Integrating Precision Agriculture Technology for Increasing Yields of crops: An Innovative Farming System

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Abstract

Precision agriculture is a transformative approach to enhancing crop yields and improving sustainability. This study explores integrating precision agriculture technologies, including remote sensing, soil sensors, and predictive analytics, into modern farming systems to address productivity challenges. The geographical information system (GIS) and global positioning system (GPS) are most important for advanced agriculture practice, enabling site-specific management of inputs such as water, fertilizer, and pesticide. Demographic data and satellite navigation technologies are essential in multifaceted procedures in agricultural research. It also minimizes environmental waste while maximizing crop production. The key innovations include using drones for aerial monitoring, real-time soil moisture analysis for irrigation scheduling, and data-driving insights for optimizing planting density and nutrient management. This chapter concludes that precision agriculture technology enhances crop yields and supports sustainable agriculture practices by reducing input costs and environmental footprints.

Keywords: Agriculture, GIS, GPS, Soil health, Crop, Technology, Management

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Introduction

The global population is expected to grow to 9.2 billion people by 2050. Thus, rising demands for food, water, and energy would probably put immense pressure on ecosystems, soil, and water (Si et al., 2024). Precision agriculture is an innovative crop management technology that intends to give specific crop inputs to precise small-farmer units within large-scale commercial farmers through technology assimilation with standard practices The term precision agriculture refers to a technology-based system that seeks to tailor agricultural practices according to variation within farms to conserve resources better, maximize profits, and increase the sustainability of the farm (Mezouari et al., 2022). Precision agriculture is a management technique that uses information and communication technologies to point out spatial and temporal differences in farming. It also calls for a creative strategy for the appropriate consumption of agricultural produce. The previously mentioned strategy can help increase yields to decrease costs. Moreover, fertilizers and chemicals are used in certain areas, thus avoiding polluting the surface and groundwater sources (Xie et al., 2023). Precision Autoclaved Aerated Concrete will raise cost efficiency and offer great environmental benefits.

This chapter addresses the role of climate change on agriculture by increasing water demand, decreasing crop productivity, and limiting water supply in the irrigation sector (Alam, 2023). Such facts support the theoretical discussion of emergent technologies in various forms of organizations and their evaluation of environmental, economic, and social impacts. They emphasize the importance of developing sustainable agriculture in today's emerging world. Past uses of the term have involved crop yield, cultivated acreage, and the preservation of biotic homogeny within ecosystems (Abdullahi et al., 2024).

The application of Precision Agricultural Technologies (PATs) in Precision Agriculture (PA) can markedly diminish greenhouse gas emissions there are certain strategies associated with the planning and management of tillage: (i) The reduction of tillage promotes improvements in the compaction and organic carbon of the soil and decreases nitrogen fertilizer use. (ii) Reducing fuel use through less tractor working time; (iii) Reducing inputs used. Regarding these challenges, modern precision agriculture practices, which include the Normalized

Difference Vegetation Index and Remotely Piloted Aircraft Systems (RPAS) or Unmanned Aerial Vehicles (UAV), make useful solutions (Kaushik et al., 2021). The MEDSS for specialized farm management will help secure the highest per unit yield while minimizing resource utilization by applying Precision Agriculture for variability measurement within and between field levels. This chapter aims to increase the current level of knowledge regarding the impacts of precision agriculture applying the UAV / RPAS and Normalized Difference Vegetation Index as well as opportunities for the agricultural sector in the present and the future (Yang et al., 2024).

2. Key Features of Precision Agriculture Technology

The main features of Precision Agriculture Technology are shown in Figure 1, which illustrates different related technology which creates better agricultural methods. Geographic Information Systems (GIS) can be extremely useful for terrestrial features mapping and analysis, which helps farmers to coordinate crop management as well as resources.

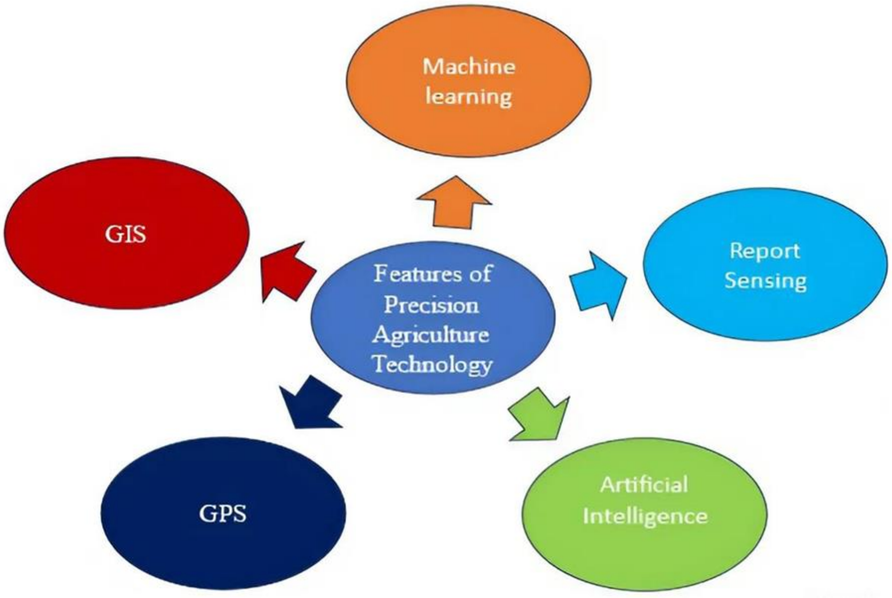

Fig. 1: Precision Agriculture Technology features (Retrieved from word)

Global Positioning Systems (GPS) provide accurate information of location, which enables farmers to map fields and guide agricultural equipment to apply resources such as water, fertilizers, and pesticides more precisely. Machine Learning uses algorithms to examine large data sets, enabling predictions on crop performance and input optimization, leading to improved yields and less waste.

2. 1. Remote Sensing

Understanding an object can occur without touching it a process known as remote sensing. In the context of remote sensing, information is transmitted in the form of electromagnetic waves, which travel through a vacuum at the speed of light across a given spectrum (Shamshiri et al., 2022). Data coming from instruments that work in visible light, near-infrared, short-wave infrared, thermal infrared, and microwave ranges are included in the classes of remotely sensed data. Remote sensing as a term generally describes a variety of methods that use satellite and other space-borne instruments combined with ground-based measurements to increase the precision. Furthermore, it has been used for the past twenty years in precision agriculture in the determination of crop health conditions (Erazo-Mesa et al., 2022). Remote sensing is a method of assessing the condition of the Earth and environment using signals that are emitted or reflected without direct contact. These cameras are specialized, and the images captured are for analyzing the different characteristics of a given area. Different structures are used to mount these cameras; the targets of interest are recorded in these structures (Arthur et al., 2024).

Remote Sensing is based on the principle that the earth's surface features be assessed from an advanced distance using electromagnetic energy. While vegetation, bare soil, water, and similar objects react differently to these wavelengths, it is possible to differentiate by these ranges. The domains of classifications in remote sensing data are, for the most part, passive and active (Kowalska & Ashraf, 2023). Remote sensing employs kinetic energy only from solar radiation without the use of power from another form of energy When the sun is favoring the earth and light is used source internally within the set activity this is happening. In this arrangement, the sensor releases energy towards the subject in question under investigation. The component describes and evaluates the target in the reflected radiation emitted (Cheng et al., 2024).

The weed information is easily detected by satellite or UAV sensors so that the determination and delineation of weeds are done with ease in fields (Tziolas et al., 2023). Acquisition of integrated data remotely is vital, and thus remote sensing technology plays a significant role. Data sensors may include those carried or held handheld, installed onboard the aircraft, or those from orbiting satellites. Information about the state of crops can be gathered through data that is collected through remote sensing (Shrestha & Wei, 2024).

2.2 Structure of GIS and GPS

Syndicated Geographic Information Systems (GIS) use information technology to obtain feature details and geographic location thus developing an informational map. The GIS hardware is composed of a CPU essential in capturing and processing images to produce informational layers, such as SM, nutrients, and yield (Zhao et al., 2023) .

2. 3. Artificial Intelligence and Machine Learning

The two primary domains of smart farming AI applications are used as follows: Precision agriculture works with sensors, drones, and satellites to determine crop conditions and associated environmental factors as well as soil quality (Akbari et al., 2024). Given the current and future trends affecting population growth and climate change affecting the agriculture business, the use of artificial intelligence in farming practices provides a unique solution to the current conventional methods of farming by replacing time-consuming processes, inefficiency, and vulnerability to disruptions in the agricultural business around the world (Kathole et al., 2024) . It allows farmers to apply water for irrigation, fertilizers, and pesticides, and the time and the place which is least disruptive to the environment. Presently, AI has been gradually incorporated into precision agriculture over the years. AI has been used in research to help assess crop status and needs, diseases and threats, as well as opportunities and risks by analyzing large amounts of data from satellites and sensors with image recognition and predictive analytics. Artificial intelligence means the utilization of intelligent aids and robots while machine learning is the application of machines that self-train (Majumdar et al., 2023). On the other hand, the term DL stands for learning associated with deep neural networks. The primary concept of artificial intelligence is to develop a know-how solution through the ANNs, or Artificial Neural Networks, a computer brain model. AI is the branch of computer science that encompasses model fabrication and methods that enable the computer to learn using experience (Medennikov et al., 2021).

Artificial intelligence is crucial in developing new sustainable methods of weeding and pest mass elimination in the process of ATV in agricultural practices. Due to the integration of methodological approaches based on machine learning in ATV systems, the formation of new approaches to weed identification and classification becomes possible (Kebe et al., 2023). Integrated pest management systems that operate fully automated ATVs with machine learning decision algorithms that identify pests in the environment process environmental data attributes to forecast situations when pest invasions can occur and facilitate rapid pest control (Koshariya et al., 2023).

Pest detection, disease diagnosis, crop examination, and analysis intervention are possible through AI vision systems. Machines can be intelligent and used for demanding tasks, including planting, spraying, and harvesting tasks within the context of agricultural fields, use of machine learning algorithms and artificial vision technology (Choudhari et al., 2024).

3. Efficient Technology Adoption in Precision Agriculture

Increasing the effectiveness of fertilizers, water supply, and plant protection chemicals in the sphere of agricultural activity. The management of water in agriculture has been enhanced by a modern farming management technique known as precision agriculture (Raveena & Shirly Edward, 2021). This approach uses information from soil moisture, meteorological prediction, satellite imagery, and IOT sensors to make decisions on irrigation. This strategy enables a proper assessment of the quantity of water required in a field for each segment of operation, and hence its application; using minimal water is possible, and the crops are provided with the necessary quantity of water. These are concerning crop watering, conservation of water in agriculture, and minimizing the incidence of water-borne illnesses (Sekhar et al., 2024).

Fertilizer management is a best practice that could help in lowering pollution and also increase production. Optimal fertilization is the placement of essential nutrients in qualitative proportions and at the right time as a way of raising crop yields and improving the quality of produce. For this reason, Precision Farming is a good approach to applying fertilizers since it uses sensors and GPS technology to fertilize crops. This technology enables the right number of fertilizers to be used in the right places and at the right time to reduce cases of fertilizer leaching (Marina et al., 2023). The initial rudimentary approach to using the nutrient status of the plant in solving the above problem is by conducting soil tests, followed by choosing the correct type/form of fertilizers. Crucial to enhancing the widespread use of the splitting band or subsurface injection application technology in agriculture is the encouragement of the splitting band. The fact that the application of fertilizer in concentrated forms around zones of root offers better nutrition and reduces nutritional wastage, prompts enhanced crop performance (Abdelbaki & Udelhoven, 2022). Subsurface injection refers to a precise method of applying fertilizers below the soil surface in order to prevent running off and polluting underground water. This curtails the interaction of the atmosphere with the plants and enhances the rate of nutrient delivery to the plant's roots. As a result, the application of these methods in the use of fertilizer increases crop yields and quality, reduces the amount of fertilizer used and its impacts on the environment, and ultimately increases farmers' yields and returns (Kouadio et al., 2023).

Drip irrigation options enable farmers to increase yields while cutting water consumption in half, at the very least (Lanki & Onwu, 2024). A closed irrigation control system in the protected crop production system saved about 83% of water and minimized plant diseases due to the setting of the right amounts of water needed. When a wireless sensor network was applied to control irrigation in a nursery, the profit was boosted by 65% due to better quality of crops and quantity of yield. Drones can be used to spray pesticides or release beneficial insects, making it virtually impossible to achieve imprecision in the exercise. This study helps in the right use of chemicals and also minimizes impacts on the environment as well as pest control in vegetable farming (Mia et al., 2023).

4. Soil Health Management

Precision agriculture uses technologies such as GPS, remote sensing, and IoT devices to change the management of soil by undergoing specific techniques (Govi et al., 2024). The evaluation of additional parameters like pH, nutrients, and capacity of water retention in different parts of the field helps in making accurate ratings. Farmers can later on optimize how they target each segment when fulfilling the needs of the segment's specific soils relating to certain inputs like fertilizers or water. It improves yields and quality of the products, efficiency in the consumption of inputs such as fertilizers and water, and it also helps to eradicate some evils like nutrient leaching and water pollution (Padiya et al., 2023). In addition, precision agriculture makes it possible to assess the soil state and characteristics at once, and, thus, make changes immediately. Sensors and aerial systems help in the quick detection of quality, soil status, pest, and nutrient problem areas that can then be managed effectively. It uses big data analysis and machine learning to predict terrestrial conduct, enabling farmers to avoid complications before aggravating. Therefore, precision agriculture keeps the productivity of soil high and improves sustainable soil health, for the promotion of sustainable agriculture and food security (Cudjoe et al., 2023).

5. Control of Pathogens and pests

Technological approaches, together with systematic methods such as Integrated Pest and Disease Management (IPDM), are used to implement this principle of pest and disease control Describe in Table 1. IPDM is the term for pest and disease management that integrates the use of biological control and cultural and the minimum use of pesticides or fungicides as a means of minimizing impacts on beneficial organisms and the environment (Nielsen et al., 2024). The IoT, in conjunction with other innovations such as remote sensing, drones, and artificial intelligence, can generate information on pests and diseases, crop status, weather, etc., amongst others. Abiding 2 Consequently, it can be employed to develop effective and precise pest and disease eradication and control strategies. A system management approach, commonly called Integrated Pest and Disease Management (IPM), is the identification of complex relationships between biotic and abiotic factors affecting crops and the ability to handle such relations to produce a healthy crop (Ravikishore et al., 2022). Table 1 summarizes the integrated pest and pathogen management strategies of precision agriculture. The application of the management of diseases and pests has benefits that include the use of fewer pesticides and fungicides, higher production, efficiency, and sustainability, better impacts on the environment and human health, and better pest and disease control, leading to better results for farmers' lower costs.

Table 1: Integrated Pest and Pathogen Control Strategies in Precision Agriculture (Kumar et al., 2024).

Category	Strategy	Description	Precision	Benefits	Limitations
Agriculture Integration	Induced systemic resistance (ISR)	Application of elicitors that activate plant defense mechanisms.	Precise application of elicitors based on plant stress indicators and disease.	Enhanced plant immunity, reduced reliance on direct pesticides.	Requires understanding of plant signaling pathways, potential for negative impacts on yield.
Chemical Control	Targeted pesticide application	Application of synthetic pesticides only where needed.	Variable rate sprayers, GPS-guided application, drone spraying with precise nozzle control.	Reduced chemical usage, minimized environmental impact.	Potential for resistance development, residue concerns, cost of technology.
	Seed treatment	Application of fungicides or insecticides to seeds before planting.	Precision seeders with integrated treatment capabilities.	Early-season protection, reduced need for foliar sprays.	Limited to seed-borne pathogens and early season pests, potential for non-target effects.
Cultural Control	Crop rotation	Changing the type of crop grown in a specific field over time.	Optimized rotation planning based on historical pest/disease data and soil health maps.	Disruption of pest/pathogen life cycles, improved soil health.	Requires careful planning, potential for yield reductions in certain rotations.
	Resistant varieties	Planting crop varieties that are resistant to specific pests or pathogens.	Selection of varieties based on local pest/disease pressure and genetic analysis.	Reduced need for chemical control, long-term protection.	Potential for resistance breakdown, limited availability of resistant varieties.
	Sanitation practices	Removal of infected plant material and debris from fields.	Automated debris detection and removal using robotic systems or drones.	Reduced pathogen inoculum, improved field hygiene.	Labor-intensive, potential for spreading pathogens if not done correctly.
	Intercropping	Growing two or more crops in close proximity.	Spatial optimization of intercropping patterns based on pest/disease interactions.	Diversified ecosystem, reduced pest/disease pressure.	Requires careful management, potential for competition between crops.
Physical/Mechanical Control	Traps and barriers	Use of sticky traps, pheromone traps, or physical barriers to exclude pests.	Automated trap monitoring with sensors, precision placement of barriers based on pest migration.	Targeted control, reduced chemical use.	Limited efficacy for large infestations, labor-intensive maintenance.
	Thermal treatments	Use of heat to kill soilborne pathogens and pests (e.g., soil solarization).	Automated solarization systems with temperature monitoring, steam sterilization with precise control.	Effective for soilborne pests and pathogens, reduced chemical use.	Energy-intensive, may harm beneficial organisms, limited depth of treatment.
	UV-C Light	Application of ultraviolet-C light to kill pathogens.	Robotic UV-C application systems, targeted application based on disease risk maps.	Non-chemical control, effective against a wide range of pathogens.	Potential damage to non-target organisms, safety concerns.
Monitoring/ Prediction	Remote sensing	Use of sensors (e.g., satellite imagery, drones) to detect plant stress.	Early detection of outbreaks, real-time monitoring of crop health.	Large-scale monitoring, early warning system.	Requires data analysis expertise, potential for false positives.
	Sensor networks	Collection of environmental data (e.g., soil moisture, temperature, humidity).	Predictive modeling, automated alerts for farmers.	Site-specific monitoring, improved decision making.	Requires investment in sensor technology, data interpretation challenges.
	Pest/disease modeling	Use of mathematical models to predict pest/disease outbreaks.	Optimized timing of control measures, reduced risk of outbreaks.	Improved risk assessment, proactive management.	Requires accurate data and model validation, potential for inaccuracies.

6. Benefits of Precision Agriculture to crop Production

Precision agriculture intends to enhance crop productivity. Many technologies such as GIS, GPS, and remote sensing can obtain farm-specific information about the type of soil, moisture content, and nutrient status (Sharma et al., 2023). The information helps in improving culture management practices appropriate for each type to improve growth and yields. Precision agriculture can easily detect and contain pests and diseases, hence enhancing crop production outcomes. PATs are also posing a rapid development impact on the agricultural industry because the production pace is not a lightweight advancement (Olson & Anderson, 2021). Another shift in precision agriculture is where the concept of machine learning is seen in precision planting by utilizing controlled autonomous tractors to improve the planting process. Artificial Intelligence and Machine Learning improve methodologies in selecting seeds in a way that eliminates variability in crop production and boosts yield (Slimani et al., 2024).

Innovative Wealth Generation Strategy: Marketing Factors: Financial Accessibility of the Produce and Benefits for the Agricultural Producers (Yépez-Ponce et al., 2023). That way, farmers can achieve high yields, use few inputs, and, therefore, maximize their profits through the use of precision agriculture techniques. Managing inputs and timely identification of stress factors affecting crops help farmers improve their production plans and obtain improved income. Further, precision agriculture entails decision-making regarding crops, input, output, and markets to enhance yields and enhance farmers' position in the agricultural value chain (Peladarinos et al., 2023). It enhances automation, optimizes the way data is collected and processed, and on supervised experimental domains, recommended rates for applying fertilizer and possible multiple operations that can be carried out at once (Yaqot et al., 2023).

However, as a result of its progressive enhancement of the efficiency and sustainability of existing agricultural systems, precision agriculture (PA) faces many global issues. The costs underlying the formation of PATs remain always high and are beyond the capacity of many of the farmers, especially smallholders (Mana et al., 2024). Costs related to machinery and hardware necessary for using the technology are expenses on equipment like GPS-enabled machinery and sensors, for example, drones, while costs that limit the usage of the technology are costs linked to data acquisition and analysis. Vague connection to the Internet and electricity in rural areas is a significant challenge to the effective application of smart instruments, including precision agriculture, relying on the IoT (Singh et al., 2021).

Precision agriculture has the enormous potential to transform farming by enhancing productivity and the use of resources most efficiently; all the same, there are numerous barriers to its implementation. One of them is that PATs are associated with a high initial investment that farmers have to make to acquire these technologies (Emmi et al., 2023). This must be offset against the need for substantial capital expenditure in GPS-fitted equipment, drones, and sophisticated sensors, which are beyond the reach of constant farmers, let alone newcomers to agriculture. Fixed and variable costs are both high due to maintenance, improvements, and operations, making the costs unbearable for beginners or small investors (Rozenstein et al., 2024).

One major issue is the technical difficulty that accompanies many of the precision agriculture instruments. Farmers and other people involved in agricultural business may not be in a position to successfully manage and control some of the innovative solutions like IoT devices, remote sensors, and machine learning models (Mathenge et al., 2022). The analysis of big data arising from the use of these technologies requires technical skills that many farmers lack. Lack of infrastructure is also a major hindrance to the efficient use of precision agriculture as well. Stable access to the Internet, electricity, and sound telecommunication systems are necessary for the function of IoT devices as well as PCs and cloud computing and storage. However, these infrastructures are usually poorly developed or absent in rural and remote areas of agricultural activity, which makes the operation of precision agriculture solutions unreliable and inefficient (Medici et al., 2021).

To that, data management and privacy issues are also of concern. The intelligent application of technologies produces a range of data that has to be stored and analyzed, which is beyond the capability of many farmers (Alexopoulos et al., 2023). This has raised concerns about who owns data associated with farming and the potential misuse of collected information by third-party service providers to make farmers reluctant to adopt such systems (Tangkesalu et al., 2023). Firstly, resistance to change is greatly evident as many farmers prefer to continue with traditional methods due to skepticism, cultural beliefs, or simple fear of upsetting the balance of the working frameworks they have already developed. In addition, appropriate governmental measures and irregularity of laws negatively influence adoption. Scarce resources of funding, subsidies, or support systems all restrain farmers from investing in PATs (Raouhi et al., 2023).

Conclusion

Precision agriculture technology has proven to be the most important for modern farming, offering innovative solutions to enhance crop yields and promote environmental sustainability. Crucially, the development of adaptive and predictive information systems that effectively integrate diverse data sources is essential for ensuring sustainable and intelligent precision agriculture. While precision agriculture offers numerous benefits, it also poses challenges for its widespread adoption. The initial investment in technology, concerns related to data privacy, and compatibility issues with existing farming systems can be significant barriers for small scale farmers. Moreover, the scalability and adaptability of these technologies to different farming conditions may limit their applicability in certain regions. Overcoming these challenges necessitates the implementation of education and training programs to equip farmers with the necessary skills to leverage these technologies effectively. This chapter concluded that due to precision technology, the growth and yields of crops increased to fulfill the needs of the increased world population and reduced the environmentally hazardous effects. As we move forward, precision agriculture stands as a cornerstone of innovative, sustainable, and resilient farming systems that can meet the challenges of future food security.

References

Abdelbaki, A., & Udelhoven, T. (2022). A Review of Hybrid Approaches for Quantitative Assessment of Crop Traits Using Optical Remote Sensing: Research Trends and Future Directions. In *Remote Sensing* (Vol. 14, Issue 15). https://doi.org/10.3390/rs14153515

Abdullahi, M. O., Jimale, A. D., Ahmed, Y. A., & Nageye, A. Y. (2024). Revolutionizing Somali agriculture: harnessing machine learning and IoT for optimal crop recommendations. *Discover Applied Sciences*, *6*(3). https://doi.org/10.1007/s42452-024-05739-y

Akbari, M., Syed, A., Kennedy, W. S., & Erol-Kantarci, M. (2024). AoI-Aware Energy-Efficient SFC in UAV-Aided Smart Agriculture Using Asynchronous Federated Learning. *IEEE Open Journal of the Communications Society*, *5*. https://doi.org/10.1109/OJCOMS.2024.3363132

Alam, S. (2023). Security Concerns in Smart Agriculture and Blockchain-based Solution. *2022 OPJU International Technology Conference on Emerging Technologies for Sustainable Development, OTCON 2022*. https://doi.org/10.1109/OTCON56053.2023.10113953

Alexopoulos, A., Koutras, K., Ali, S. Ben, Puccio, S., Carella, A., Ottaviano, R., & Kalogeras, A. (2023). Complementary Use of Ground-Based Proximal Sensing and Airborne/Spaceborne Remote Sensing Techniques in Precision Agriculture: A Systematic Review. In *Agronomy* (Vol. 13, Issue 7). https://doi.org/10.3390/agronomy13071942

Arthur, K. K., Bannor, R. K., Masih, J., Oppong-Kyeremeh, H., & Appiahene, P. (2024). Digital innovations: Implications for African agribusinesses. In *Smart Agricultural Technology* (Vol. 7). https://doi.org/10.1016/j.atech.2024.100407

Cheng, Y. H., Kuo, C. N., & Lin, Y. Da. (2024). An Artificial IoT-Enabled Smart Production Line for 360° Visual Defect Detection and Classification of Cherry Tomatoes. *IEEE Internet of Things Journal*, *11*(10). https://doi.org/10.1109/JIOT.2024.3360715

Choudhari, A., Bhoyar, D. B., & Badole, W. P. (2024). MFMDLYP: Precision Agriculture through Multidomain Feature Engineering and Multimodal Deep Learning for Enhanced Yield Predictions. *International Journal of Intelligent Systems and Applications in Engineering*, *12*(7s).

Cudjoe, D. K., Virlet, N., Castle, M., Riche, A. B., Mhada, M., Waine, T. W., Mohareb, F., & Hawkesford, M. J. (2023). Field phenotyping for African crops: overview and perspectives. In *Frontiers in Plant Science* (Vol. 14). https://doi.org/10.3389/fpls.2023.1219673

El Mezouari, A., El Fazziki, A., & Sadgal, M. (2022). Hadoop–Spark Framework for Machine Learning-Based Smart Irrigation Planning. *SN Computer Science*, *3*(1). https://doi.org/10.1007/s42979-021-00856-6

Emmi, L., Fernández, R., Gonzalez-de-Santos, P., Francia, M., Golfarelli, M., Vitali, G., Sandmann, H., Hustedt, M., & Wollweber, M. (2023). Exploiting the Internet Resources for Autonomous Robots in Agriculture. *Agriculture (Switzerland)*, *13*(5). https://doi.org/10.3390/agriculture13051005

Erazo-Mesa, E., Echeverri-Sánchez, A., & Ramírez-Gil, J. G. (2022). Advances in Hass avocado irrigation scheduling under digital agriculture approach | Avances en la programación del riego de aguacate Hass bajo un enfoque de agricultura digital. *Revista Colombiana de Ciencias Horticolas*, *16*(1).

Govi, D., Pappalardo, S. E., De Marchi, M., & Meggio, F. (2024). From Space to Field: Combining Satellite, UAV and Agronomic Data in an Open-Source Methodology for the Validation of NDVI Maps in Precision Viticulture. *Remote Sensing*, *16*(5). https://doi.org/10.3390/rs1605073

Kathole, A. B., Vhatkar, K. N., Kumbhare, S., Katti, J., & Kimbahune, V. V. (2024). IoT-Based Smart Agriculture for Onion Plant Disease Management: A Comprehensive Approach. *International Journal of Intelligent Systems and Applications in Engineering*, *12*(13).

Kaushik, I., Prakash, N., & Jain, A. (2021). Integration of Blockchain IoT in Precision Farming: Exploration, Scope and Security Challenges. *2021 IEEE 12th Annual Ubiquitous Computing, Electronics and Mobile Communication Conference, UEMCON 2021*. https://doi.org/10.1109/UEMCON53757.2021.9666554

Kebe, A. A., Hameed, S., Farooq, M. S., Sufyan, A., Malook, M. B., Awais, S., Riaz, M., Waseem, M., Amjad, U., & Abbas, N. (2023). Enhancing Crop Protection and Yield through Precision Agriculture and Integrated Pest Management: A Comprehensive Review. *Asian Journal of Research in Crop Science*, *8*(4). https://doi.org/10.9734/ajrcs/2023/v8i4225

Koshariya, A. K., Sharma, N., Satapathy, S. N., Thilagam, P., Akanksha, Laxman, T., Rai, S., & Singh, B. veer. (2023). Safeguarding Agriculture: A Comprehensive Review of Plant Protection Strategies. *International Journal of Environment and Climate Change*, *13*(11). https://doi.org/10.9734/ijecc/2023/v13i113168

Kouadio, L., El Jarroudi, M., Belabess, Z., Laasli, S. E., Roni, M. Z. K., Amine, I. D. I., Mokhtari, N., Mokrini, F., Junk, J., & Lahlali, R. (2023). A Review on UAV-Based Applications for Plant Disease Detection and Monitoring. In *Remote Sensing* (Vol. 15, Issue 17). https://doi.org/10.3390/rs15174273

Kowalska, A., & Ashraf, H. (2023). Advances in Deep Learning Algorithms for Agricultural Monitoring and Management. *Applied Research in Artificial Intelligence and Cloud Computing*, *6*(1).

Kumar, A., Mangla, S. K., & Kumar, P. (2024). Barriers for adoption of Industry 4.0 in sustainable food supply chain: a circular economy perspective. *International Journal of Productivity and Performance Management*, *73*(2). https://doi.org/10.1108/IJPPM-12-2020-0695

Lanki A. D., & Onwu C. A. (2024). Geographic Information System (GIS) Application in Soil Fertility Management: A Review. *Journal of Global Agriculture and Ecology*, *16*(2). https://doi.org/10.56557/jogae/2024/v16i28592

Majumdar, P., Bhattacharya, D., Mitra, S., & Bhushan, B. (2023). Application of Green IoT in Agriculture 4.0 and Beyond: Requirements, Challenges and Research Trends in the Era of 5G, LPWANs and Internet of UAV Things. In *Wireless Personal Communications* (Vol. 131, Issue 3). https://doi.org/10.1007/s11277-023-10521-1

Mana, A. A., Allouhi, A., Hamrani, A., Rahman, S., el Jamaoui, I., & Jayachandran, K. (2024). Sustainable AI-based production agriculture: Exploring AI applications and implications in agricultural practices. *Smart Agricultural Technology*, *7*. https://doi.org/10.1016/j.atech.2024.100416

Marina, I., Sujadi, H., & Indriana, K. R. (2023). *Optimizing Soybean Cultivation Efficiency through Agricultural Technology Integration in Plant Monitoring System*. *1*(2).

Mathenge, M., Sonneveld, B. G. J. S., & Broerse, J. E. W. (2022). Application of GIS in Agriculture in Promoting Evidence-Informed Decision Making for Improving Agriculture Sustainability: A Systematic Review. In *Sustainability (Switzerland)* (Vol. 14, Issue 16). https://doi.org/10.3390/su14169974

Medennikov, V. I., Butrova, E. V., & Sklyarov, A. E. (2021). Modeling the Forecast of Economic Effects from the "digital Earth" Project Results Application for Digitalization of the Russian Federation (on the Example of Agricultural Sector at the Macro Level). *IOP Conference Series: Earth and Environmental Science*, *666*(6). https://doi.org/10.1088/1755-1315/666/6/062045

Medici, M., Pedersen, S. M., Canavari, M., Anken, T., Stamatelopoulos, P., Tsiropoulos, Z., Zotos, A., & Tohidloo, G. (2021). A web-tool for calculating the economic performance of precision agriculture technology. *Computers and Electronics in Agriculture*, *181*. https://doi.org/10.1016/j.compag.2020.105930

Mia, M. S., Tanabe, R., Habibi, L. N., Hashimoto, N., Homma, K., Maki, M., Matsui, T., & Tanaka, T. S. T. (2023). Multimodal Deep Learning for Rice Yield Prediction Using UAV-Based Multispectral Imagery and Weather Data. *Remote Sensing*, *15*(10). https://doi.org/10.3390/rs15102511

Nielsen, M. B., Meyer, A. S., & Arnau, J. (2024). The Next Food Revolution Is Here: Recombinant Microbial Production of Milk and Egg Proteins by Precision Fermentation. In *Annual Review of Food Science and Technology* (Vol. 15, Issue 1). https://doi.org/10.1146/annurev-food-072023-034256

Olson, D., & Anderson, J. (2021). Review on unmanned aerial vehicles, remote sensors, imagery processing, and their applications in agriculture. In *Agronomy Journal* (Vol. 113, Issue 2). https://doi.org/10.1002/agj2.20595

Peladarinos, N., Piromalis, D., Cheimaras, V., Tserepas, E., Munteanu, R. A., & Papageorgas, P. (2023). Enhancing Smart Agriculture by Implementing Digital Twins: A Comprehensive Review. In *Sensors* (Vol. 23, Issue 16). https://doi.org/10.3390/s23167128

R. Shamshiri, R., K. Balasundram, S., Kaviani Rad, A., Sultan, M., & A. Hameed, I. (2022). An Overview of Soil Moisture and Salinity Sensors for Digital Agriculture Applications. In *Digital Agriculture, Methods and Applications*. https://doi.org/10.5772/intechopen.103898

Raouhi, E. M., Lachgar, M., Hrimech, H., & Kartit, A. (2023). Unmanned Aerial Vehicle-based Applications in Smart Farming: A Systematic Review. *International Journal of Advanced Computer Science and Applications*, *14*(6). https://doi.org/10.14569/IJACSA.2023.01406123

Raveena, S., & Shirly Edward, A. (2021). Secure B-IoT Based Smart Agriculture- A Brief Review. *Journal of Physics: Conference Series*, *1964*(4). https://doi.org/10.1088/1742-6596/1964/4/042006

Ravikishore, M., Supriya, P., & Subbaiah, K. R. (2022). Farm Mechanisation 2.0: The Future of Indian Agriculture. *Food and Scientific Reports*, *3*(11).

Rozenstein, O., Cohen, Y., Alchanatis, V., Behrendt, K., Bonfil, D. J., Eshel, G., Harari, A., Harris, W. E., Klapp, I., Laor, Y., Linker, R., Paz-Kagan, T., Peets, S., Rutter, S. M., Salzer, Y., & Lowenberg-DeBoer, J. (2024). Data-driven agriculture and sustainable farming: friends or foes? *Precision Agriculture*, *25*(1). https://doi.org/10.1007/s11119-023-10061-5

S. D. Padiya, Atharva Raut, Bhavy Mittal, Mayur Patel, & Vedant Polshettiwar. (2023). Machine Learning and IoT Applications in Agriculture. *International Journal of Advanced Research in Science, Communication and Technology*. https://doi.org/10.48175/ijarsct-9416

Sekhar, M., Rastogi, M., Rajesh C M, Saikanth, D. R. K., Rout, S., Kumar, S., & Patel, A. K. (2024). Exploring Traditional Agricultural Techniques Integrated with Modern Farming for a Sustainable Future: A Review. *Journal of Scientific Research and Reports*, *30*(3). https://doi.org/10.9734/jsrr/2024/v30i31871

Sharma, B., Tiwari, S., Kumawat, K. C., & Cardinale, M. (2023). Nano-biofertilizers as bio-emerging strategies for sustainable agriculture development: Potentiality and their limitations. In *Science of the Total Environment* (Vol. 860). https://doi.org/10.1016/j.scitotenv.2022.160476

Shrestha, M. M., & Wei, L. (2024). Review—Perspectives on the Roles of Real time Nitrogen Sensing and IoT Integration in Smart Agriculture. *Journal of the Electrochemical Society*, *171*(2). https://doi.org/10.1149/1945-7111/ad22d8

Si, H., Li, M., Li, W., Zhang, G., Wang, M., Li, F., & Li, Y. (2024). A Dual-Branch Model Integrating CNN and Swin Transformer for Efficient Apple Leaf Disease Classification. *Agriculture (Switzerland)*, *14*(1). https://doi.org/10.3390/agriculture14010142

Singh, R. K., Berkvens, R., & Weyn, M. (2021). AgriFusion: An Architecture for IoT and Emerging Technologies Based on a Precision Agriculture Survey. In *IEEE Access* (Vol. 9). https://doi.org/10.1109/ACCESS.2021.3116814

Slimani, H., El Mhamdi, J., & Jilbab, A. (2024). Assessing the advancement of artificial intelligence and drones' integration in agriculture through a bibliometric study. *International Journal of Electrical and Computer Engineering*, *14*(1). https://doi.org/10.11591/ijece.v14i1.pp878-890

Tangkesalu, D., Pedro, J. C., Tooy, D., Judijanto, L., & Saprudin, S. (2023). Precision Agriculture: Integrating Technology for Enhanced Efficiency and Sustainability in Crop Management. *Global International Journal of Innovative Research*, *1*(3). https://doi.org/10.59613/global.v1i3.37

Tziolas, E., Karapatzak, E., Kalathas, I., Lytridis, C., Mamalis, S., Koundouras, S., Pachidis, T., & Kaburlasos, V. G. (2023). Comparative Assessment of Environmental/Energy Performance under Conventional Labor and Collaborative Robot Scenarios in Greek Viticulture. *Sustainability (Switzerland)*, *15*(3). https://doi.org/10.3390/su15032753

Xie, B., Su, Q., Tang, B., Li, Y., Yang, Z., Wang, J., Wang, C., Lin, J., & Li, L. (2023). Combining Neural Architecture Search with Knowledge Graphs in Transformer: Advancing Chili Disease Detection. *Agriculture (Switzerland)*, *13*(10). https://doi.org/10.3390/agriculture13102025

Yang, G., Li, Y., Yuan, S., Zhou, C., Xiang, H., Zhao, Z., Wei, Q., Chen, Q., Peng, S., & Xu, L. (2024). Enhancing direct-seeded rice yield prediction using UAV-derived features acquired during the reproductive phase. *Precision Agriculture*, *25*(2). https://doi.org/10.1007/s11119-023-10103-y

Yaqot, M., Menezes, B. C., & Al-Ansari, T. (2023). Roadmap to Precision Agriculture under Circular Economy Constraints. *Journal of Information and Knowledge Management*, *22*(5). https://doi.org/10.1142/S0219649222500927

Yépez-Ponce, D. F., Salcedo, J. V., Rosero-Montalvo, P. D., & Sanchis, J. (2023). Mobile robotics in smart farming: current trends and applications. In *Frontiers in Artificial Intelligence* (Vol. 6). https://doi.org/10.3389/frai.2023.1213330

Zhao, X., Wang, W., Wen, L., Chen, Z., Wu, S., Zhou, K., Sun, M., Xu, L., Hu, B., & Wu, C. (2023). Digital twins in smart farming: An autoware-based simulator for autonomous agricultural vehicles. *International Journal of Agricultural and Biological Engineering*, *16*(4). https://doi.org/10.25165/j.ijabe.20231604.8039