil laboratories to measure soil pH and perform standard soil chemistry analyses.

VII. CHALLENGES FOR ADOPTION OF PRECISION AGRICULTURE

Farmers in less developed countries face significant upfront costs when investing in setting up IoT devices for precision agriculture. Government grants can be helpful in developing affordable IoT (controllers and sensors) systems to offset this cost. Data collected and owned by individual owners will be used by precision agriculture technology and remote monitoring. However, due to the increase in cyber-attacks, it is now possible to track people's activities or their unique farming methods, jeopardizing privacy and corrupting data. Additionally, due to the importance of the framework, a single failure in the system will not bring down the entire network. Therefore, the design must be flexible enough to allow the addition of additional sensors without requiring significant hardware modifications. There is also a need for government support and a legal framework for digitalization, including the availability of e-government services as well as a legal framework for connectivity and data protection.

VIII. CONCLUSION

The unexplored potential of information and communication technology has not been fully explored. IoT technology is used to describe the meticulous application of agricultural inputs into precision agriculture, which has advantages over traditional agriculture. Farmers in this type of industrial agriculture can obtain information about their fields more rapidly, allowing them to create customized plans for their area and year. Precision agriculture technology also helps evaluate soil conditions and other related data, helping to improve operational efficiency. IoT devices use sensors to record data, providing real-time information about crop conditions. This allows farmers to monitor changes in specific locations for precision farming and respond accordingly.

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