Precision Agriculture: Towards Emerging Trends in Food Security and Sustainability

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Abstract

Concerns about better managing the world's agricultural resources while reducing the negative environmental impact are raised by the growing strain on the population worldwide and the need to boost agricultural output, especially in the food supply chain, which is currently dealing with significant sustainability and security issues that may be exacerbated by global population expansion, continuous conflicts on a global scale, and pandemic breakouts. Hence, this review investigates and evaluates the new developments in precision agriculture and how they affect sustainability and food security. Precision agriculture, often called smart farming or site-specific crop management, is an agricultural management strategy that uses remote sensing, satellite positioning data, and information technology to maximize yield while accounting for crop and soil variability. This new agricultural trend can completely transform food security and sustainability by increasing yields, lowering input costs, and lessening environmental effects. In this review paper, we shall examine the many facets of precision agriculture, including its technology, advantages, difficulties, and potential contributions to sustainable agricultural practices and global food security.

Keywords: Precision Agriculture; Food Security; Sustainability; Agriculture

Introduction

The fast rise of the world's population poses enormous difficulties to food production systems, necessitating novel techniques to meet food security and environmental problems [1]. Precision agriculture has emerged as a viable answer, enabling farmers to make educated decisions based on accurate and real-time data from their fields [2-4]. These include using sensors, data analytics, unmanned aerial vehicles (UAVs), remote sensing, geographic information systems (GIS), and GPS. Farmers can use real-time data and the spatial variability of their fields to guide their decisions about planting, irrigation, fertilizer, pest management, and harvesting by integrating various tools [5-7]. The use of precision agriculture has been fueled in large part by technological breakthroughs. With the aid of GPS technology, farmers can precisely map and monitor field conditions, allowing them to apply inputs like pesticides, fertilizers, and water [8]. Technologies for remote sensing offer important information about crop health, soil moisture content, and nutrient shortages [6,9,10]. Multispectral sensors on UAVs enable the capture of high-resolution photos for in-depth crop condition assessments [11].

Precision agriculture has various advantages for farmers as well as the environment. Farmers can minimize expenses while boosting yields by optimizing input utilization based on unique field conditions. By reducing the usage of fertilizers and pesticides, this focused method reduces the environmental effect of agricultural activities [6]. Furthermore, by promoting efficient irrigation techniques, precision agriculture aids soil conservation and water resource management. Despite the great promise, certain difficulties must be solved to optimize precision agricultural acceptance and efficacy [12]. These include the high initial cost of technology installation, rural infrastructure limitations, and barriers for small-scale farmers. A learning curve is connected with comprehending and effectively utilizing precision agriculture data [11,12]. Data privacy and security concerns must also be addressed to secure the security of important farm information. Precision agriculture, on the other hand, has the potential to become the norm across farming techniques globally as technology progresses and becomes more accessible, ensuring sustainable food production and better food security [4,10]. This paper discusses the latest trends in precision agriculture and how they contribute to improving food security and ensuring sustainable farming practices.

Key Areas of Precision Agriculture

- Remote Sensing and Imagery: Remote sensing technologies like drones and satellites are revolutionizing how farmers monitor and manage crops. These tools provide high-resolution images and data on plant health, nutrient deficiencies, and pest infestations. By using this data, farmers can efficiently allocate resources, optimize crop treatments, and minimize crop losses [11,13].
- GPS and Navigation Systems: Global Positioning Systems (GPS) and navigation systems are essential components of precision agriculture. They allow farmers to track field boundaries precisely, monitor equipment movements, and create accurate planting and harvesting maps. GPS enables precise operations, leading to minimized overlaps and reduced input usage, ultimately improving resource efficiency.
- Variable Rate Technology: Variable rate technology (VRT) helps farmers apply inputs, such as fertilizers, pesticides, and water, precisely where and when needed. By utilizing VRT, farmers can tailor the application rates based on field variability, optimizing resource allocation and significantly reducing environmental impact.
- Big Data Analytics: Integration big data analytics in precision agriculture provides opportunities for data-driven decision-making. Large datasets from various sources, such as weather stations, sensors, and historical records, can be analyzed using machine learning algorithms to generate insights and predictions about crop growth, yield potential, disease outbreaks, and optimal harvest timing [11].
- Precision Irrigation: Water scarcity is a significant concern in agricultural systems. Precision irrigation techniques, such as drip irrigation and soil moisture sensors, ensure water is delivered precisely where and when plants most need it [7]. These technologies contribute to efficient water usage, reduced runoff, and improved crop yield.

Benefits and Implications

Precision agriculture offers numerous benefits for both farmers and the environment. PA management systems combine traditional agriculture and computer technology, enhancing crop production, reducing input costs, and reducing environmental effects [12,13]. They allow farmers to apply inputs heterogeneously across a field, leading to better production stability and reduced environmental impacts [14]. PA has been shown to enhance food security in various production and management areas. Precision agriculture also benefits the environment by lowering chemical pollution, cutting carbon emissions from farm gear, and preserving water resources.

Furthermore, by increasing crop monitoring and management, precision agriculture helps to reduce yield variability and improve overall food security [4]. Instead of being a machine operator working in the field, handling machine steering, and manually adjusting equipment, today's commercial farmer, who is fully versed in the current farming skills and knowledge, will need to become a sort of information technology (IT) manager working from an office or in front of a screen (computer, mobile phone, tablet, etc.) [3]. PA can improve crop yields, reduce water and fertilizer use, improve soil health, enhance biodiversity, and increase resilience to climate change [8,15]. PA also helps farmers reduce their carbon footprint by promoting conservation tillage and using cover crops to sequester carbon and aids the enhancement of farming systems' resilience to climate change by enabling real-time adaptation [15].

PA adoption varies globally based on crop and cropping systems and farmer characteristics. Despite its three-decade history, its widespread use is limited. High-use areas include developed countries with mechanized agriculture and large fields, while lower-use areas are common in developing countries without mechanization and smaller fields. PA management systems are a crucial aspect of precision farming, allowing farmers to manage their resources efficiently and effectively [12]. Early mechanical inventions and non-digital practices were simple and widely used, but today, PA systems are technology-dependent and can exist outside sensors,

computers, software, and controllers. However, knowledge specific to the situation is crucial for small landholders to successfully implement a non-digital-based PA management system, as finding competent advisors and workers can be challenging even at the retail level.

Future Perspectives

Today, the digital revolution's promise has introduced technology in which sensors offer data converted into information to influence crop and animal management decisions, aid in breeding, and better link farmers, processors, distributors, retailers, and others [11,16]. PA's future provides promise for additional innovation and integration as technology advances. Precision agriculture will benefit from the development of artificial intelligence (AI) algorithms for predictive modeling and decision support systems. Integration with smart farming practices and the Internet of Things (IoT) will allow for seamless interaction between various agricultural operations components [11]. Furthermore, as global challenges such as climate change and population growth place increasing pressure on food systems, precision agriculture will play a vital role in meeting the demands for sustainable food production [2]. Also, agricultural operations using tractors integrate traditional mechanics with geolocation technologies, improving efficiency and saving time, fuel, labor, and production factors, thereby advancing precision agriculture [3,9]. With a growing global population and increasing pressure on agricultural resources, precision agriculture offers a pathway to meet the demand for food sustainably. As a result, several competencies approaches, and scientific disciplines must work together to develop sustainable agriculture, given that the overall trend in agriculture is toward more complex, technologically-based crop production, with increasing regulation and supervision regarding the use of fertilizers, pesticides, and other chemicals [13,14]. It helps to ensure a secure food supply for present and future generations by maximizing yields while limiting inputs. Precision agriculture and its influence on food security align with environmental aims by supporting prudent land management techniques [4]. Targeted input application decreases chemical runoff into bodies of water and reduces greenhouse gas emissions associated with excessive fertilizer use. Precision agriculture contributes to the long-term viability of agricultural systems by conserving resources and optimizing production.

Conclusion

Agriculture faces enormous challenges—the agricultural sector is expected to meet multiple goals and societal values simultaneously (e.g., increased food production, preserving and developing cultural heritage, biodiversity, climate change, and recreational values) while remaining both sustainable and economically viable over the long term. PA is changing how farmers work by giving them vital insights and tools to help them optimize their practices and improve overall food security and sustainability. The development related to precision agriculture described in this review study includes remote sensing, GPS navigation, variable rate technologies, big data analytics, and precision irrigation. Farmers may cut costs, optimize resource utilization, and make a difference in a more equitable and resilient food system by applying precision agricultural practices. It can address modern agriculture's challenges by leveraging cutting-edge technologies and data-driven insights while promoting efficient resource utilization, reducing farmer production costs, contributing to a more sustainable and secure food system, and environmental stewardship.

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