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Digitalizing Agriculture for Sustainable Crop production

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Abstract

With the ever-increasing dilemma experienced by the agricultural sector, due to the ever-increasing and continuous demand for food, feed, and fiber amidst population growth and declining conditions that favor agricultural productivity, there is a need to develop means of producing agricultural products more sustainably through highly efficient and effective models. Digital technologies in the agriculture sector, present a ray of hope with tools such as Geographical Information System (GIS), Remote Sensing (RS), Artificial Intelligence (AI), Precision Agriculture (PA), etc. The incorporation of digital technologies in agriculture may help solve the problem of global warming and the ever-increasing population associated with declining levels of natural resources. Hence, digital agriculture has the potential to revolutionize sustainable crop production substantially, to achieve the goal of 'zero hunger'. Therefore, the present review highlights some of the digital technology tools and their role in sustainable crop production if utilized efficiently.

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Introduction

In this changing world, the continuously growing demand for fiber, feed, and food has been increasing the pressure on the agroecosystems (Okolo et al., 2019; Clapp and Ruder, 2020; Bahn et al., 2021). Agroecosystems' natural resilience is adversely affected by increased stress whether biotic or abiotic, and it is anticipated to cause unprecedented environmental changes globally (Okolo et al., 2019; Strizhkova et al., 2020). Changing climatic conditions may result in altered rainfall patterns, low and high heat stress, increased frequency of floods, droughts, cyclonic disturbances, etc. these events, in turn, result in high unsustainable crop production costs, disease incidences and pest infestation which collectively have the potential to increase pressure on the agricultural land globally (Lobell et al., 2012, Abhilash and Dubey, 2014; Garske et al., 2021; Mondejar et al., 2021). The rising demand for food and the pressure on global agricultural land depicts a huge task for future agriculturalists in meeting the food requirements of an estimated 9.7 billion people by 2050 (Dubey et al., 2019; Hrusteck, 2020; Prause, 2021). However, the emergence of digital technologies in the agriculture sector presents a ray of hope (Mondejar et al., 2021). Therefore, the objective of this review is to uncover the contributions and the potential that digitalization has in enhancing sustainable crop production.

Literature Review

Central to agriculture development has been an emphasis on operational feasibility (Bersani, 2020: Hrusteck, 2020). Suffice to say, among some pivotal challenges in today's agriculture is sustainable crop production, which lies in efficient and effective processes in agriculture at lower costs, the provision of better and safe working conditions for all stakeholders and the environment, and an increased synergy among them, creating the possibility to making decisions on issues that are beyond their capacity (Hrusteck, 2020; Arvanitis et al., 2020; Lorenzo, 2020). To achieve, sustainable crop production, there is a need to simultaneously consider, areas of social aspects, economics, and the environment (Belaud et al., 2019; CAP, 2020). The proposal from the European Commission on an agricultural policy covering the period of 2021 to 2027 includes nine goals and these are; ensuring a fair income to farmers, rebalancing the power in the food chain, increased competitiveness, environmental care, climate change action, landscaping, and biodiversity conservation, supporting of generational renewal and vibrant rural areas, and the protection of food and health quality (Garske et al., 2021). According to Garske et al., 2021, these objectives form a basis for strategic plan development that can and has a high potential of ensuring and enhancing the achievement of sustainable crop production based on digital technologies and the revolutionizing of the agricultural sector. The focus of the objectives on economic issues, and social and environmental aspects have helped in giving a clear signal that it is important to establish sustainable crop production achieved through digitalizing the agricultural sector (Hrusteck, 2020; Garske et al., 2021).

Uncertainty and risk are on the rise, scarce resources and their cost, climate change, and fluctuating market conditions present a bottleneck that limits decision making for both farmers and different stakeholders i.e., policymakers (Lammers et al, 2018; Meike, 2019; Arvanitis et al., 2020; Hrusteck, 2020). The ever-changing trends have resulted in a new era in which digital technologies achieve more than human capabilities, even in activities that were previously unattainable through automation, such as those activities that involve pattern recognition in changing or uncertain environments (Yahya, 2018). Therefore, digital transformation becomes inevitable for any business that has growth, expansion, quality, and sustainability as its core and central purpose. Digital transformation has five key factors through which digital maturity can be achieved, these include; strategic orientation, ICT and process infrastructure, customer centricity, talent, capability and capacity strengthening, organizational culture, and innovation (Hrusteck, 2020). Hrusteck (2020) further states that digital technologies have a transformative effect on the society and economy globally. To achieve this transformational effect globally, there is a need for the preparation and implementation of strategies that incorporate digital technologies (Clapp, 2020; Strizhkova et al., 2020; Bahn et al., 2021; Paushinger and Klauser, 2021).

Until now, digital technology's usefulness in agriculture has had its limitations in areas of sustainable crop production (Garske et al., 2021, Paushinger and Klauser, 2021). However, the basis of future research will be smart digital services that can and have the potential to help the agricultural sector in meeting the challenges of sustainable crop production (Prause, 2021). The increasing and exponential growth of computing capabilities are expected to result in cheaper, faster, and greater availability of solutions that are effective, efficient, and smart, in the agricultural sector (Arvanitis et al., 2020; Strizhkova et al., 2020; Bahn et al., 2021; Prause, 2021).

Digitalization and Agriculture

The advent of digitalization in the agriculture sector has up-scaled the sustainability of crop production through sustainable management of land and other resources as well as strengthening the associated services, productivity, and livelihood security globally. Rapid and significant strides have been made within the agricultural sector by digitalization, making its impact felt in different subsectors of agriculture such as soil-crop suitability, land assessment, crop-growth, weather information, precision farming, biomass, and productivity, etc. (Mondejar et al., 2021). Optimization of digital agriculture has the potential to contribute multipurpose benefits for sustainable crop production through real-time monitoring, and other means such as satellite and weather information-based consultation. Digital technologies in agriculture, are also helping in selecting precise resource inputs, high yielding optimum practices, geo-tagging for precise prediction, less production cost, elastic and vigorous farming methods, post-harvest services, crop data management, and agro-based industries. Several technologies such as GIS, RS, robotics, smartphones, genomics, AI, and bioinformatics are being employed in achieving targeted sustainable crop production (Basso and Antle, 2020). According to Mondejar et al., (2021) and Basso and Antle, 2020, to achieve sustainable crop production globally, there is a need to optimize the effective and efficient use of several hardware (Sensors, drones, ground robots, robotics, nursery automation, robotics-based irrigation, automated tractors for precise crop fertilization and harvesting), software (computer imaging technology, geo-mapping, etc.), and their combination (automated weed uprooting, micro-spraying robots for precise herbicide application, and pruning robotics with computer imaging).

Digital technologies and their contribution, and potential to the agricultural sector

GIS and RS

GIS techniques and RS offers several solutions for sustainable crop production which include genotype/crop species identification, landscape and farm-level sustainable management of farming systems, and also the formulation of better policies (Basso and Antle, 2020). Therefore, leading to an increase in crop production, conservation of resources and biodiversity, and opportunities that empower farmers. The incorporation of RS and GIS-based technologies using the Analytical Hierarchy Process produces a superior database and offers a guide map for effective and efficient land use, agroecosystem activity monitoring, and better decision making. The said techniques have fast and efficient access to information, showing relationships, patterns, and very useful trends used in combining soil survey information for proper land use assessment (Singha and Swain, 2016). Different studies have demonstrated the benefits of optimally incorporating these technologies as a viable means for sustainable crop production (Bahn et al., 2021; Pauschinger and Klauser, 2021; Mondejar et al., 2021). Mondejar et al., (2021), further state that, the smart incorporation of GIS-based technologies in agriculture, promises far much better farming systems that could be used to achieve the targeted sustainable crop production while enhancing production area resilience and mitigating climate change.

Mobile Apps

Generally, the transformation of agriculture has been proceeding rapidly, with agricultural digital technologies being the major and central player behind the novel transformation. Mobile application software usage, by almost all the stakeholders in the agriculture sector, has the potential to enhance the effective and efficient use of resources and further help in reducing costs related to production while at the same time increasing yields and economic returns (Qiang et al., 2011). The use of mobile apps by technical and scientific professionals, including farmers, is enabling access to information related to climate-smart agricultural practices. If optimally used, mobile apps have the potential to contribute significantly to sustainable crop production. The incorporation of digital technologies in agriculture assists in the process of decision-making during crop production and later stages i.e., stages of the supply chain. The effectiveness and efficiency of mobile apps and their impact on agricultural information dissemination to farmers have been validated (Mittal and Mehar, 2016; Mondejar et al., 2021). According to Deressa et al., (2011) and Bu and Wang (2019), the incorporation of APP-based agricultural services in crop production with climate-smart agricultural practices could be the main driver of greener and cleaner sustainable crop production, which is one of the agenda for sustainable global development.

AI

According to Frankenfield (2021), AI can be defined as the incorporation of human intelligence into the machines programmed to perceive things like how the human being would perceive and imitate their behavior/action. The concept of AI applies when referring to machines that show characteristics related to human minds and central to AI are machine learning, deep learning, and computer vision (Paschen, 2020). AI can be applied through robotics and this has the potential to help the agricultural sector reach and explore areas that have not been previously explored, at the same time providing easy ways of executing what would have been explored. Various studies have proven AI to contribute to the significant impact of precision agriculture in sustainable crop production (Vasconez et al., 2019; Jung et al., 2021). For instance, the incorporation of advanced AI models, and cloud technology have the ability and high potential to preserve and conserve critical agricultural resources while enhancing sustainable crop production (Bu and Wang, 2019 Mondejar et al., (2021).

PA

PA can be defined as a farming practice that is undertaken at an accurate place and specific timing than uniform adoption across the whole field (Maes and Steppe 2019; Vasconez et al., 2019; Jung et al., 2021). PA is part of the digital technologies that have the potential to contribute to sustainable crop production. Some of the fundamental attributes of PA are; lesser ecological risks, economic gains to the farming societies, and higher crop yield. PA employs deep learning processes, AI, and robotics and is climate-smart and a sustainable crop production practice. The path of PA is strengthened by tools such as modern unmanned aerial vehicles or drones, that enable the provision of hyper-class remote sensing spatiotemporal and spectral recordings that are capable of solving multifarious problems that are associated with farming communities and agroecosystems. Tools such as modern unmanned aerial vehicles contain several sensors used in predicting real-time information on parameters such as soil nutrients, drought, yield, plant growth, diseases, weeds, weather parameters, moisture content, soil type, fertilizer, and spray pesticides (Vasconez et al., 2019). If optimally used, such tools can significantly affect the implementation of sustainable crop production positively.

Conclusion

Digital technologies have the potential to revolutionize the agriculture sector by significantly impacting the concept of sustainable crop production with a smart approach. Digitalization in agriculture presents a ray of light given the current challenges experienced in achieving sustainable crop production. The benefits that lay in the application of digital technologies cannot be questioned anymore, and Geographical Information System (GIS), Remote Sensing (RS), Artificial Intelligence (AI), Mobile Apps, Precision Agriculture (PA), Bioinformatics, etc. are being used, and still can be optimally applied to achieve sustainable crop production. The current review has provided an overview of the contributions that digital technologies have made to the agricultural sector, specifically the subsector of crop production. Besides, unlike other reviews, the current review highlights the untapped and under-highlighted potentials that digital technologies have if used effectively and efficiently, in a bid to achieve sustainable crop management.

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Conflict of Interest

The authors declare no conflict of interest.

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