

IoT, Big Data Analytics and Deep Learning for Sustainable Precision Agriculture

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Abstract
Agriculture is undergoing a digital transformation because of population growth, climate change, and food security concerns. Agriculture is influenced by information technology in terms of cost reduction, efficiency, and sustainability. Precision agriculture employs IoT, deep learning, predictive analytics, and AI-based technologies to aid in the detection of plant diseases, pests, and poor plant nutrition in the field. The study's objectives are as follows: 1) evaluate the role of smart technologies and their impact on precision agriculture sustainability; 2) assess the typical application of IoT data analytic and deep learning in precision agriculture; and 3) investigate the barriers to the adoption of sustainable precision farming. IoT technologies collect data and relay it to data analytics and deep learning for in-depth analysis. According to the findings, data assists farmers in managing crop variety, phenotypes and selection, crop performance, soil quality, pH level, irrigation, and fertilizer application quantity. Technological issues, safety, privacy, cost, and legal issues also influence the adoption of these technologies.
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1. Introduction

Agriculture, like many other industries, is undergoing a digital transformation because of population growth, climate change, and food security concerns, which necessitate the adoption of innovative crop productivity methods [33]. Agriculture's role in climate change and global warming, on the other hand, has been the subject of a long-running and contentious debate [8]. Precision agriculture drives by technological and innovative methods for efficiently managing agricultural characteristics such as crop, soil, production, and management by understanding the temporal and spatial changes of these aspects [45]. Agriculture makes an important contribution to the global economy [28]. Farming also plays a role in the global socio-economic activity. Because of market growth, both agricultural research and industry are aiming for sustainable agricultural productivity [24], as well as addressing societal needs in acquiring, managing, analyzing, visualizing, and utilizing data and information in dealing with cross-disciplinary precision agriculture problems [45]. The rising trend in crop demand, combined with rising fertilizer and pesticide prices, has highlighted the need for resource-efficient, environmentally friendly agriculture [8]. Precision farming defines as the management of spatial and temporal variability with ICT-enabled technologies to provide food security [46]. Precision agriculture, according to [14], is a strategic approach that collects, processes, and analyzes temporal, spatial, and individual data, integrating it with other information to support managerial decisions based on estimated variations to improve utilization efficiency, productivity, quality, profit margins, and sustainability of agricultural output. Precision agriculture is based on the idea that production inputs such as seed, chemicals, fertilizer, and so on should only be applied when and where they are needed to achieve the most efficient production [35]. In precision agriculture, thorough plant phenology tracking of agricultural plants transversely by deep learning at large spatial levels is critical. The precise information aids in the timing of farm management practices such as farm monitoring, harvesting, yield prediction, pest control, and disaster warning, among others. Governments can use crop-mapping information to invalidate farmer subsidies, detect fraud, and process insurance claims. The application's design is similar to that of the Internet of Things (IoT)-based irrigation systems and sensors capable of tracking pH, soil moisture, temperature, humidity, and digital soil mapping [26]. Adoption of IoT, predictive analytics, and deep learning in precision agriculture is important for 1) profitability; 2) efficiency of input cost reduction; 3) food safety; 4) sustainability; 5) and environmental safety [1].

Agriculture is expected to meet societal values such as increased food productivity, cultural diversity, recreation, and climate conservation, as well as economic, environmental, and social viability. This has not been the case due to a variety of impediments. Precision agriculture is one of the farming practices that are efficient and safe for the environment. The farmer through observation, measurement, and a quick response to variability on crops through the treatment of variable rates with high precision and accuracy [29] achieves it. To achieve sustainable farm productivity, it is critical to forecast and understand the various variability and dynamics of the agricultural system to improve crop performance. Climate change, fertilization, and irrigation, as well as soil insights, are all part of this. Precision agriculture enables a data-driven method that enables farmers to make the best crop variety, selection, and decisions to cope with changing conditions, resource scarcity, and the effects of agricultural production on society. Agricultural activities are a major source of income for the majority of Kenyans. Its practices have long been unsatisfactory in terms of yield maximization and cost minimization due to an over-reliance on traditional farming orientation. The vice is not information-driven, particularly in terms of management practices as inputs in terms of timing or quantification, but most farmers rely on estimates. However, they failed to account for field variability, resulting in resource misallocations such as under or over-application of inputs, which had a significant impact on the ecosystem and harmed production sustainability [49].

The issues have an impact on food security, requiring farmers to adopt other effective, efficient, and productive farm practices. This is realized with precision agriculture and the adoption of novel technologies. Soil variability and crop management are critical in precision agriculture for achieving productivity, profitability, and environmental effluence control [15]. Agriculture is expected to meet societal values such as increased food productivity, cultural diversity, recreation, and climate conservation, as well as economic, environmental, and social viability. These have not been the case due to various barriers. Precision agriculture is considered as one of the farming practices that are efficient and safe to the environment achieved through observation, measurement with quick response to variability's on crops by the farmer through the treatment of variable rates with high precision and accuracy [29].

According to the United Nations Food and Agriculture Organization, food production must increase by 60% by 2050 to keep up with the world's rapid population growth. Precision farming is seen as a long-term solution to the problem of food scarcity and unprofitable farm practices [19]. The environmental impact has been alarming globally because of various pollutants. Sociable and sustainable agriculture entails excellent agricultural resource utilization management for sustainability in fulfilling the food production demand, conserving the environment, and natural resources. As a result, a policy framework that guides the use and effects of poor agricultural practices on the environment is required. This necessitates a transformation of our dominant conventional farming into smart farming through strategic alignment of agricultural product development with the environment using smart technologies. Pollutants can be reduced by preventing soil erosion, avoiding the overuse of fertilizers, herbicides, and pesticides, protecting biodiversity, and conserving natural resources [12]. The study will benefit a variety of stakeholders, including individual farmers, communities, government, and agricultural authorities. It will provide insight and understanding to facilitate economic impact by providing good agricultural services, important data collection, analysis, and insight exposure for decision-making and farming practice management. These will boost productivity, food security, and long-term sustainability. It aids stakeholders in development while also improving their standard of living. It encourages entrepreneurship and job creation.

1.1 Sustainable Agriculture

Precision agriculture significantly contributes to addressing agricultural challenges. It can also contribute to a more sustainable agricultural system while remaining profitable [8]. Precision agriculture and the concept of sustainability are inextricably linked. The term "sustainability" refers to the economic ability to maintain consistent productivity without jeopardizing the needs of future generations. Sustainable agriculture improves environmental quality and resource-based agriculture, where agriculture is based on basic human food and economic viability, thereby improving farmers' lifestyles and society. Sustainability has remained a comprehensive examination of the economic, environmental, and sociological consequences of any expansion [6]. Agro-technology and precision farming, as well as digital agriculture, use data-driven approaches to increase agricultural productivity while minimizing environmental impacts [28].

Precision agriculture's critical success is hampered by factors such as a lack of training, a low return on investment, high costs, and a lack of precision agriculture big data analytics [45]. Precision farming collects real-time data on farm elements such as crops, air, and soil to protect the environment while also ensuring profits and sustainability [1]. The incorporation of AI techniques in agricultural practices has advanced aspects such as crop and soil health, irrigation systems, crop disease identification, weed control, and recommended control measures [26]. Farming problems may be addressed by robotics and sensing technologies. As a result, adopting a robotic agricultural system will have a significant impact on crop production, efficiency, and sustainability [22].

1.2 Precision agriculture

Precision agriculture has recently received a lot of attention due to the world's ever-increasing demand for water and food [20]. Precision agriculture is no exception to how information systems have influenced and shaped every aspect of our society [8]. Precision agriculture, according to [11], is the "collection of real-time data from farm variables and use of predictive analytics for smart decisions to maximize yields, minimize environmental impact, and reduce cost." Precision agriculture's goal is to understand the soil and crop qualities that are specific to each section of the field and to streamline production inputs in small sections of the field [35]. According to

[4], precision farming has the potential to provide both economic and environmental benefits by reducing the use of water, fertilizers, herbicides, and pesticides, as well as farm machinery. Thereby resolving both the economic and climate change issues that currently plague production agriculture precision agriculture is a field in which technology can be used to effectively manage agriculture by understanding the temporal and spatial changes in soil, crop, production, and management via innovative techniques [45]. The Internet of Things (IoT) technology plays an important role in precision farming by driving the total market value, which is expected to be around $4.7 billion by 2021. Despite an increase in research and novel projects in smart farming projects, agriculture as an industry has been slow to adopt emerging M2M and IoT technologies in comparison to other industries. Smart farming necessitates the incorporation of sensor technologies capable of collecting data from the crop, soil, animal behavior, tractor status, and a variety of environmental characteristics. Sensor data from IoT computing and analytics can provide a farmer with valuable information on weather conditions, forecasts, yield prediction, crop monitoring, animal and plant disease detection, and crop monitoring [33].

Precision Agriculture enables more efficient use of inputs (such as seed, pesticide, fertilizer, or herbicide), new efficient tillage equipment operation, better crop and field measurements, and improved management decisions [4], [35]. The use of Smart greenhouses encourages crop cultivation with a minimum of human intervention by constantly monitoring climatic conditions such as humidity, luminosity, temperature, and soil moisture, generating automated actions based on the assessed changes, and enacting corrective mechanisms to maintain the most valuable conditions for development [1]. Deep Learning's contribution to improving precision agriculture includes the following: 1) Optimal control of the agricultural production system 2) Management of the agricultural economic system, Agriculture information processing, and smart agriculture machinery equipment [44]. Growing agricultural technology has enabled the use of high-precision sensors to remotely monitor nutrients, water, humidity, light, and temperature. The collected data is exposed through an advanced analysis using robust algorithms to aid in prediction processes and strategic decision-making. Machine learning and deep learning technologies are important in precision agriculture because they enable computers to become intelligent through the development of image and video processing algorithms [9]. Information and communication technologies (ICT) are a tool for promoting industrial transformations. It is expected that the availability of analytics and modern farming techniques will increase agricultural production output to 60% by 2030. Agriculture has been influenced by information technology, which has improved cost reduction, efficiency, and sustainability [26]. Precision agriculture is a method of managing farm practices that involve the use of various technologies such as remote sensors, RFID, and cameras to achieve the proximal collection of key data in real-time. Using data analytics strategies and other intelligent technologies, these can be converted into information insights. Farmers can then use this information to optimize their input returns, improve their efficiency, and reduce their environmental impact. Precision agriculture can be defined as "applying the right treatment in the right place at the right time." It is a collection of IT artifacts that includes information systems, smart sensors, and improved machinery with cognizance management for production optimization via tracking and monitoring of uncertainties and variability in agricultural structures. It is a concept for managing farm activities that are based on observation, measurement, and response to any internal or external field variation in crops [13]. Precision agriculture employs IoT, deep learning, predictive analytics, and AI-based technologies to detect plant diseases, pests, and poor plant nutrition in the field [11]. Precision agriculture enables efficient observation and close monitoring of crops as they grow by using information collected directly from the field (such as weather or soil condition). It is also known as satellite farming [32]. Precision agriculture necessitates the collection and interpretation of detailed field data to account for variability in productivity. New technologies, such as wireless sensor networks, are now assisting in the real-time streaming of data for strategic decision-making. Sensor networks are used in agriculture for a variety of reasons, including 1) Agriculture with pinpoint accuracy 2) Consumer advertisement 3) Plant growth optimization 4) Farm surveillance 5) Research 6) Farming education and training 7) Farm administration [27].

2. IoT Technologies in Agriculture

The Internet of Things (IoT) entailed the connection of objects via RFID [36]. It is no longer a buzzword, but it is being used practically all over the world as a result of the advancement and use of devices such as mobile, distributed systems, embedded systems, cloud computing, ubiquitous communication, and big data analytics. It enables physical object interconnection over a network, sensing, information collection, sharing, and analysis, all of which aid in decision making, planning, and management [40]. Precision farming makes use of smart technologies such as IoT and big data analytics. It can handle farming problems adequately by monitoring crops, soil, environment, irrigation, and fertilization with IoT sensors, RFID, and cameras. These IoT technologies collect data and relay it to data analytics for in-depth analysis. Farmers receive the analyzed data via devices such as smartphones. The data helps farmers manage crop varieties, phenotypes, and selection, crop performance, soil quality, pH level, irrigation, and fertilizer application quantity [19]. With the use of IoT, farmers will find that agricultural problems are a thing of the past. It plays an important role in gathering relevant information [32].

Drones are used in agricultural applications such as monitoring fields, crops, and livestock, as well as scanning large areas, whereas sensors on the ground collect a vast amount of data [1]. The Internet of Things (IoT) refers to intelligent networks that connect objects to allow information exchange and communication via sensing devices over the internet using certain standards and protocols. An IoT is a framework of integrated technologies (such as RFID, cloud computing, wireless sensor networks, Internet protocols, data analytics, and so on) [36]. It identifies, tracks, locates, monitors, and manages things efficiently and effectively [7]. [38] Propose a low-cost IoT sensing platform that consists of three components: 1) the monitoring sensors; 2) the sensing box and 3) the available interfaces. They are intended to provide soil data that is critical for increasing crop yield. The soil humidity, pH, temperature, light, and camera sensors in the monitoring sensors collect soil images for computer vision analysis. These sensors are collected in the Sensing Box, which collects data from smartphones or clouds. The Sensing Box communicates with the smartphone/cloud and sensor essentials via radio and analog/digital interfaces, respectively, allowing monitoring and support for other soil, environmental, and camera sensors. IoT connectivity includes people, machines, tools, and locations that are designed to perform intelligent functions such as data sharing and information exchange. The Internet of Things (IoT) is playing an important role in agricultural product management in real-time data, alongside 1) control; 2) tracking; 3) evaluating; 4) searching; 5) monitoring; 6) managing; and 7) logistic operations [1].

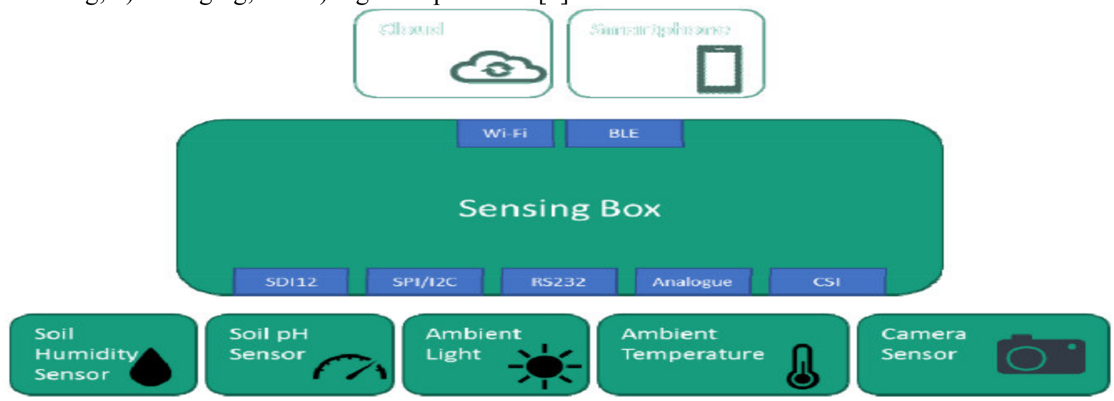

Figure 1 – IoT Sensing Platform Architecture (Adapted from [38])

3. Big Data Analytics (BDA) and Deep Learning in agriculture

3.1 Big Data Analytics (BDA)

Currently, big data analytics is being increasingly adopted to meet the evolving needs of big data technologies across a wide range of topics. Big data's approachability, accessibility, and rapid emergence have fueled consistent technological developments and applications [17]. Big data is defined as a large data set that can be structured, semi-structured, or unstructured and collected, analyzed, distributed, and managed for informed decision-making. The data sources for BDA are incorporated through the integration of IoT devices (RFID and sensors) within a network-enabled environment. The BDA enables knowledgeable insights to be extracted from massive IoT data sets through the application of data mining approaches aimed at predicting, identifying patterns, correlations, trends, and decision making. The massive amounts of data generated by IoT have made a significant contribution to the vast field of big data. Big data characteristics include the 5 Vs: volume, veracity, variety, value, and velocity [30], [31]. Big data provides predictive insights into farming practices, drives real-time effective decisions, and redesigns business processes to create game-changing business models [41]. The smart decision made possible by data analytics results in less waste of resources such as water, pesticides, fertilizer, and so on [11].

The BDA is responsible for capturing, storing, analyzing, searching, and identifying hidden patterns in the collected data. As a result, BDA necessitates the use of (a) tools for classification and clustering; (b) techniques for data mining, machine learning, and statistical analysis; and (c) technologies like Hadoop and Spark. It aids in accurately forecasting and decision-making in agricultural practices [1]. Adoption and optimization of innovation and technologies will help to ensure the long-term viability of precision farming through better practices and increased productivity. These can be realized by measuring, storing, and analyzing data to improve yield quality; managing cost revenues through crop risk probability and minimization, and adopting improved preventive care methods to increase productivity satisfaction [51]. Adoption of IoT Big Data is critical in farm management practices such as crop imaging, irrigation, soil analysis (Acidity, PH), pesticide and herbicide application, fertilizers, temperature, and moisture monitoring [2]. Precision agriculture enables efficient observation and close monitoring of crops as they grow by using information collected directly from the field (such as weather or soil condition). It is also known as satellite farming [32].

There is a disconnect between research and practice. There is a need for researchers to not focus on a specific restricted domain or problem, but rather to take a holistic approach for farmers to understand crop production with the incorporation of technology and innovation. A farmer focuses on new techniques and approaches based on individual perceptions such as resource availability, experience, age, education level, and risk management attitude [29]. Adoption of IoT big data technologies can have a positive economic impact by facilitating the provision of good agricultural services, important data collection, analysis, and the dissemination of insights that assist farmers in making informed and correct decisions about farming practices and management. These will increase farmer productivity, and a ready market will allow farmers to sell their products and use them for development while also improving their livelihood. It encourages entrepreneurship and job creation [51]. The government contributes significantly to the success or failure of agriculture by encouraging farmers to be risk-averse. Factors such as drought, heavy rain, pest and disease infestations, or poor seed quality contribute to the high risk. The government must provide full intervention to farmers, such as input subsidies, permits, rates, irrigation facilitation, and training and sensitization for the adoption of modern farming technologies for high yields and productivity [2]. The expansion of big climate data and its analytics has resulted in the widespread use of smart information management systems, precision agriculture, and intelligent automatic agriculture [17].

3.2 Deep Learning

According to [16], deep learning technologies are now being used in a variety of agricultural and farming systems. Autonomous weed identification can aid in weed control, resulting in higher yields. Weed detection in crops using imagery is a difficult task because weeds and crops have similar colors, shapes, and textures during the growth stage. Deep learning is an important branch of machine learning. Deep learning is a type of artificial intelligence that is trained on data sets and then learns on its own, and it is at the heart of many technologies [39]. Aside from image segmentation, object detection, and identification, deep learning algorithms have several advantages over previous machine learning approaches. Machine learning algorithms can be used in precision agriculture decision support tools to recognize statistical correlations rather than causal explanations. It takes into account a set of entities such as crop yields in addition to data characteristics (training data) linked to entities such as weather conditions and soil conditions to predict the outcome [5]. Deep learning is defined as an "algorithm-assisted structure that mimics human learning" [9]. Robotic vision is based on machine learning from real-world datasets using methods such as deep neural networks, allowing robots to share their knowledge by learning from Big Data [10]. Machine Learning is an Artificial Intelligence subset that can detect patterns and anomalies in data generated by smart sensors [41].

Deep Learning algorithms have been used in agriculture in a variety of ways. Recurrent Neural Networks (RNN), Convolutional Neural Networks (CNN), and Generative Adversarial Networks (GAN) are examples of these (GAN). Deep Neural Networks can extract their features, allowing them to prompt multifaceted relationships or patterns amongst the data [52]. Convolutional neural networks (CNNs) are Deep Learning models that interact with images by extracting features or objects and learning to differentiate between them [18]. Deep learning enables computational models with multiple layers of processing that represent multiple data levels of abstraction. The layering aspect is learned from data rather than created by humans using a general-purpose learning technique. Several Deep Learning algorithms rely heavily on the Back Propagation Neural Network. Weather forecasting, plant disease detection, image translation, fruit counting, land classification, obstacle detection, plant classification, weed identification, animal behavior classification, and yield prediction are all areas where deep learning is used in agriculture [44], [9].

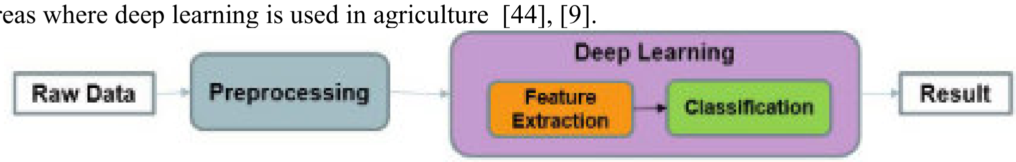

Figure 2: Deep Learning Approach (Adapted from [52])

4. Typical Application Areas

Pest Management is one of the most common applications of smart technologies in precision agriculture. Insect pest infestation in agriculture has been a major issue for farmers, resulting in significant economic losses. These can be mitigated by the development of computerized systems that identify active pests and advise on control measures [3]. Modern and intelligent technology, such as the use of drones, can independently eradicate pests and selectively target agrichemicals, reducing collateral damage to the ecosystem, lowering resistance, and lowering costs [22].

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Figure 3: Drones with precision sprayers (adapted from [22])

Weed Control: The direct application of herbicides in the field to control weeds has had a significant impact on the environment and human health complications. Nonetheless, technological advancements have enabled the use of artificial intelligence for safe and risk-free herbicide applications. The use of a rule-based expert system; machine vision; neural network models (backpropagation, counter propagation, and radial basis function-based model); and image analysis are among the approaches that are now taking center stage in weed identification and elimination [47]. Artificial intelligence sensors can detect and target weeds before determining which herbicides are needed and when. As a result, we save money by not using as many herbicides and we reduce the number of toxins in our food. Machine vision can aid in site-specific crop management by detecting and distinguishing the presence of weeds in the crop and identifying the weed for the appropriate chemical to spray [27].

Agricultural Product Monitoring: Food monitoring and quality control mechanisms based on proper drying, storage, and grading of harvested crops are critical. These practices can be aided by the conception of artificial intelligence [1]. *Storage Management:* Many agricultural products are lost as a result of poor storage management systems. Unrequired temperature, moisture, and other environmental factors can contribute to the toxicity of food products or aid in the infestation of insects, microorganisms, rodents, and other pests, all of which harm the quality and quantity of food products. IoT, AI, and data analytics will be used to improve agricultural product storage [11]. *Crop disease management:* Crop diseases reduce crop productivity yield. Precision agriculture is the adaptation of a computer-aided system that can assist in the identification of crop diseases and proposed control measures. Various systems and algorithms for predicting, classifying, detecting, and controlling crop diseases have been proposed. Rule-based systems, a fuzzy logic-based model, an artificial neural network-based model, an image processing model, and the k-means segmentation algorithm are among the techniques used [3]. *Weather Monitoring:* The growth of plants is dependent on weather conditions and factors such as sunlight and rainwater, which are now naturally unpredictable as a result of human pollution and global warming. The new technologies can monitor and predict the weather, providing farmers with useful information to help them avoid unfavorable conditions that can reduce crop yields [42]. *Irrigation Management:* IoT-based smart irrigation systems help improve irrigation efficacy by reducing water loss and conserving current water resources [1].

Yield Prediction: The prediction model is critical for precision agriculture analytics because it forecasts crop yield, which is critical for marketing strategies and crop cost estimation. A backpropagation learning algorithm of an artificial neural network has been used to forecast yield based on soil parameters, atmospheric inputs, and fertilizer consumption [3]. *Management of Soils:* Soil management is a critical area in agriculture that requires attention because improper soil management results in a loss of crop yield and quality. Soil minerals and pH levels must be measured and monitored for plants to grow healthier as a result of proper soil minerals and pH levels [42]. Any farmer will find the soil to be a fascinating resource. The use of large harvesters has greatly damaged and compacted soil, and the overuse of agrochemicals, such as nitrogen fertilizer, has harmed the environment. Aside from autonomous technologies, the use of robotics could be of great assistance and relief to farmers. Drone data analytics are used to make smarter nitrogen fertilizer applications for healthy vegetation. Bonirob (a car-sized robot) is used to measure soil value indicators using various sensors and components, including a moisture sensor and a penetrometer that can evaluate soil compaction [22]. Artificial intelligence techniques can help with supervised activities such as crop and land suitability mapping, stem water intake estimation, soil water content management, soil moisture, and rainfall prediction [3].

Figure 4: Bonirob (car-sized robot) for measuring soil quality (adapted from [22])

Agricultural Machinery Management: Agricultural machinery, such as tractors, must be managed to improve agricultural efficiency, competitiveness, and sustainability. Integrating these types of machinery with smart technologies will aid in reducing negative environmental effects, increasing soil productivity, and promoting economic yields. Smart agricultural machines are quick, versatile, precise, and intelligent, with low carbon dioxide emissions and bioenergy utilization [1]. IoT-enabled agricultural machinery can boost crop productivity while reducing grain losses. Furthermore, the use of global positioning systems and global navigation satellite systems can improve machinery because they can be driven in autopilot mode. Machines with vehicles, unmanned aerial vehicles, and robots can be controlled remotely, allowing farmers to map their field management practices such as fertilizing, irrigation, nutrition, and so on [11].

Figure 5: Autonomous Harvester (adapted from [10])

5. Economic Benefits

Advances in technological services, new business models, and markets drive significant GDP growth [45]. Radical advancements in information systems, such as satellites, the internet, mobile phones, and social media, are now being used to solve agricultural challenges. Artificial intelligence and the Internet of Things are revolutionizing agricultural activities, addressing productivity issues such as weather unpredictability, crop loss, and economic stagnation [26]. These IoT technologies collect data and relay it to data analytics for in-depth analysis. Farmers receive the analyzed data via devices such as smartphones. The data helps farmers manage crop varieties, phenotypes, and selection, crop performance, soil quality, pH level, irrigation, and fertilizer application quantity [19].

As of the popularity of IoT, it can now be used in a variety of fields (i.e. smart home, smart agriculture, smart city, smart health-care, smart logistics, smart transport, smart energy, and so on) It is estimated that the world's population will reach 9.7 billion by 2050, up from 7.7 billion today [20]. This raises concerns about food security, in addition to global warming, which has made climatic conditions uncertain, scarcity of natural resources, and arid land, which are the most significant challenges faced by the majority of countries. This necessitates the implementation of novel and strategic agricultural production methods. As a result, for future food sustainability, most countries are opting for precision farming with the use of both IoT and data analytics. This will enable smart agriculture, which is expected to improve operational efficiency, crop quality, and crop yields [11]. Big data's role is to extract valuable insights from massive amounts of heterogeneous data about crop growth and other parameters measured [31].

6. Challenges Affecting Adoption of Sustainable Precision Farming

The adoption of innovative technologies in precision agriculture has not been easy. Industrial agriculture techniques are already heavily criticized for harming the environment, according to [8]. Examples of such effects include: I Monocultures reduce biodiversity in plants and animals. (ii) The use of chemical pesticides and fertilizers pollutes the soil and groundwater. (iii) Soil degrades much faster than it can be replenished. (iv) Extinction of fish. (v) Excessive use of water and fossil fuels. (vi) The global population is expected to increase significantly, increasing global food demand. (vii) Fertilizer and pesticide prices are also projected to increase. According to [35], the following are the barriers to precision farming implementation in developing countries: a) The cultures and perceptions of users. b) A scarcity of technical expertise on the local level. c) Taking into account system heterogeneity and market imperfections. d) The availability, quality, and cost of data. e) A small farm size and a lack of success stories. f) Knowledge and technology gaps. h) Land ownership, infrastructure, and institutional constraints.

Among the factors impeding full implementation among farmers are *Concerns about privacy and trust:* The presence of malware attacks and data thefts is a risk factor for connected systems. Because of their presence in the complex IoT system, these malicious third-party programs are difficult to detect and remove. There is an urgent need for a strong security and policy framework for agricultural IoT and other technologies for systems to promote trust and be more acceptable to customers [43], [50]. *Agronomical challenges* include a lack of basic information, limited sampling and inspection procedures, information misuse, a lack of qualified agronomic services, and a lack of site-specific fertilizer references [25]. *Profitability issue:* The inability to demonstrate that the use of precision agriculture technology improves farm profitability through the strategy of “right quantity of crop inputs in the right location at the right time” [34], [21]. *Lack of skills:* Precision agriculture is primarily information-intensive and technology-driven, necessitating extensive technical skills gained through education and training to analyze data and exhaustively interpret information derived from data mining techniques and algorithms [37],[25]. *Cost challenge:* Precision agriculture management activities such as the use of machinery such as driverless tractors with sensors that are suitable for large-scale farmers are not cost-effective for domestic farmers. Financial constraints and a lack of credit for technological machinery and inputs are deterring farmers from adopting precision farming [50].

Lack of broadband infrastructure: Due to the unfavorable landscape, internet connectivity in remote rural areas in developing countries is unreliable. As a result, improved network performance and bandwidth speeds are required in these areas. Precision agriculture systems located in farm environments with poor connectivity cannot effectively share data with other systems on the same farm. The issues with GPS signals and agro-sensors/gateways have an impact on cloud services in terms of data transmission and storage [48]. *Technical challenges:* Any mechanical failure in technological equipment, such as hardware or IoT sensors, causes serious crop damage. For example, if a smart irrigation sensor fails, crops may be under-watered or over-watered, affecting crop growth. Food security can also be jeopardized if storage technologies fail or if there is a power outage with no backup power [25], [48]. *Perception of utilitarianism:* Farmers' negative attitudes toward the use of precision agriculture technologies in comparison to traditional farming methods. This has had a significant impact on adoption rates, necessitating the need for farmer education, sensitization, and awareness [25].

7. Critical Success Factors for Implementation of Precision Agriculture

Agricultural service providers are filling the gap in assisting farms in making use of the data they collect and optimizing it for strategies such as variable rate application, zone-based soil sampling, soil electrical conductivity mapping, cloud solutions, and areas-based plant tissue testing [14]. *Adoption of new technologies:* Smart devices and methods for detecting and monitoring biotic factors such as weeds and diseases must be implemented. This technology aids in the management of soil moisture as well as variable irrigation applications [23]. *Transdisciplinary approach:* By combining several competencies and academic fields, ICT can make a significant contribution to long-term sustainable development. These disciplines must collaborate to help develop sustainable agricultural development through a transdisciplinary approach that has the potential to impact society on multiple levels [29]. *The assistance provided by governments and the private sectors:* As a result, early adoption assistance from governments and the private sector is critical [35].

Training programs: Farmers must be trained in the proper use of innovations and consultation, particularly data, software management, and analysis resources. This can instill confidence that today's precision agriculture tools provide the most critical insights [23]. *Bringing together temporal and spatial data*: Bringing together temporal and spatial output data can help farmers and advisers manage fields or farms due to differences in agricultural average yield and variation to improve nutrient uptake [14]. *Data quality assurance* is required because quality data must be handled and retrieved. It is necessary to ensure the use of predictable or precise sensors for smarter agronomic data for inputs explaining receptiveness under various environmental pressures [23].

8. Conclusions and Recommendation

The study assessed the application of various technologies in precision agriculture. Farmers will find agricultural problems obsolete as a result of the use of IoT, Big Data, and Deep Learning. Big data provides predictive insights into farming practices, drives real-time effective decisions, and redesigns business processes to create game-changing business models. Weather forecasting, plant disease detection, image translation, fruit counting, land classification, obstacle detection, plant classification, weed identification, animal behavior classification, and yield prediction are all areas where deep learning is used in agriculture. The study also looks at the typical application areas and challenges in precision agriculture adoption. The study examines the critical success factors for implementing precision agriculture. According to the findings, technological advancements, new business models, and markets drive significant GDP growth. The study recommends the adoption and optimization of innovations and technologies that will enable precision farming to be sustainable through quality practices and increased productivity.

References

[1] Alreshidi, E. (2019). Smart Sustainable Agriculture (SSA) solution underpinned by Internet of Things (IoT) and Artificial Intelligence (AI). *International Journal of Advanced Computer Science and Applications*, *10*(5), 93–102.

[2] Alves, G. M., & Cruvinel, P. E. (2016). Big Data Environment for Agricultural Soil Analysis from CT Digital Images. Proceedings - 2016 IEEE 10th International Conference on Semantic Computing, ICSC 2016, 429–431.

[3] Bannerjee, G., Sarkar, U., Das, S., & Ghosh, I. (2018). Artificial intelligence in agriculture. *Agricultural and Livestock Technology / АгроЗооТехника*, *7*(4 (4)).

[4] Banus, S. (2015). Precision Agriculture: Tomorrow's Technology for Today's Farmer. *Journal of Food Processing & Technology*, *06*(08).

[5] Boghossian, A., Linsky, S., Brown, A., Mutschler, P., & Ulicny, B. (2018). *Threats to Precision Agriculture*.

[6] Bongiovanni, R., & Lowenberg-deboer, J. (2004). Precision Agriculture and Sustainability.*Precision Agriculture*, *5*, 359–387.

[7] Chen, S., Xu, H., Liu, D., Hu, B., & Wang, H. (2014). A vision of IoT: Applications,Challenges and opportunities with China Perspective. *IEEE Internet of Things Journal*, *1*(4), 349–359.

[8] Demestichas, K., & Daskalakis, E. (2020). Data Lifecycle Management in Precision Agriculture Supported by Information and Communication Technology. *Agronomy*, *10*(11), 1648.

[9] Diaz, M. C. A., Medina Castaneda, E. E., & Mugruza Vassallo, C. A. (2019). Deep Learning for Plant Classification in Precision Agriculture. *2019 International Conference on Computer, Control, Informatics, and Its Applications: Emerging Trends in Big Data and Artificial Intelligence, IC3INA 2019*, 9–13.

[10] Duckett, T., Pearson, S., Blackmore, S., Grieve, B., Chen, W.-H., Cielniak, G., Cleaversmith, J., Dai, J., Davis, S., Fox, C., From, P., Georgilas, I., Gill, R., Gould, I., Hanheide, M., Hunter, A., Iida, F., Mihalyova, L., Nefti-Meziani, S., … Yang, G.-Z. (2018). *Agricultural Robotics: The Future of Robotic Agriculture*.

[11] Elijah, O., Rahman, T. A., Orikumhi, I., Leow, C. Y., & Hindia, M. N. (2018). An Overview of Internet of Things (IoT) and Data Analytics in Agriculture: Benefits and Challenges. *IEEE Internet of Things Journal*, *5*(5), 3758–3773.

[12] Far, T. S., & Rezaei-Moghaddam, K. (2017). Determinants of Iranian agricultural consultants' intentions toward precision agriculture: Integrating innovativeness to the technology acceptance model. *Journal of the Saudi Society of Agricultural Sciences*, *16*(3), 280–286.

[13] Ferrández-Pastor, F. J., García-Chamizo, J. M., Nieto-Hidalgo, M., & Mora-Martínez, J. (2018). Precision agriculture design method using a distributed computing architecture on the internet of things context. *Sensors (Switzerland)*, *18*(6).

[14] Flis, S. A. (2020). Data Management and Variability: Precision Agriculture Considerations for 4R Management Planning. *Crops & Soils*, *53*(4), 14–17.

[15] Fountas, S., Blackmore, S., Ess, D., Hawkins, S., Blumhoff, G., Lowenberg-Deboer, J., & Sorensen, C. G. (2005). Farmer experience with precision agriculture in Denmark and the US Eastern Corn Belt. *Precision Agriculture*, *6*(2), 121–141.

[16] Hasan, A. S. M. M., Sohel, F., Diepeveen, D., Laga, H., & Jones, M. G. K. (2021). A Survey of Deep Learning Techniques for Weed Detection from Images. *ArXiv:2103.01415 [Cs]*.

[17] Hassani, H., Huang, X., & Silva, A. E. (2019). Big data and climate change. *Big Data and Cognitive Computing*, *3*(1), 1–17. https://doi.org/10.3390/bdcc3010012

[18] Høye, T. T., Ärje, J., Bjerge, K., Hansen, O. L. P., Iosifidis, A., Leese, F., Mann, H. M. R., Meissner, K., Melvad, C., & Raitoharju, J. (2021). Deep learning and computer vision will transform entomology. *Proceedings of the National Academy of Sciences*, *118*(2), e2002545117.

[19] Jayaraman, P. P., Yavari, A., Georgakopoulos, D., Morshed, A., & Zaslavsky, A. (2016). Internet of things platform for smart farming: Experiences and lessons learned. *Sensors (Switzerland)*, *16*(11), 1–17.
[20] Kashyap, P. K., Kumar, S., Jaiswal, A., Prasad, M., & Gandomi, A. H. (2021). Towards Precision Agriculture: IoT-enabled Intelligent Irrigation Systems Using Deep Learning Neural Network. *IEEE Sensors Journal*, 1–1.
[21] Khosla, R. (2010). *Precision agriculture: Challenges and opportunities in a flat world*. *August*, 26–28.
[22] King, A. (2017). The Future of Agriculture. *Springer Nature*, *544*(21), 174–184.
[23] Kitchen, N. R., Snyder, C. J., Franzen, D. W., & Wiebold, W. J. (2002). Educational Needs of Precision Agriculture. *Precision Agriculture*, *3*, 341–351.
[24] Kounalakis, T., Triantafyllidis, G. A., & Nalpantidis, L. (2019). Deep learning-based visual Recognition of rumex for robotic precision farming. *Computers and Electronics in Agriculture*, *165*(November).
[25] Kritikos, M. (2017). Precision agriculture in Europe: Legal, social and ethical considerations. In *European Parliamentary Research Service* (Issue November).
[26] Lakshmi, V., & Corbett, J. (2020). How Artificial Intelligence Improves Agricultural Productivity and Sustainability: A Global Thematic Analysis. *Proceedings of the 53rd Hawaii International Conference on System Sciences*, *3*, 5202–5211.
[27] Lee, W. S., Alchanatis, V., Yang, C., Hirafuji, M., Moshou, D., & Li, C. (2010). Sensing Technologies for precision specialty crop production. *Computers and Electronics in Agriculture*, *74*(1), 2–33.
[28] Liakos, K. G., Busato, P., Moshou, D., Pearson, S., & Bochtis, D. (2018). Machine learning in agriculture: A review. *Sensors (Switzerland)*, *18*(8), 1–29. https://doi.org/10.3390/s18082674
[29] Lindblom, J., Lundström, C., Ljung, M., & Jonsson, A. (2017). Promoting sustainable Intensification in precision agriculture: Review of decision support systems development and strategies. *Precision Agriculture*, *18*(3), 309–331.
[30] Machii, J. K., & Kaara, M. (2018). Big Data Analytics on Decision Making By Smart Firms in Kenya. *Research Acies International Journal of Computing and Knowledge Management (RICKM)*, *1*(1), 1–19.
[31] Marjani, M., Nasaruddin, F., Gani, A., Karim, A., Hashem, I. A. T., Siddiqa, A., & Yaqoob, I. (2017). Big IoT Data Analytics: Architecture, Opportunities, and Open Research Challenges. *IEEE Access*, *5*, 5247–5261.
[32] Mekala, M. S., & Viswanathan, P. (2017). A Survey: Smart agriculture IoT with cloud Computing. *2017 International Conference on Microelectronic Devices, Circuits and Systems, ICMDCS 2017*, *2017-Janua*, 1–7.
[33] Mekonnen, Y., Namuduri, S., Burton, L., Sarwat, A., & Bhansali, S. (2020). Review—Machine Learning Techniques in Wireless Sensor Network Based Precision Agriculture. *Journal of the Electrochemical Society*, *167*(3), 037522. https://doi.org/10.1149/2.0222003jes
[34] Mintert, J., Widmar, D., Langemeier, M., Boehlje, M., & Erickson, B. (2016). *The Challenges of Precision Agriculture: Is Big Data the Answer?* 1–9.
[35] Natikar, P. K., R A Balikai, & Ch Anusha. (2020). *Pest Management Strategies in Precision Farming*. https://doi.org/10.13140/RG.2.2.27009.48484
[36] Nukala, R., Panduru, K., Shields, A., Riordan, D., Doody, P., & Walsh, J. (2016). Internet of Things: A review from "Farm to Fork." *2016 27th Irish Signals and Systems Conference, ISSC 2016*.
[37] Ofori, M., & El-Gayar, O. (2021). Drivers and challenges of precision agriculture: A social Media perspective. *Precision Agriculture*, *22*(3), 1019–1044.
[38] Oliveira-jr, A., Resende, C., Gonçalves, J., & Soares, F. (2020). IoT Sensing Platform for e-Agriculture in Africa. In M. C. and P. C. (Eds) (Ed.), *IST-Africa 2020 Conference Proceedings* (pp. 1–8). IEEE.
[39] Pantoja, M., Kurfess, F., & Humer, I. (2020). Deep Learning for Agriculture. *2020 ASEE Virtual Annual Conference Content Access Proceedings*, 34371.
[40] Patel, K. K., Patel, S. M., & Scholar, P. G. (2016). Internet of Things-IoT: Definition,Characteristics, Architecture, Enabling Technologies, Application & Future Challenges. *International Journal of Engineering Science and Computing*, *6*(5), 1–10.
[41] Rabah, K. (2018). Convergence of AI, IoT, Big Data and Blockchain: A Review. *The Lake Institute Journal*, *1*(1), 1–18.
[42] Ramdinthara, I. Z., & Shanthi, B. P. (2019). A comparative study of IoT technology in Precision agriculture. *2019 IEEE International Conference on System, Computation, Automation, and Networking, ICSCAN 2019*.
[43] Rotz, S., Duncan, E., Small, M., Botschner, J., Dara, R., Mosby, I., Reed, M., & Fraser, E. D. G. (2019). The Politics of Digital Agricultural Technologies: A Preliminary Review. *Sociologia Ruralis*, *59*(2), 203–229.
[44] Saiz-Rubio, V., & Rovira-Más, F. (2020). From smart farming towards agriculture 5.0: A Review on crop data management. *Agronomy*, *10*(2).

[45] Salam, A., & Shah, S. (2019). Internet of things in smart agriculture: Enabling technologies. *IEEE 5th World Forum on Internet of Things, WF-IoT 2019 - Conference Proceedings*, 692–695.
[46] Tagarakis, A. C., F, V. E., Kempenaar, C., Ljubicic, N., Milic, D., Bengin, V., & Crnojevic, V. (2018). Opportunities for precision agriculture in Serbia. *14th International Conference on Precision Agriculture June 24 – June 27, 2018*, 1–12.
[47] Talaviya, T., Shah, D., Patel, N., Yagnik, H., & Shah, M. (2020). Implementation of artificial intelligence in agriculture for optimization of irrigation and application of pesticides and herbicides. *Artificial Intelligence in Agriculture*, *4*, 58–73.
[48] Tantalaki, N., Souravlas, S., & Roumeliotis, M. (2019). Data-Driven Decision Making in Precision Agriculture: The Rise of Big Data in Agricultural Systems. *Journal of Agricultural and Food Information*, *20*(4), 344–380.
[49] Tey, Y. S., & Brindal, M. (2012). Factors influencing the adoption of precision agricultural Technologies: A review for policy implications. *Precision Agriculture*, *13*(6), 713–730.
[50] Wiseman, L., Sanderson, J., Zhang, A., & Jakku, E. (2019). Farmers and their data: An Examination of farmers' reluctance to share their data through the lens of the laws Impacting smart farming. *NJAS - Wageningen Journal of Life Sciences*, 1–10.
[51] Yadav, R., Rathod, J., & Nair, V. (2015). Big Data Meets Small Sensors in Precision Agriculture. *International Journal of Computer Applications*, 1–4.
[52] Yalcin, H. (2017). Plant phenology recognition using deep learning: Deep-Pheno. 2017 6th International Conference on Agro-Geoinformatics, Agro-Geoinformatics 2017. Kitchen, N. R., Snyder, C. J., Franzen, D. W., & Wiebold, W. J. (2002). Educational Needs of Precision Agriculture. Precision Agriculture, 3, 341–351.