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A review on smart farming agriculture

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Abstract
Smart farming encourages precision agriculture with the use of cutting-edge, sophisticated technology and allow farmers to remotely monitor the plants. Harvesting and crop yields are two agricultural activities that benefit from smart farming because the farming labor is now more productive due to the automation of sensors and machines. A technological revolution in agriculture results from the technologies' conversion of conventional farming techniques into automated machinery. To determine the demands of farmers and choose appropriate solutions for their issues, modern ICT technologies including the Internet of Things, GPS (Global Positioning Systems), sensors, robotics, drones, precision equipment, actuators, and data analytics are used. As a result, smart agriculture is defined as precision agriculture advanced by modernization and clever ways to gather different farm activity data that are then remotely managed and supported by appropriate real-time farm maintenance alternatives.

Keywords: Smart farming, smart greenhouse technology, precision farming and nutrient-sensitive agriculture

Introduction
Since ancient time, traditional agricultural practices have served as the foundation of agriculture, relying on physical labor, simple tools, and time-honored skills. While these techniques have helped to sustain communities and provide livelihoods for millions of farmers around the world, they also confront several issues that require modernization. Traditional farming operations frequently rely largely on manual labor for planting, weeding, and harvesting. With the global population growing and the rural workforce declining due to migration to cities, the supply of trained farm labor is reducing.

Without access to contemporary agricultural techniques, tools, and data, traditional farmers could find it difficult to maximize crop yields, efficiently control pests and illnesses, and adjust to shifting environmental circumstances. They frequently entail the wasteful use of natural resources including fertilizer, water, and land. Modernization can help strengthen market access by enabling farmers to produce high-quality, marketable crops and connect with buyers through online platforms, supply chains, and climate-smart agriculture, which incorporates technologies like precision farming, drought-resistant crop varieties, and weather forecasting tools to mitigate climate risks and enhance resilience in farming systems. Modernization also reduces reliance on manual labor and improves the efficiency of agricultural operations.

Some the modern methods are included in this chapter *i.e.*, Nutrient-sensitive agriculture it revolutionizes the way we approach soil fertility and plant nutrition. Smart greenhouse technology represents use of advanced sensors, automation systems, and data analytics, smart greenhouses enable growers to create optimized microclimates tailored to specific crop requirements. Smart farming encompasses a holistic approach to agricultural management, integrating data-driven decision-making, connectivity, and automation across the entire farming operation. Precision farming represents the pinnacle of agricultural innovation, combining the principles of data science, remote sensing, and geospatial analysis to optimize field-level management practices.

Smart farming

Traditional agricultural era 1.0 in which old agricultural methods were associated with the production of food on cultivated lands for human survival and animal breeding (Tekinerdogan *et al*., 2018) [25]. Shovels and sickles were among the basic implements used in farming. Steam engines were among the new machinery types that emerged in the agricultural sectors during the 19th century. The agricultural age 2.0 was ushered in by farmers widespread use of agricultural machinery and an abundance of chemicals, which also increased farms and farmers overall productivity and efficacy. In the agricultural era 3.0 emerged during the 20th Century, Robotic techniques, programed agricultural machinery, and other technologies were used (Dhanaraju *et al*., 2022) [9].

Smart farming encourages precision agriculture with the use of cutting-edge, sophisticated technology and allow farmers to remotely monitor the plants. Harvesting and crop yields are two agricultural activities that benefit from smart farming because the farming labor is now more productive due to the automation of sensors and machines (O'grady 2017) [19]. A technological revolution in agriculture results from the technologies' conversion of conventional farming techniques into automated machinery (Quy *et al.,* 2022) [21]. To determine the demands of farmers and choose appropriate solutions for their issues, modern ICT technologies including the Internet of Things, GPS (Global Positioning Systems), sensors, robotics, drones, precision equipment, actuators, and data analytics are used. As a result, smart agriculture is defined as precision agriculture advanced by modernization and clever ways to gather different farm activity data that are then remotely managed and supported by appropriate real-time farm maintenance alternatives.

Benefits of smart farming (Subhan *et al*., 2023) [24]

- Smart farming promotes sustainable farming practices by minimizing the use of resources such as water, fertilizers, and pesticides
- By optimizing inputs and reducing waste, smart farming can lead to significant cost savings for farmers.
- Smart farming can help farmers improve the quality of their crops by providing insights into crop health and identifying potential issues early on
- Smart farming provides farmers with real-time data and insights into their farming practices.

Challenges in smart farming (Debhangshi *et al.,* 2023)

- Investing in technology such as sensors, drones, and IoT devices can be expensive, particularly for small farmers who may not have the financial resources to invest in this technology. In addition to the initial cost of the technology, there may also be ongoing maintenance and repair costs to consider.
- Farmers need to be trained on how to use the technology, collect and analyze data, and interpret insights. This can be a time-consuming process and may require farmers to take time away from their daily farming activities.
- Farmers may need to invest in infrastructure upgrades to support the use of smart farming technology.
- Smart farming generates a large amount of data, and farmers need to have the necessary tools and skills to manage and analyze this data effectively.
- The use of technology in farming raises concerns about data security and privacy. Farmers need to ensure that their data is protected from unauthorized access and that they are complying with relevant data privacy regulations.

Tools of smart farming

Remote Sensing

The practice of detecting and monitoring an area's physical features by measuring its reflected and emitted radiation at a distance (usually via satellites or aircraft) is known as remote sensing. It is helpful for mapping soil, determining the appropriateness of a piece of land, assessing crop conditions, and managing irrigation.

Geographic Information System (GIS) &Global Positioning System (GPS)

A Geographic Information System (GIS) is an integrated system of computer hardware, software, protocols, and human analysts that facilitates the collection, management, modification, analysis, modeling, and display of geographically referenced data. We may ascertain both horizontal and vertical displacement at the same time and location because GPS readings are three-dimensional (Segall and Davis 1997) [22].

Kisan Drone

They are more formally known as unmanned aerial vehicles (UAVs) weigh between two and twenty kilograms. They can be remotely controlled or can fly on their own thanks to software-controlled flight plans in their embedded systems, which combine GPS and onboard sensors (Mourik, 2016) [18]. Drone operations encompass a range of tasks, such as soil analysis, planting, spraying, irrigation, crop health monitoring, and crop inspection (Mohammed, 2021) [17]. With a multispectral camera built into a drone, farmers may map the vegetation index (VI), reveal important crop health information, identify abnormalities, and allocate resources more effectively.

Automated Tractor or Driverless Tractor

For tillage and other agricultural operations, a driverless tractor is an autonomous farm vehicle that delivers high tractive effort (or torque) at low speeds. These tractors can be operated remotely. As technology like GPS, light detecting tools, vision systems, and more improve, smart tractors will become more and more independent in their agricultural applications. It features GPS-based auto-steer technology that helps the tractor go in a straight path. The sensors on the tractors will be able to gather information about the state of the soil, crop upkeep for crops that have already been planted, and harvest information both before and after cultivation.

IoT -based Agricultural Sensor

Internet of Things (IoT) is defined as the connection of network, hardware devices, software, and most importantly human beings exchanging data for specific purposes. Sensors used to monitor environmental conditions such as soil nutrients, air temperature, and humidity, defining the best time and location for planting, irrigation, fertilizer application, and so on, resulting in more efficient use of agricultural land and resources, improved output, and higher quality production (Wolfert *et al.,* 2014) [28]. IoT-powered sensors can obtain accurate real-time information on greenhouse conditions and this IoT-smart services and industry could account for a 3 percent carbon reduction by increasing efficiency. With IoT sensors, farmers can collect a plethora of metrics on every aspect of the field microclimate and ecosystem, including lighting, temperature, soil condition, humidity, CO_2 levels, and pest infections (Chalimov, 2022) [2].

Use of Artificial Intelligence & Data Analytics AI, or Artificial Intelligence, refers to the development of computer systems that can perform tasks that typically require human intelligence. These tasks include learning from experience (machine learning), understanding natural language, recognizing patterns, and problem-solving. AI-powered solutions will not only help farmers improve efficiencies, but they will also increase crop quantity and quality while also ensuring a faster time to market (Lobell *et al.*, 1980) [16].

Smart green house

Because of the changing climate the crop growth, yield are being affected. So, in order to maintaian this Controlled Environment Agriculture (CEA) and smart greenhouses are key solutions to overcome these challenges as they can optimize crop production by manipulating the indoor climate while mitigating the climate change effect (Ouammi *et al.*, 2020) [20]. The term Controlled Environment Agriculture (CEA) refers to the growth and development of plants in a fully controlled environment with the use of modern horticultural techniques and technological advances resulting in achieving higher yields and improving product quality (Gomez *et al.*, 2019) [11] CEA is a broader term that includes greenhouses, rooftop green-houses, growth chambers, plant factories as well as vertical farms. On the other hand, greenhouses are structures with transparent materials in which the microclimatic parameters are also modified to enhance plant growth and productivity and ensure all-year-round production. Currently, greenhouse crop production is facing increased demand for automation and robotics. In fact, although the initial reason for using greenhouses was to grow crops in controlled environments, today the integration of smart systems can reduce reliance on labor and increase profit-ability while ensuring efficiency and sustainability. Indeed, smart greenhouse solutions incorporating advanced sensor technologies have become widely used for crop growth (Karanisa *et al.*, 2022) [15].

Advantages of a smart green house

- Smart greenhouses provide real-time information across the set-up so that one can monitor the climatic conditions. Motion sensors are used within the greenhouse set-up that helps detect if any doors or other openings remain open.
- A smart greenhouse also monitors the moisture content and salinity in the soil to stay on top of crop conditions.
- Smart greenhouses generate data based on machine learning that can aid the farmers to decide the chemicals that need to be used, in the right amount and time. This prevents the excessive use of chemicals making the agri-commodities produced safer and healthier.
- Smart greenhouses are under surveillance as they are equipped with CCTVs, smart door locks, and other sensors. These security devices are connected to alarms that get activated to detect suspicious activity within the smart greenhouse.

Challenges in a smart green house (Jacob, 2015) [14]

- As several smart devices are used Setting up smart greenhouses can be a costly affair.
- Require skilled persons.
- Pollination becomes difficult as the natural carriers of pollen grains are absent in a smart greenhouse.
- Farmers need proper training and knowledge about smart greenhouses in order to execute the cultivation properly.
- More power supply is needed.

Components of a green house

A smart greenhouse system comprises several interconnected components that work together to create an optimal environment for plant growth while maximizing resource efficiency and sustainability.

Sensing and Monitoring Technologies

Temperature Sensors: These sensors monitor the ambient temperature inside the greenhouse. They ensure that the temperature remains within the optimal range for plant growth, which varies depending on the crop.

Humidity Sensors: Humidity sensors measure the moisture content in the air. Maintaining appropriate humidity levels is crucial for preventing issues like mold growth and ensuring proper plant transpiration.

Light Sensors: Light sensors gauge the intensity and duration of light exposure. They help optimize natural light utilization and assist in controlling artificial lighting systems, ensuring that plants receive adequate light for photosynthesis.

Soil Moisture Sensors: These sensors monitor the moisture level in the soil. They enable precise irrigation management by triggering watering systems only when necessary, thus preventing both under and over-watering.

Carbon Dioxide (CO_2) Sensors: CO_2 sensors measure the concentration of carbon dioxide in the air. Monitoring CO_2 levels is essential for optimizing photosynthesis rates and maximizing crop productivity.

Automated Control Systems

Actuators: Actuators are devices that translate control signals from the automation system into physical actions. Examples include motors for adjusting ventilation systems, valves for controlling irrigation, and shades for managing light exposure.
Controllers: Controllers are the brains of the automation system. They receive data from sensors, analyze it, and send commands to actuators to adjust environmental conditions accordingly. Controllers can be programmed to maintain specific parameters such as temperature, humidity, and light intensity.

Data Analytics and Decision Support Systems

Data Collection and Storage: Smart greenhouses generate vast amounts of data from sensors and other sources. Data analytics systems collect, process, and store this data for analysis.
Analytics Algorithms: Advanced analytics algorithms analyze collected data to identify patterns, trends, and anomalies. These insights help optimize greenhouse operations, such as adjusting climate control parameters or detecting early signs of plant stress.
Decision Support Tools: Decision support tools provide actionable recommendations based on data analysis. They assist growers in making informed decisions regarding irrigation scheduling, nutrient management, pest control, and other aspects of crop cultivation.

Renewable Energy Integration

Solar Panels: Solar panels convert sunlight into electricity, providing a renewable energy source to power greenhouse operations. They can be integrated into the greenhouse structure or installed in adjacent areas.

Wind Turbines: In regions with sufficient wind resources, wind turbines can supplement solar power generation, further reducing reliance on grid electricity.

Energy Storage Systems: Battery storage systems store excess energy generated by renewable sources for use during periods of low sunlight or wind. They ensure continuous power supply to critical greenhouse systems, even in the absence of renewable energy generation.

Communication and Connectivity

Internet of Things (IoT): IoT technology enables seamless communication and connectivity between various components of the smart greenhouse system. It allows for remote monitoring and control, real-time data transmission and integration with other smart devices and platforms.

Wireless Communication Protocols: Wireless protocols such as Wi-Fi, Bluetooth, Zigbee, and LoRaWAN facilitate communication between sensors, actuators, controllers, and data analytics systems within the greenhouse network.

Cloud Connectivity: Cloud-based platforms enable centralized data storage, analysis, and management. They also support remote access to greenhouse systems from anywhere with an internet connection, allowing growers to monitor and control operations using mobile devices or computers.

User Interface and Visualization Tools

Dashboard Interfaces: User-friendly dashboard interfaces provide growers with real-time insights into greenhouse conditions and performance metrics. They display sensor readings, control settings, alerts, and analytics results in a visually intuitive format.

Mobile Applications: Mobile applications allow growers to remotely monitor and manage greenhouse operations from smartphones or tablets. They offer convenience and flexibility, enabling growers to stay informed and responsive even when they are away from the greenhouse.

Visualization Tools: Visualization tools such as charts, graphs and heatmaps help growers interpret data trends and make informed decisions. They provide visual representations of environmental parameters, crop health indicators, and resource utilization metrics.

Security and Data Privacy Measures

Encryption: Data encryption techniques ensure the security and privacy of sensitive information transmitted between greenhouse devices and cloud servers. Encryption prevents unauthorized access and data breaches.

Authentication and Access Control: Authentication mechanisms verify the identity of users and devices accessing the greenhouse system. Access control policies restrict privileges based on user roles and permissions, preventing unauthorized actions.

Data Privacy Policies: Clear data privacy policies and compliance with regulations such as GDPR (General Data Protection Regulation) ensure that grower and crop data is handled responsibly and ethically. Transparent data practices build trust with stakeholders and safeguard against privacy violations.

Presicion farming

The science of enhancing agricultural yields and supporting management choices with advanced sensor and analysis technologies is known as precision agriculture, or PA. The world has embraced PA, a novel idea that promises to boost output, cut down on labor costs, and guarantee efficient management of irrigation and fertilizer systems. It makes use of a lot of data and information to enhance crop quality, yields, and the utilization of agricultural resources. Although a clear definition of what technologies are included in PA is still required technologies can be classified into the following: data collection technologies, including global satellite positioning (Coble *et al.*, 2018) [5] remote sensing technologies (Vasisht *et al.*, 2017] [27], soil sampling and mapping, data processing and decision-making technologies and sensor networks (Das *et al.*, 2019) [6] and application technologies, including variable rate technologies (VRT) (Davis, 1989) [7]. The goal of PA, an agricultural innovation and optimized field level management method, is to increase resource production on agricultural fields. It needs an enormous amount of high spatial resolution data regarding the health or status of the crop during the growth season. Utilizing data from various sources, precision agriculture aims to boost agricultural yields and make crop management techniques, such as pesticide application, irrigation control, and fertilizer inputs, more economically viable. Multispectral data are typically used in satellite- and UAV-based precision agricultural applications of remote sensing to estimate high-spatial resolution information about soil characteristics, plant health, and crop yields (Hrynevych *et al*., 2022) [13].

Benefits of Precision Farming

- Minimizing the cost of materials and resources, like water, seeds, fuel, etc.
- Maintaining soil health by reducing the number of pesticides.
- Lowering agriculture’s dependence on weather conditions;
- Maximum realization of the genetic potential of the produced crops.

Precision farming is enabled by a suite of advanced technologies that facilitate data acquisition, analysis, and application. Global Positioning System (GPS) technology serves as the backbone of precision farming, providing accurate geospatial information for mapping and navigation. Remote sensing technologies, including satellite imagery, aerial drones, and ground-based sensors, offer valuable insights into crop health, soil conditions, and environmental parameters. Geographic Information Systems (GIS) software enables the integration and visualization of spatial data, empowering farmers to make informed decisions based on spatially explicit information. Additionally, precision farming relies on precision agriculture machinery equipped with GPS-guided steering systems and variable rate application technology, allowing for precise placement of inputs such as seed, fertilizer, and pesticides. Variable Rate Application (VRA) technology is a key component of precision farming that enables farmers to apply inputs such as fertilizers, pesticides, and seeds at variable rates across a field based on spatial variability in soil properties, crop requirements, and other factors.

Site-Specific Crop Management (SSCM): It is an agricultural management concept based on monitoring, counting, and reacting to crop variability between fields or within one area.

Most current SSCM methods use accurate global positioning combined with site-specific measurements to quantify spatial changing field conditions. They are field data collection (such as pest presence) and remote sensing data (such as from satellites). EOSDA Crop Monitoring allows growers to use management zones in precision agriculture effectively. It can identify problem areas in a field with various possible pathogens: pests, fungus, fertilizer misuse, weeds, lack of moisture, etc. Once identifying a site with deviations, the farmer can send a scout to make a report based on the data collected during the inspection. VRT technology allows farmers to tailor application rates to match the specific needs of different zones within the field. By applying inputs at variable rates, farmers can optimize resource use efficiency, minimize input wastage, and maximize crop yields (Thakur *et al*., 2019) [26].

Challenges in Precision Farming

- Lack of awareness among farmers
- Require high initial cost, maintenance
- Complex and require specialized knowledge and skills to implement and operate effectively.
- Protecting the privacy and security of the data is paramount to prevent unauthorized access, data breaches, and misuse (Gupta *et al*., 2020) [12].

Nutri sensitive agriculture

Nutrition-sensitive agriculture is a food-based approach to agricultural development that puts nutritionally rich foods, dietary diversity, and food fortification at the heart of overcoming malnutrition and micronutrient deficiencies. The overall objective of nutrition-sensitive agriculture is to make the global food system better equipped to produce good nutritional outcomes. Nutrition-sensitive agriculture also means educating families about nutrition so they can produce, purchase, prepare and consume healthy foods. Many traditional crops and varieties contain high levels of micronutrients, and screening of germplasm collections for nutritionally relevant traits shows that there is considerable genetic variability in important food crops.

How can we improve nutrition rich foods

Enhancing Soil Fertility and Promoting Nutrient Cycling

- Plants require three factors for growth and reproduction: light, water, and nutrients. The third of these factors, managing crops to provide an optimum nutrient supply, is where some of the major differences among farming systems occurs. Plant nutrients are chemical elements that are mostly absorbed by plant roots as inorganic chemicals dissolved in water. There are at least 16 essential chemical elements for plant growth. The “ideal” fertile soil has high nutrient concentrations in the soil solution when crop growth rates are high and a large storage capacity to retain nutrients when crop needs are low or there is no growing crop. Nutrient pools in the soil include organic matter, soil microorganisms, soil minerals, cation exchange, surface adsorption Soil fertility can be maintained when nutrients are efficiently recycled through the soil food web and soil-plant-animal system. The cycles include carbon cycle, nitrogen cycle, phosphorous cycle.

Crop Rotations

- Crop rotation increases soil biodiversity and nutrient cycling capacity by supplying different residue types and food sources, reduces the buildup and carryover of soil-borne disease organisms and insect pests (breaks disease and pest cycles), and can help create favorable growing conditions for healthy, well-developed crop root systems. Differences in plant rooting patterns, including root density and root branching at different soil depths, also results in more efficient extraction of nutrients from all soil layers when a series of different crops is grown. Crop rotation can also be done using crop coves and green manures.

Soil & Water Conservation Practices

- Soil erosion removes topsoil, which is the richest layer of soil in both organic matter and nutrient value. Implementing soil and water conservation measures that restrict runoff and erosion minimizes nutrient losses and sustains soil productivity. Tillage breaks down soil aggregates and also increases soil aeration, which accelerates organic matter decomposition. Drainage improvements on poorly drained soils reduce runoff, erosion, and soil compaction. Improving aeration in the plant-root zone also promotes healthy root growth.

Compost & other Soil Amendments

- Composting is a decomposition process similar to the natural organic matter breakdown that occurs in soil. Proper composting conserves volatile and soluble N, and other mobile nutrients in waste products, by incorporating them into organic forms where they are more stable and less readily lost.
- Inorganic byproducts also can be recycled through the soil and supply plant nutrients. Available materials vary by region, but wood ash, rock dust from quarries, gypsum from scrubbers in power plants burning high-sulfur coal, and waste lime from water treatment plants are among the waste. Maintain the soil Ph is also very important because high or low pH. Soil cause unavailability of some minerals to the plant and can cause physiological disorder so soil amending should be followed.

Fertilizer Applications

- Many materials can be applied to soil as sources of plant nutrients, but the term “fertilizer” is often used to refer to relatively soluble nutrient sources with a high analysis or concentration. Commercially available fertilizers supply essential elements in a variety of chemical forms, but many are relatively simple inorganic salts.

Mixed Crop & Livestock

- Farms with both crops and livestock have the potential to recycle a large portion of the nutrients used by crops back to the soil, because about 75% or more of the NPK consumed in animal feed is excreted in manure or urine. Depending upon the balance between crop and livestock enterprises, whole-farm nutrient budgets on mixed farms include different amounts of nutrient losses in milk, meat, or eggs, and different levels of nutrient inputs from purchased feed and fertilizer. (https://conservancy.umn.edu/bitstream/handle/11299/197962/fruit-vegetable-nutrient-cycling-soil-fertility.pdf?sequence=1&isAllowed=y)

Soil Testing

- Soil testing is the foundation of precision nutrient management. It involves analyzing soil samples to determine nutrient levels, pH, organic matter content, and other relevant soil properties. Soil testing provides valuable information to develop tailored nutrient management plans for each field.

Bio-fortification

- Bio-fortification" or "biological fortification" explains nutritionally enhanced food crops with higher bioavailability to the human which can be done by adopting proper agronomic practices. Conventional breeding methods, transgenic approaches, many varieties have been developed by using biofortification which include golden rice, anthocyanin rich vegetables, high zinc and iron High Iron, High Zinc varieties.
- VRA, Remote sensing, Data Integration and Decision Support Systems also helps in adjustments of fertilizer dose, placement, timing, identifying pest and diseases.

Conclusion

In conclusion, the chapter on smart farming, smart greenhouses, precision agriculture, and nutrient-sensitive agriculture explores the intersection of cutting-edge technologies and innovative practices that are reshaping the agricultural landscape. From the adoption of precision technologies such as GPS, remote sensing, and data analytics to the implementation of smart greenhouse systems and nutrient-sensitive farming practices, the chapter highlights the diverse range of tools and techniques available to modern farmers. These technologies empower farmers to make data-driven decisions, optimize resource use, enhance productivity, and promote environmental sustainability in agricultural production. While the chapter acknowledges the numerous benefits of these approaches, it also recognizes the challenges and barriers to adoption that must be addressed. High initial investment costs, technical complexity, data management issues, and regulatory constraints are among the challenges that farmers and stakeholders may encounter in implementing smart farming and precision agriculture practices. By embracing the principles of smart farming, smart greenhouses, precision agriculture, and nutrient-sensitive agriculture, farmers can build resilient, efficient, and sustainable agricultural systems that ensure food security, protect natural resources, and promote economic prosperity for future generations.

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