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# Smart Agriculture

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## ABSTRACT

Smart agriculture (also referred to as digital, precision or climate-smart agriculture or smart farming) is the use of modern advanced technology to improve the efficiency, quality, productivity, and sustainability of agricultural practices. These are tools used to digitally collect, store, analyze, and share electronic data and/or information in agriculture. Digital agriculture includes (but is not limited to) precision agriculture. However, unlike precision agriculture, digital agriculture impacts the entire agri-food value chain – before, during, and after on-farm production. Therefore, on-farm technologies like yield mapping, GPS guidance systems, and variable-rate application, fall under the domain of precision agriculture and digital agriculture. Under digital agriculture are e-commerce platforms, e-extension services, warehouse receipt systems, blockchain-enabled food traceability systems, tractor rental apps, but not under precision agriculture. This paper dives into the pros, cons, benefits, and the future prospects of smart agriculture.

***KEYWORDS:*** *Smart agriculture, blockchain, on-farm technology, sustainable development goals, variable-rate application (VRA), artificial intelligence (AI), robotics, sensors, drones, satellites, Big data, machine learning, IoT*

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## INTRODUCTION

For thousands of years ago, farming has always been an essential human activity sustaining civilization. Due to the rapid increase in human population leading to the high demand for food, this has led to the increasing importance to optimize farming practices in order to meet the needs of the world's growing population [1, 2]. Therefore, in recent years, technological advancements have helped to revolutionize the approach to farming which has now led to the emergence known as "smart farming [3].

Smart farming is an innovative approach to agriculture integrating technology into farming practices, thereby enabling farmers to maximize crop yields, reduce waste, and improve efficiency [4], by the use of various technologies like sensors, drones and satellites, Big data, machine learning, artificial intelligence and the internet of things (IoT), to gather data and provide real-time insights into crop health, soil quality, and other key indicators [5], as shown in Figures 1, 2, and 3. Other benefits through smart farming include increased productivity, reduced labor costs, improved crop quality, more sustainable approach to farming, greater precision, reduced use of chemicals and fertilizers, improved decision making, greater food security, reduced vulnerability to climate change [6].

Climate smart agriculture (CSA) is a comprehensive strategy for managing farmlands, crops, livestock, and forests that counteracts the negative impacts of climate change on agricultural productivity – so as to ensure productivity, adaptation, and mitigation [7], as shown in Figures 4 and 5.

## HISTORICAL CONTEXT

The game-changer from traditional agricultural practices is the emerging innovations in digital technologies. This is referred to by the Food and Agricultural Organization of the United Nations as a revolution: "a digital agricultural revolution will be the newest shift which could help ensure agriculture meets the needs of the global population into the future" [8, 9]. This is also referred to by some others as "Agriculture 4.0," indicating its role as the fourth major agricultural revolution [10]. However, the precise dates of the Fourth Agricultural Revolution

are unclear. The World Economic Forum announced that the "Fourth Industrial Revolution" (which includes agriculture) will unfold throughout the 21st century, so perhaps 2000 or shortly thereafter marks the beginning of Agriculture 4.0 [11].

Agricultural revolutions denote the periods of technological transformation and increased farm productivity [12]. Agricultural revolutions include the First Agricultural Revolution, the Arab Agricultural Revolution, the British/Second Agricultural Revolution, the Scottish Agricultural Revolution, and the Green Revolution/Third Agricultural Revolution. Previous or past agricultural revolutions had many unresolved problems despite boosting agricultural productivity. The Green Revolution caused inequality and environmental damage, via exacerbated inter-farm and interregional inequality [8], typically biased towards large farmers with the capital to invest in new technologies [8]. Its policies was known to promote the heavy input use and dependence on agrochemicals, which led to adverse environmental effects like soil degradation and chemical runoff [13, 14], as shown in Figure 6. These negative side effects of the Green Revolution can be resolved or addressed by the adoption of digital agricultural technologies.

There is the prediction of social backlash that may arise with the fourth revolution due to use of artificial intelligence or robotics [15, 16]. Digital Agriculture Revolution is distinct as a result of the fact that: 1. Digital technologies will affect all parts of the agricultural value chain, and off-farm segments [17, 18]. 2. The farmer's role will require more analytical skills and less physical interaction with livestock/fields [18, 19]. 3. Due to the reliance on empirical evidence, the volume of data cum methods of analysis will undergo drastic changes in the digital revolution e. g as smart farm systems will continuously monitor the behavior of animals, giving insight into their behavior every moment of the day [20]. Furthermore, the increased reliance on big data would increase the power differential between farmers and information service providers [17, 21], or between farmers and large value chain actors (like the supermarkets) [17], as shown in Figures 7, 8 and 9.

## TECHNOLOGY

A wide range of technologies are involved in digital or smart agriculture, most of which have multiple applications along the agricultural value chain, some of which are:

- Cloud computing/Big Data analysis tools [17]
- Artificial intelligence
- Machine learning
- Distributed ledger technologies, including blockchain and smart contracts
- Internet of Things [22]
- Digital communications technologies, such as mobile phones
- Digital platforms, such as e-commerce platforms, like bighaat, agribegri, krisikart India. Provide digital information, pesticides, agro products delivery doorstep of farmers. Agro-advisory apps like platix offers detection of crops diseases quickly which continent and economically, or e-extention website help farmers to extend their profits.
- Precision agriculture technologies, including:

- Sensors (food and soil sensors), as shown in Figure 10.
- Guidance and tracking systems (by GPS, GNSS, RFID, IoT)
- Variable-rate input technologies
- Automatic section control
- Advanced imaging technologies, including satellite and drone imagery, to look at temperature gradients, fertility gradients, moisture gradients, and anomalies in the field, as shown in Figures 11, 12 and 13.
- Automated machinery and agricultural robots [23].

## IMPACT OF ADOPTING DIGITAL AGRICULTURE

Digital adoption is a part of the digital transformation process, which is how a company learns to get the most out of a new technology, maximizing value from software investments, providing more options for customers through new digital tools, and increasing employee productivity. The adoption of digital agriculture is to find solutions to the challenges of:

1. Producing more food to feed the over 9 billion people in 2050 [24];
2. The combating of malnutrition, climate change, food waste, and changing diets [25]; and
3. Curbing the menace of greenhouse gas emission, and maintaining (or reducing) the land used in agriculture [26] – which can be achieved by making the agricultural value chain more efficient, equitable, environmentally friendly and sustainable.

Further impacts of adopting digital agriculture will include:

*Efficiency:* This enhances economic activity by lowering the costs of replicating, transporting,

tracking, verifying, and searching for data leading to improved efficiency throughout the value chain [27].

*On-farm efficiency:* This helps to minimize inputs required for a green yield through the use of variable-rate application (VRA) technologies which makes use of precise amounts of water, fertilizer, pesticide, herbicide, etc. [28, 29]. Digital agriculture also improves labor productivity via improved farmer knowledge e. g e-extension services – by disseminating videos about agricultural practices in more than 50 languages [30, 31], which is to support and enhance productivity via decision-support services on mobile apps or other digital platforms. Allocative efficiency of physical capital is made possible within and between farms by digital agriculture e. g "Uber for tractors," which are equipment-sharing platforms like Hello Tractor, WeFarmUp, MahineryLink Solutions, TroTro Tractor, and Tringo to facilitate farmer rental of expensive machinery [32, 33], as shown in Figure 14.

*Off-farm/market efficiency*: Furthermore, digital agricultural technologies can as well make agricultural markets more efficient. Mobile phones, online ICTs, e-commerce platforms, digital payment systems, and other digital agriculture technologies can mitigate market failures and reduce transaction costs through the value chain. These can be achieved through [8]:

- Reducing information asymmetry
- Matching buyers and sellers
- Lowering transaction costs in commercial markets
- Lowering transaction costs in government services

Since no single digital agriculture technology can solve one discrete market failure, hence systems of digital agriculture technologies must work together to solve multifaceted problems.

## BENEFITS OF SMART FARMING

Some of the benefits of smart farming include [34]:

- Enhanced crop, fertilizer, and fuel storage management
- Improved operational efficiency
- Enhanced security for farm boundaries and structures
- Sustainable agricultural practices
- Enhanced safety for farm workers and livestock
- Cost-effective farming solutions

## CHALLENGES TO SMART FARMING AND SOLUTIONS

Some of the key challenges to smart farming and solutions are [35]:

- Connectivity issues in rural/remote areas: This can be addressed by the use of Low-Power Wide-Area Networks (LPWAN) like LoRaWAN and Sigfox – these networks provide long-range communication while consuming minimal power, making them ideal for remote areas. Satellite connectivity can also be used.
- High initial costs of technology: Farmer can explore government subsidies and grants aimed at promoting smart agriculture to lessen the financial burden. Many governments offer financial incentives to encourage the use of IoT in agriculture as part of broader efforts to enhance food security and sustainability. Scalable IoT solutions can as well be adopted.
- Data security and privacy concerns: To guide against cyber threat, strong encryption protocols should be used such as Advanced Encryption Standard (AES) to provide a high level of security for IoT data.
- Simplifying data integration and management: In order to manage large volumes of data, farmers can use IoT data management platforms such as IBM Watson IoT or Google Cloud IoT Core. Integrating artificial intelligence (AI) with IoT data management can further enhance data analysis.
- Overcoming interoperability issues: Farmers should prioritize IoT devices and platforms that adhere to "open standards" such as MQTT (Message Queuing Telemetry Transport) or CoAP (Constrained Application Protocol) – these standards facilitate communication between devices from various manufacturers, ensuring that they can work together within the same system.
- Limited access to technology for smaller farmers (digital divide)
- Adaptation to changing weather patterns due to climate change: Selecting climate-resilient crop varieties that can better withstand extreme weather conditions (crop diversification).
- Training and technical support: Farmers need to be trained to ensure bridging knowledge gap. Organizations could partner with technology providers to offer workshops and hands-on training in IoT setup and data interpretation.
- Regulatory framework: The solutions in this area should include addressing data privacy, ensuring standards for sensor accuracy/reliability, security, responsible use of drones (operating permits and pilot certification), clear guidelines for data sharing, robust certification for smart agriculture

technologies, ensuring ethical and sustainable implementation while promoting innovation in the sector.

- Data management: Due to large volumes of sensor data analysis which can be complex, hence the need to develop user-friendly data analysis platforms, cloud-based services, and data visualization tools.

## CONCLUSION

Smart agriculture has the potential to significantly revolutionize the agricultural sector by making use of advanced technologies such as IoT sensors, data analytics and precision farming techniques in order to increase crop yields, enhancing sustainability, and enabling more informed decision-making, that would ultimately lead to improved food security and economic viability. The successful implementation of smart agriculture will require that the challenges must be fully addressed such as infrastructure development, farmer training, data security and privacy concerns, policy/regulatory frameworks, among others so as to ensure wide-spread adoption across diverse agricultural communities. This will therefore help to address the issue of feeding the growing population and as well as protecting the environment through collaborative efforts from farmers, policymakers, technology providers and researchers to achieve its full potential. More information on smart agriculture can be found in [36, 37].

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**Figure 1. Organic farming**

Source:https://www.google.com/search?q=images+on+smart+agriculture+by+wikipedia&sca_esv=74940b13bb8c626e&udm=2&biw=1036&bih=539&sxsrf=AHTn8zq4NBC76OTj9eebFCDLQUbROBDwQ%3A1741050640811&ei=EFPGZmZMeGFhbIPpdy92Ak&ved=0ahUKEwjp4eyHnLAxXhQkEAHSVuD5sQ4dUDCBE&oq=images+on+smart+agriculture+by+wikipedia&gs_lp=EgNpbWciKGltYWdlcyBvbiBzbWFydCBhZ3JpY3VsdHVyZSBieSB3aWtpcGVkaWFIy3BQ_wpYwlJwAXgAkAEAmAG6AqABmhaqAQcwLjguNC4xuAEMyAEAAEBmAIBoAILwgIHECMYJxjJApgDAIgGAZIHATGgB8kE&sclient=img#vhid=W0ccvnUq06LgcM&vssid=mosaic

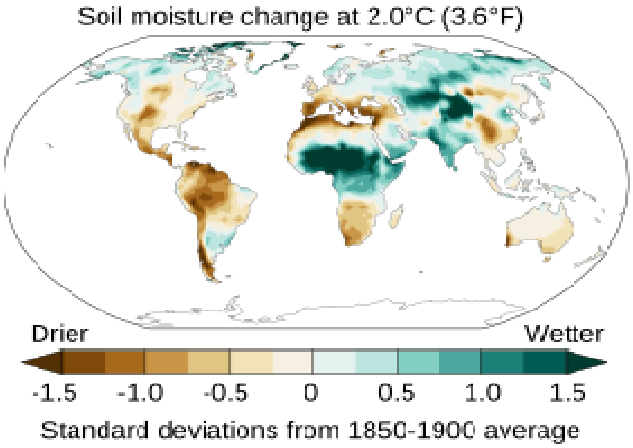


**Figure 2. Agriculture**

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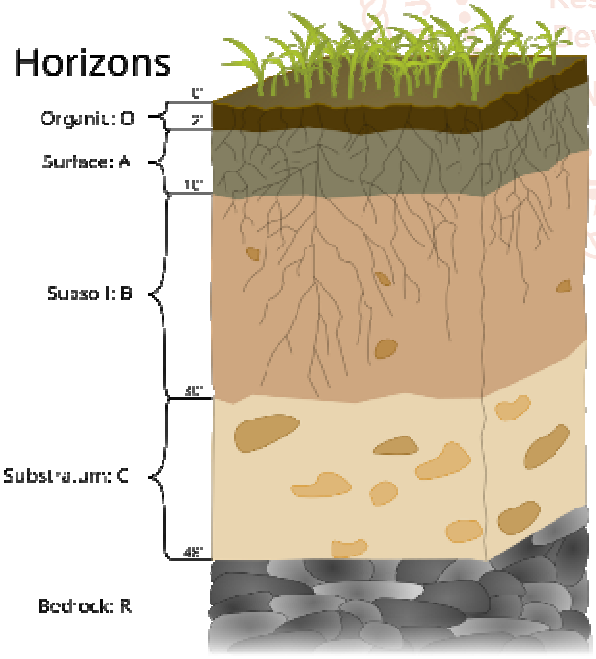


**Figure 3. Soil fertility**

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**Figure 4. Climate-smart agriculture**

Source:https://www.google.com/search?q=images+on+smart+agriculture+by+wikipedia&sca_esv=74940b13bb8c626e&udm=2&biw=1036&bih=539&sxsrf=AHTn8zq4NBC76OTj9eebFCDLQUbROBDwQ%3A1741050640811&ei=EFPGZmZMeGFhbIPpdy92Ak&ved=0ahUKEwjp4eyHnLAxXhQkEAHSVuD5sQ4dUDCBE&oq=images+on+smart+agriculture+by+wikipedia&gs_lp=EgNpbWciKGltYWdlcyBvbiBzbWFydCBhZ3JpY3VsdHVyZSBieSB3aWtpcGVkaWFIy3BQ_wpYwlJwAXgAkAEAmAG6AqABmhaqAQcwLjguNC4xuAEMyAEAAEBmAIBoAILwgIHECMYJxjJApgDAIgGAZIHATGgB8kE&sclient=img#vhid=DdaNhP46HrRh3M&vssid=mosaic

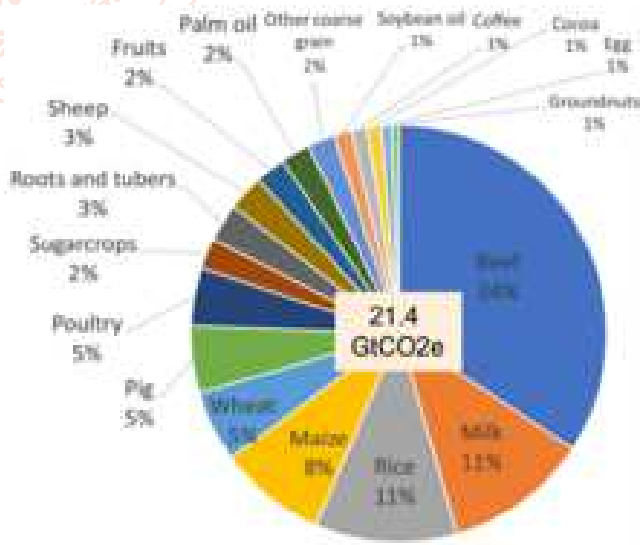


**Figure 5. Climate-smart agriculture**

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**Figure 6. Green Revolution in India**

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**Figure 7. Digital agriculture**

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**Figure 8. Agriculture**

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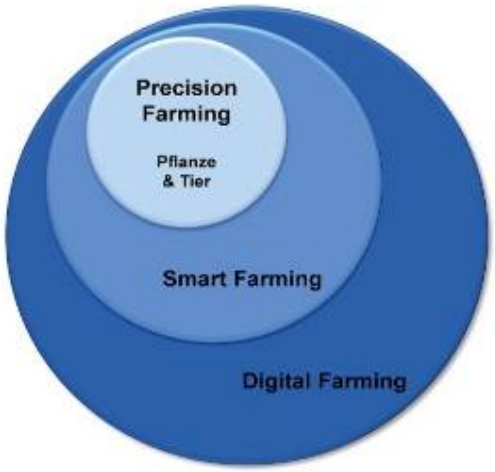


**Figure 9. Digital-Farming Systeme**

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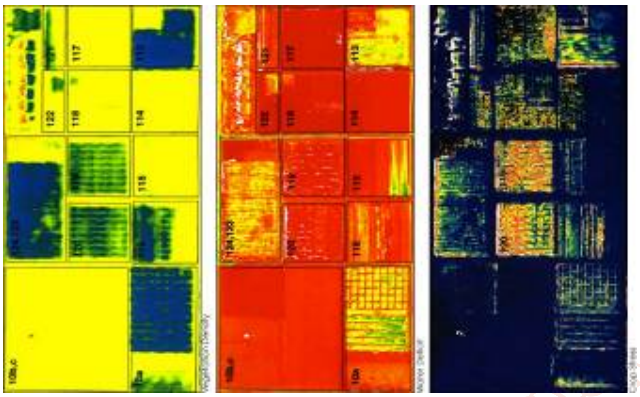

**Figure 10. Daedelus comparison, remote sensing in precision farming (rotated)**

Source:https://www.google.com/search?q=images+on+smart+agriculture+by+wikipedia&sca_esv=74940b13bb8c626e&udm=2&biw=1036&bih=539&sxsrf=AHTn8zq4NBC76OTj9eebFCDLQUbROBDwQ%3A1741050640811&ei=EFPGZmZMeGFhbIPpdy92Ak&ved=0ahUKEwjp4eyHnLAxXhQkEAHSVuD5sQ4dUDCBE&oq=images+on+smart+agriculture+by+wikipedia&gs_lp=EgNpbWciKGltYWdlcyBvbiBzbWFydCBhZ3JpY3VsdHVyZSBieSB3aWtpcGVkaWFIy3BQ_wpYwlJwAXgAkAEAmAG6AqABmhaqAQcwLjguNC4xuAEMyAEAAEBmAIBoAILwgIHECMYJxjJApgDAIgGAZIHATGgB8kE&sclient=img#vhid=u8HNlOzzbo71KM&vssid=mosaic

**Figure 11. Drip irrigation**

Source:https://www.google.com/search?q=images+on+smart+agriculture+by+wikipedia&sca_esv=74940b13bb8c626e&udm=2&biw=1036&bih=539&sxsrf=AHTn8zq4NBC76OTj9eebFCDLQUbROBDwQ%3A1741050640811&ei=EFPGZmZMeGFhbIPpdy92Ak&ved=0ahUKEwjp4eyHnLAxXhQkEAHSVuD5sQ4dUDCBE&oq=images+on+smart+agriculture+by+wikipedia&gs_lp=EgNpbWciKGltYWdlcyBvbiBzbWFydCBhZ3JpY3VsdHVyZSBieSB3aWtpcGVkaWFIy3BQ_wpYwlJwAXgAkAEAmAG6AqABmhaqAQcwLjguNC4xuAEMyAEA

**Figure 12. Vertical farming**

Source:https://www.google.com/search?q=images+on+smart+agriculture+by+wikipedia&sca_esv=74940b13bb8c626e&udm=2&biw=1036&bih=539&sxsrf=AHTn8zq4NBC76OTj9eebFCDLQUbROBDwQ%3A1741050640811&ei=EFPGZmZMeGFhbIPpdy92Ak&ved=0ahUKEwjp4eyHnLAxXhQkEAHSVuD5sQ4dUDCBE&oq=images+on+smart+agriculture+by+wikipedia&gs_lp=EgNpbWciKGltYWdlcyBvbiBzbWFydCBhZ3JpY3VsdHVyZSBieSB3aWtpcGVkaWFIy3BQ_wpYwlJwAXgAkAEAmAG6AqABmhaqAQcwLjguNC4xuAEMyAEAAEBmAIBoAILwgIHECMYJxjJApgDAIgGAZIHATGgB8kE&sclient=img#vhid=eYLzQQhsk-IQTM&vssid=mosaic

**Figure 13. Hydroponics**

Source:https://www.google.com/search?sca_esv=cf8f2fd86c54593d&sxsrf=AHTn8zrvxnEBxWsC6itM_C6Sy5uCurMORw:1741053130858&q=images+on+smart+agriculture+by+wikipedia&udm=2&fbs=ABzOT_CWdhQLP1FcmU5B0fn3xuWpAdk4wpBWOGsoR7DG5zJBkzPWUS0OtApxR2914vrjk7XZXfnfKsaRZouQANLhmphfsaRlDNPoWc6rCumaYm3VojqsiuBofLuYVqeJuzeVFrArtYn8anrtQg9oucHCeTR27yMHxAF31k9lv_a8NXq9Jk1mNfGFUy8ZFut1MXrV1vBhNe7WnE43Sd7e7305krgzHUJQw&sa=X&ved=2ahUKEwjhmpmrqOLAxVwXEEAHdXAADUQtKgLegQIERAB&biw=1036&bih=539&dpr=1#vhid=CWl78AIKHzxurM&vssid=mosaic

Figure 14. Tractor

Source:https://www.google.com/search?sca_esv=cf8f2fd86c54593d&sxsrf=AHTn8zrvxnEBxWsC6itM_C6Sy5uCurMORw:1741053130858&q=images+on+smart+agriculture+by+wikipedia&udm=2&fbs=ABzOT_CWdhQLP1FcmU5B0fn3xuWpAdk4wpBWOGsoR7DG5zJBkzPWUS0OtApxR2914vrjk7XZXfnfKsaRZouQANLhmphfsaRlDNPoWc6rCumaYm3VojqsiuBofLuYVqeJuzeVFrArtYn8anrtQg9oucHCeTR27yMHxAF31k9lv_a8NXq9Jk1mNfGFUy8ZFut1MXrV1vBhNe7WnE43Sd7e7305krgzHUJQw&sa=X&ved=2ahUKEwjhmpmrqOLAxVwXEEAHdXAADUQtKgLegQIERAB&biw=1036&bih=539&dpr=1#vhid=cnd9KKFzTJiEM&vssid=mosaic