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Importance of Smart Farming Practices for Sustainable Agriculture

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Abstract

Smart farming is a development that has emphasized information and communication technology used in machinery, equipment, and sensors in network-based hi-tech farm supervision cycles. Innovative technologies, the Internet of Things (IoT), and cloud computing are anticipated to inspire growth and initiate the use of robots and artificial intelligence in smart farming. Such groundbreaking deviations are unsettling current agriculture approaches. This paper investigates importance of smart farming practices for sustainable agriculture. This paper explores the development of agriculture into smart farming and technologies in smart farming. It was concluded that every piece of farmland is important to enhance sustainable agriculture by dealing with every inch of land using smart farming technologies. It has to be noted that transformation of agriculture in to smart farming in Africa will take some time as the nature of the sector is different and it was once a traditional sector. Issues such as communicating with older farmers, who could often not understand the technicalities of new technologies will also need to be addressed. However, with the rapid industrial revolution, every player in different industries will eventually need to embrace and adopt the change.

Keywords: smart farming, sustainable agriculture, Internet of Things, artificial intelligence

Introduction

Sustainable agriculture is a measure of the endurance and sustenance of food grains produced in an eco-friendly manner (Ai Kok, 2020). Sustainable agriculture helps in the encouragement of farming practices and approaches to help sustain farmers and resources. It is economically feasible and maintains soil quality, reduces soil degradation, saves water resources, improves land biodiversity, and ensures a natural and healthy environment (Bangkok Post. 2019). Sustainable agriculture plays a significant role in preserving natural resources, halting biodiversity loss, and reducing greenhouse gas emissions (Campbell, Thornton, Zougmoré, van Asten, & Lipper, 2014). According to Saad, & Udoh, (2023) Globally, farming provides employment opportunities and hence an important source of uplifting the socio-economic status.

Sustainable agriculture farming is a method of preserving nature without compromising the future generation's basic needs, whilst also improving the effectiveness of farming. The basic accomplishments of smart farming in terms of sustainable agriculture are crop rotation, the control of nutrient deficiency in crops, the control of pests and diseases, recycling, and water harvesting, leading to an overall safer environment. Living organisms depend on the nature of biodiversity, and are contaminated by waste emissions, the use of fertilizers and pesticides, degraded dead plants, etc. The emission of greenhouse gases affects plants, animals, humans, and the environment; hence, it necessitates a better environment for living things (Denyer, & Tranfield, 2009).

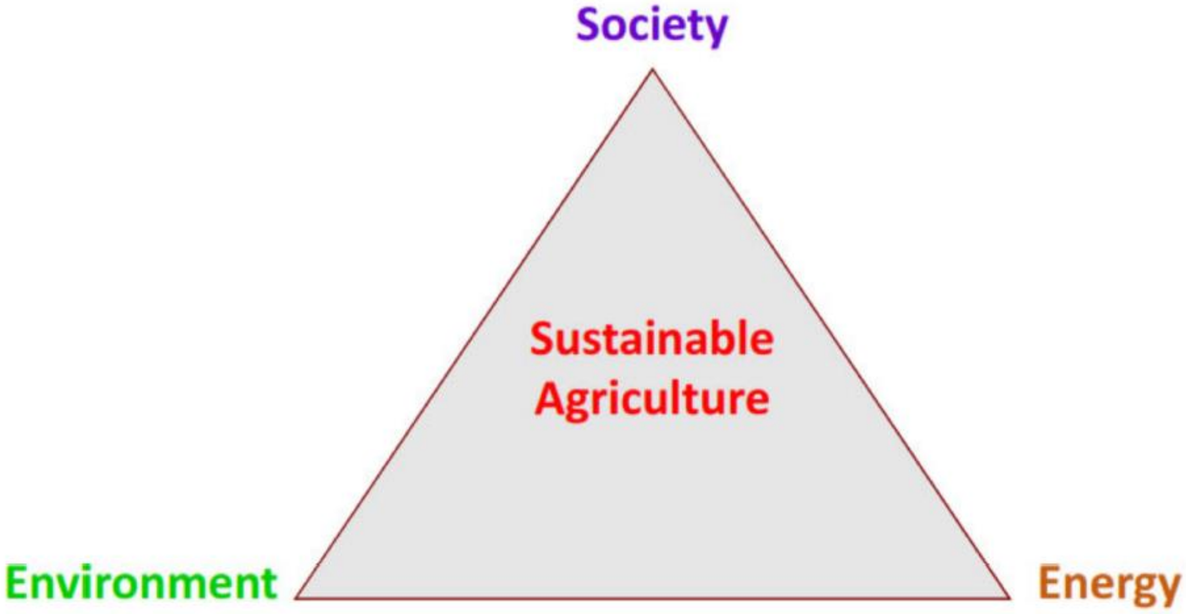

Figure 1: sustainable agriculture factors

Regrettably, not all parts of the Earth's surface are suitable for agriculture due to various restrictions, such as: soil quality, topography, temperature, climate, and most relevant cultivable areas are also not homogenous (Feenstra, 2020). Further, existing farming land is fragmented by political and fiscal features, and rapid urbanization, which consistently increases pressure on arable land availability. Recently, total agricultural land used for food production has declined (FOA, 2017). Furthermore, every crop field has different critical characteristics, such as soil type, flow of irrigation, presence of nutrients, and pest resistance, which are all measured separately both in quality and quantity regarding a specific crop. Both spatial and temporal differences are necessary for optimizing crop production in the same field by crop rotation and an annual crop growth development cycle (FOA, 2019).

In most cases, variations in characteristics occur within a single crop, or the same crop is grown on the whole farm and requires site-specific analyses for optimum yield production. New technology-based approaches are needed to produce more from less land, and to address these various issues. In traditional farming practices, farmers frequently visit their fields throughout the crop's life in routine farming activities to better understand the crop conditions (Fountas, Carli, Sorensen, Tsiropoulos, Cavalaris & Vatsanidoud, 2015). The current sensor and communication technologies offer an precise view of the field, from which farmers can detect ongoing field activities without being in the field in person. Wireless sensors monitor the crops with higher accuracy and detect issues at early stages, often facilitating the use of smart tools from initial sowing to the harvest of crops (Garnett, Appleby, Balmford, Benton, Bloomer & Burlingame, 2013).

The timely use of sensors has made the entire farming operation smart and cost effective, due to precise monitoring. The various autonomous harvesters, robotic weeders, and drones have sensors attached to collect data over short intervals. However, the vastness of agriculture puts extreme demands on technological solutions for sustainability with minimum ecological impact. Sensor technology through wireless communication helps farmers to know the various needs and requirements of crops without being in the fields, and they are then able to take remote action (Gil, Reidsma, Giller, Todman, Whitmore & van Ittersum, 2019).

Transition to Smart Farming

The urgency to achieve food security has always been whether or not we could feed the 9 billion of the world population. Malthus in his work on Population: The First Essay (Arbor, 1957) highlighted that population grows geometrically the output of food grows arithmetically which will inevitably result in the scarcity of food. Most of the literatures in smart farming are technical and explains the importance of technology in food production. Literatures on smart farming in the social sciences are still lacking especially on the impact of digital transformation in agriculture on farmers and society. For instance, Santiteerakul et al. (2020) investigated how technology applications could help farmers to utilize appropriate data in their decision-making which can lead to the use of low-input agriculture. Walter et al. (2017) studied technical improvement through the use of ICT in agriculture including the challenges of property rights on the owner and use of data. Further, Klerkx et al. (2019) in his review of social science literatures on digital agriculture, smart farming and agriculture 4.0 and suggested that one of the emerging cluster which needs to be given more emphasis is digitally enabled agricultural transition pathways.

As technology is embedded in the agricultural sector, this raised a question of whether agriculture is still regarded as a traditional sector. Advanced countries like Japan and The Netherlands have utilized technology in their farming which is in line with the fourth industrial revolution which coincidentally supports the SDGs, particularly the 9th SDG to 'build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation'. Thus, this link needs to be explored especially its potential to meet the global demand and for countries to be self-sufficient especially when there is unprecedented crisis, for instance the COVID-19 pandemic.

The digital transformation is exciting and fast-moving including agriculture. Walter et al. (2017) suggested that agriculture is undergoing a fourth revolution as a result of the exponentially increasing use of ICT in agriculture. The fourth industrial revolution is a popular term and remains a growing interest in many countries. However, agricultural revolution is yet to be explored. As agriculture is undergoing a new technology revolution, it should not be overlooked. The summary of agricultural revolution can be seen below.

Table 1: Agricultural Revolution

The first agricultural revolution	Occurred when humans started farming around 12,000 years ago.
The second agricultural revolution	The reorganisation of farmland from the 17th century onwards that followed the end of feudalism in Europe.
The third agricultural revolution (also known as the green revolution)	The introduction of chemical fertilisers, pesticides and new high-yield crop breeds alongside heavy machinery in the 1950s and 1960s.
The fourth agricultural revolution (much like the fourth industrial revolution)	The anticipated changes from new technologies, particularly the use of Artificial Intelligence (AI) to make smarter planning decisions and power autonomous robots. Such intelligent machines could be used for growing and picking crops, weeding, milking livestock and distributing agrochemicals via drone.

Source: Rose and Chivers (2020)

From the table above, it can be seen the transition of farming from traditional to the use of latest and advanced technologies. Undeniably, technology has changed the practice in agriculture, making the food and agricultural systems more productive, profitable and sustainable.

Farming with the use of new technologies has always been associated with smart farming. Pivoto *et al.* (2018) explained smart farming as the incorporation of information and communication technologies into machinery, equipment, and sensors for use in agricultural production systems. Sensors plays an important tool in Smart Farming. In addition, Fountas et al. (2015) claimed that smart farming will help to reduce the impacts of climate change by keeping them constant or reduce production costs in agricultural activities and minimize environmental constraints. The emergence of smart farming is due to the rapid development of Internet of Things (IoT) and cloud computing (Sundmaeker *et al.*, 2016). New technologies such as the IoT and cloud computing are expected to advance this development, introducing more robots and artificial intelligence into farming (Pivoto et al., 2019). The term of agritech is also exchangeably used which refers to the use of technology and technological innovation to improve the efficiency and output of agriculture.

Smart Farming

Historically, ancient agriculture practices were related to the production of food in cultivated lands for the survival of humans and the breeding of animals (Godde, Katz, Ménard & Revellat, 2020), and was called the traditional agricultural era 1.0. This mainly resorted to using manpower and animals. Simple tools were used for farming activities, such as sickles and shovels. Work was mainly conducted through manual labor, and subsequently, productivity continued at a low level.

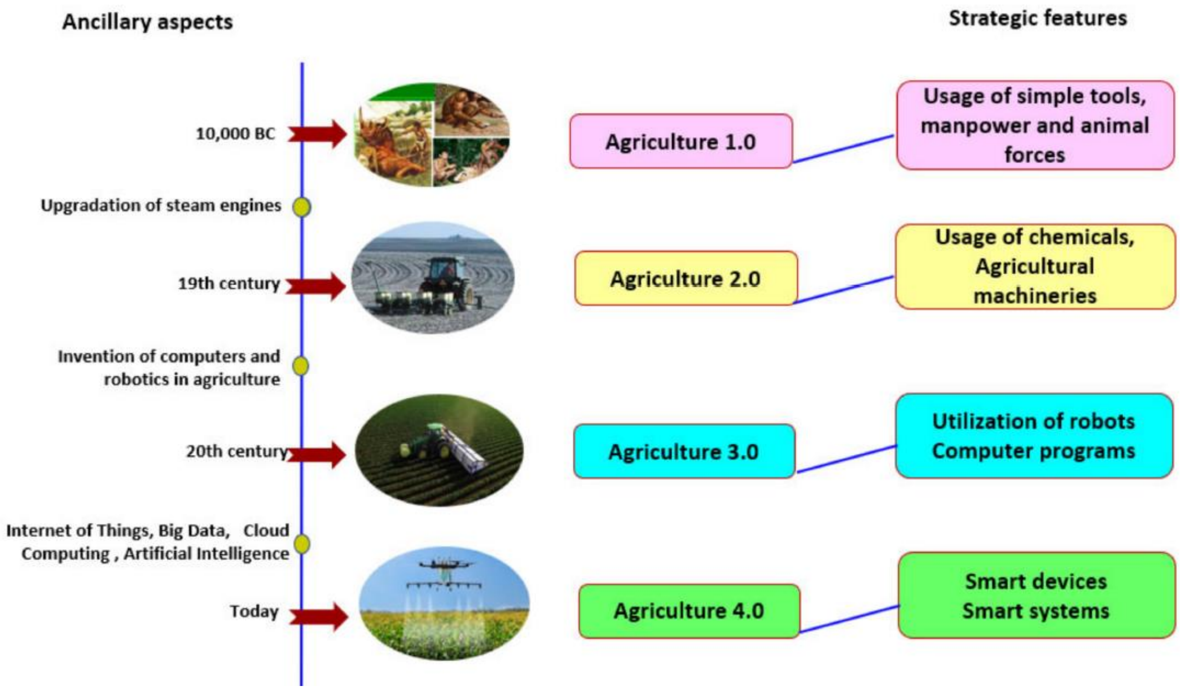

Figure 3: Agricultural decision support system framework.

During the 19th Century, new types of machinery appeared in the agricultural industries, in the form of steam engines. The wide use of agricultural machinery and abundant chemicals by farmers signaled the start of the agricultural era 2.0, and outwardly improved effectiveness and productivity of farmers and farms. However, considerably harmful implications, such as chemical pollution, environmental devastation, waste of natural resources, and excess utilization of energy, simultaneously developed.

The agricultural era 3.0 emerged during the 20th Century, due to the rapid growth of computation and electronics. Robotic techniques, programed agricultural machinery, and other technologies enhanced the agricultural processes efficiently. The issues that had arisen during agricultural era 2.0 were solved, and policies were readapted to the agricultural era 3.0 through work distribution, precise irrigation, the reduced use of chemicals, site-specific nutrient application, and efficient pest control technologies, etc.

The next agricultural era is also the current iteration of agriculture, the agricultural era 4.0, involving the engagement of recent technologies, such as the Internet of Things, big data analysis, artificial intelligence, cloud computing and remote sensing, etc. The adoption of new technologies has significantly improved agricultural activities by developing low-cost sensor and network platforms, aimed towards the optimization of production efficiency, along with reductions in the usage of water resources and energy with minimum environmental effects (Klerkx, Jakku & Labarthe, 2019). Big data in smart farming provides extrapolative overviews of real-time agricultural situations, allowing farmers to make effective decisions (Kubota Corporation, 2020). Realtime programming is developed with artificial intelligence concepts and embedded in IoT devices, helping farmers make the most suitable decisions (Marzęda-Młynarska, 2017).

Smart farming promotes precision agriculture with modern, sophisticated technology and enables farmers to remotely monitor the plants. Smart farming helps agricultural processes, such as harvesting and crop yields, as the automation of sensors and machinery has made the farming workforce more efficient (Mastoi, Abdul Rahman & Dahlan, 2014). The technologies convert traditional farming methods to automatic devices, causing a technological revolution in agriculture. Today, the technology in agriculture has altered the way farming is conducted, and conventional techniques have been transformed by the Internet of Things (Musa, Idris & Basir, 2020). In terms of optimizing farm labor requirements and increasing the quantity and quality of products, smart farming is an emerging modern technique implemented with information and communication technologies (ICT). Modern ICT technologies, such as the Internet of Things, GPS (Global Positioning Systems), sensors, robotics, drones, precision equipment, actuators, and data analytics, are used to identify the farmers' needs and select suitable solutions to their problems. These innovations increase the accuracy and timeliness of decisions taken, and improve crop productivity. Several multilateral organizations and developing countries around the world have proposed smart farming technologies to increase agricultural output (Musa, Idris & Basir, 2020).

Sensors are constantly monitoring crops with greater accuracy, detecting any undesirable conditions during the early stages of the crop's lifecycle. Current farming incorporates smart tools from crop sowing to harvest, storing, and conveyance. The appropriate use of a wide variety of sensors has made the entire operation both more efficient and profitable, due to its accurate monitoring competencies. In addition, sensors that collect data quickly are directly available online for further evaluation, and they provide crop and site-specific agriculture for every site. The many issues related to crop production are addressed by smart agriculture and monitoring, particularly regarding changes in soil characteristics, climate factors, soil moisture, etc., to improve the spatial management practices that increase crop production and avoid the excess use of fertilizers and pesticides (Pivoto, Waquil, Talamini, Finocchio, Dalla Corte & de Vargas Mores, 2018). The ANN models in smart irrigation water management (SIWM) regulate irrigation scheduling support systems (DSS) and offer data on irrigation efficiency, water productivity index, and irrigation water demand and supply on a real-time basis. Climate-smart agriculture (CSA) is an upcoming technology, especially in developing countries, due to its potential to improve food security, farm system resilience, and lower greenhouse gas emissions (Pivoto, Waquil, Talamini, Finocchio, Dalla Corte & de Vargas Mores, 2018). Smart agriculture technology based on IoT technologies has many advantages in all agricultural processes and practices in real-time, including irrigation, plant protection, improving product quality, fertilization, disease prediction, etc. (Pivoto, Waquil, Talamini, Finocchio, Dalla Corte & de Vargas Mores, 2018). The benefit of smart agriculture lies in its collection of real-time data on crops, the precise assessment of soil and crops, remote monitoring by farmers, supervising water and other natural resources, and improving livestock and agricultural production. Therefore, smart agriculture is considered to be the progression of precision agriculture through modernization and smart methods to attain various information of farm activities that are then remotely managed, and reinforced by suitable alternative real-time farm maintenance solutions.

Technologies Used in Smart Farming for sustainable agriculture

Global Positioning System (GPS)

GPS accurately records latitude, longitude, and elevation information. Global Positioning System satellites transmit signals and permit GPS receivers to compute their location in real-time, and provide continuous positions while moving. The exact location information offers farmers the opportunity to discover the precise position of field data, such as pest occurrence, type of soil, weeds, and other barriers. The system facilitates the recognition of various field locations in order to then apply the necessary inputs (seed, fertilizer, herbicide, pesticide, and water) to a particular field (Pucci, 2019).

Sensor Technologies

Technics, such as photo electricity, electromagnetics, conductivity, and ultrasound, are used to estimate soil texture and structure, nutrient level, vegetation, humidity, vapor, air, temperature, etc. Remote sensing data can differentiate between crop types, categorize pests and weeds, locate stress in soil and plant conditions, and monitor drought. Plant health is affected by many factors, such as soil moisture, nutrient availability, exposure to light, humidity, the amount of rainfall, the color of leaves, etc. The plants are monitored by maintaining the optimum temperature and light intensity, and conserving water and energy through micro-irrigation. Different sensors are used to detect many parameters. If they cross a threshold, the sensor senses the changes and transmits them to the microcontroller to perform the required actions until the parameter returns to its optimum level (Rose & Chivers, 2020). The temperature, humidity, soil pattern monitoring, airflow sensor, location, CO2, pressure, light, and moisture sensors are generally used in sensing technologies. Prominent sensor characteristics include reliability, memory, portability, durability, coverage, and computational efficiency, and make them suitable for agriculture (Rose, Wheeler, Winter, Lobley & Chivers, 2021). Currently available wireless sensors play a vital role in collecting data on crop conditions and providing other information. These sensors are standalone types and can be integrated with advanced agricultural tools and heavy machinery, based on application necessities.

Variable-Rate of Technology (VRT) and Grid Soil Sampling

Variable-rate technologies (VRT) are used in farming to predict the delivery rate of inputs based on a predetermined map extrapolated from GIS for the placement of inputs at variable amounts in the right place and at the right time. Grid soil sampling is soil collection from a systematic grid to establish a map for every parameter. These maps are the basis for VRT and are loaded into a variable-rate applicator. The computer and GPS receiver direct and control the changes in the delivery amount or fertilizer product, based on map features. New technologies, such as variable rate technology and associated practices (grid soil sampling), potentially improve soil fertility management and assess the spatial distribution of nutrients and yields (Santiteerakul, Sopadang, Tippayawong & Tamvimol, 2020). In grid sampling, samples are collected from sampled sections based on the subdivision of a field into small areas, or cells, by superimposing the grid lines onto the field. Composite samples represent an entire area of each much smaller area (grid-point sampling) at the intersections of grid lines. Soil-test values from grid sampling are mapped by interpolating methods from non-measured locations between sampled points. The variability of phosphorus and potassium is field-specific, and each field should be fertilized differently to improve nutrient management practices by uniform applications of fertilizers and manure for better precision agriculture.

Geographic Information System (GIS)

The GIS comprises hardware and software designed to provide compilation, storage, retrieval, attributes analysis, and location data to generate maps and analyze characters and geography for statistics and spatial methods. The GIS database provides information on field soil types, nutrient status, topography, irrigation, surface and subsurface drainage, quantity of chemical applications, and crop production, and also establishes the relationship between elements that affect a crop on a particular farming field (Sharon, 2020). Apart from data storage and display, the GIS is used to assess present and alternative management by compounding and altering data layers for decision-making.

Crop Management

Satellite images provide information on variations in soil conditions, as well as crop performances affected by topography within the field. Therefore, farmers can exactly monitor production factors, such as seeds, fertilizers, and pesticides, that are responsible for yield increase and efficiency. The spatial coverage and temporal revisit frequency of satellite images provide the information in near real-time at a regional scale. The relationship between the spectral properties of crops and their biomass/yield experiments is predicted by spectral reflectance properties of vegetation, especially in red and near-infrared combinations (vegetation indices) to monitor green foliage (Sharon, 2020). Among the different indices, the normalized difference vegetation index (NDVI) is the most popular indicator to assess vegetation health and crop production, due to the closely related leaf area index (LAI) and photosynthetic activity of green vegetation. Crop monitoring methods are based on the interpretation of remote-sensing-derived indicators by comparing actual crop status to previous or normal seasons. The relationship between vegetation indices and biomass permits early crop yield estimation in certain periods before harvest. The automated data acquisition, processing, monitoring, decision-making, and management of farm operations, including the basic functions of crop production (yields), profits and losses, farm weather prediction, field mapping, soil nutrients tracking, are the more complicated functionalities available through automated field management.

Soil and Plant Sensors

Sensor technology, a significant constituent of precision agriculture, provides soil properties information, fertility, and water status. Hence, new sensors have been developed based on desirable features and established apart from currently available sensors. Soil sensors and plant wearables monitor real-time physical and chemical signals in soil, such as moisture, pH, temperature, and pollutants, and provide information to optimize crop growth conditions, fight against biotic and abiotic stresses, and increase crop yields. Soil organic matters (SOMs), nitrogen (N), phosphorus (P), and potassium (K) are the most important nutrients for crop production. The NIR reflectance-based sensors measure the spatial variation of surface and subsurface soil nitrogen. SOM is predicted based on optimal wavelengths by assessing soil spectral reflectance in IR and visible wavelength regions. The soil nitrogen and phosphorus are predicted using NIR spectrophotometry technology (Sharon, 2020). The soil apparent electrical conductivity (ECa) sensors collect information continuously on the field surface, since ECa is sensitive to changes in soil texture and salinity. Soil insects/pests are detected using optoelectronic, acoustic, impedance sensors, and nanostructured biosensors.

Rate Controllers

Rate controllers are designed to control the delivery rate of inputs by monitoring the speed of vehicles across the field, and altering the flow rate of material on a real-time basis at the target rate. Rate controllers are commonly used as stand-alone systems (Sundmaeker, Verdouw, Wolfert, & Pérez, 2016).

Precision Irrigation in Pressurized Systems

Recent developments in irrigation systems have introduced irrigation machines, devoted to motion control, GPS-based controllers, sensor technologies, and wireless communication to monitor soil and climatic conditions together with an assessment of irrigation parameters, i.e., flow and pressure, to attain greater water utilization efficiency by crop. These technologies show significant potential; however, further progress is required before they can become commercially available (Sundmaeker, Verdouw, Wolfert, & Pérez, 2016).

Yield Monitor

Yield monitors are the combination of sensors and components, including a data storage device, a computer, and user interface, that control integration and interaction components. The sensor measures yield continuously by evaluating the force of mass or volume of grain flow. The mass flow sensor was based on the principle of transmitting microwave energy beams and measuring the energy that bounces back after hitting. In yield monitors, GPS receivers create yield maps based on the location yield data. The yield monitor is mounted on a harvester and connected with the mobile app for displaying live harvest data, and automatically uploads to the web-based platform. The app can generate and share high-quality yield maps with an agronomist, and farmers can export other farm management data for analysis. In horticultural crops, to precisely determine the yield quantity and quality of produce, fruit growth is considered one of the most relevant parameters in the crop progressing period. Color images are used to track fruit conditions for estimating fruit maturation, making decisions for harvesting, and targeting the right market. Satellite images are one of the options for real-time monitoring of the yield of crops over vast areas; for example, Sentinel-1A images are used to map the rice yield and crop intensity in Myanmar (Sundmaeker, Verdouw, Wolfert, & Pérez, 2016). The crop yield estimation system was designed using both software and hardware components. Based on a Bluetooth terminal android application and yield estimator software program, crop yield is estimated using a mathematical calculation through a mobile application. Satellite-based crop yield predictions based on spectral signatures reveal the estimated yields are as reliable as actual yields. The maize yield predictions were successfully carried out under varying environments using machine learning and satellite-derived data assimilation in crop models.

Software

The software has multiple tasks, such as mapping, display controller interfacing, data processing, analysis, and interpretation, etc. Most commonly, software is used to generate the maps for soil properties and nutrient status, yield maps, variable rate applications maps for inputs, and overlaying different kinds of maps with advanced geostatistical features (Sundmaeker, Verdouw, Wolfert, & Pérez, 2016).

Importance of Smart Farming for Sustainable Agriculture

Adopting the new methods based on sensor and IoT-based technologies improved the yield of crops more than conventional agriculture processes. The involvement of new sophisticated sensor-based technologies in controlled environments plays an important role in enhancing the quality and quantity of produce.

Greenhouse Farming and Protected Cultivation

Growing plants in a controlled environment gained popularity in the 19th Century, and is considered one of the oldest methods of smart farming. These practices further accelerated during the 20th Century in countries facing severe weather conditions (United Nations, 2020). Crops grown in indoor conditions are less affected by the environment. As a result, crops grown traditionally under suitable conditions are today being raised at anytime and anywhere by the use of sensors and communication devices. The success of crop production under a controlled environment depends on various factors, such as shed structures and material for controlling wind effects, aeration systems, accuracy of monitoring parameters, decision support system, etc. (Viviano, 2017). One of the greatest challenges in greenhouses is the precise monitoring of environmental parameters; hence, it requires several measurement points to predict the various parameters for controlling and ensuring the local climate. In an IoT-based greenhouse, sensors are used to measure and monitor the internal parameters, such as humidity, temperature, light, and pressure (Wallace, 2016).

The smart farming in greenhouse has helped farmers automatically conduct farm work, without manual inspection, and protects the plants from hailstorms, winds, ultraviolet radiation, and insect and pest attacks. Hibiscus plants are grown with the required wavelength during the night using lights, temperature, and air humidity sensors. A study revealed a reduction in 70–80% water requirement, and the IoT enables direct contact between the farmer and consumer to make farming as efficient and profitable as possible (Walter, Finger, Huber & Buchmann, 2017). The IoT-enabled automated system increased the productivity of rose plants grown in a greenhouse by monitoring and controlling various parameters, such as humidity, mist, CO2 level, UV light intensity, pH and EC value, water nutrients solution level, temperature, and amount of pesticides, through sensors for further efficient detection and diagnosis (Wong, 2020).

Hydroponics

Hydroponics, a subdivision of hydroculture, is growing plants without soil to improve greenhouse farming benefits. Hydroponic-based irrigation systems enable a balanced rate of application of dissolved nutrients in the water to crop roots as a solution. Presently, the available systems and sensors detect a wide range of parameters and perform data analysis at predetermined intervals. Precise measurement and monitoring of nutrient content in solution is crucial for plant growth and considers its demands. On a realtime basis, the wireless-sensor-based prototype has delivered a solution for soilless cultivation, and measures the concentration of numerous nutrients and water levels (Viviano, 2017). An automated smart hydroponics system integrated with IoT consists of three major components: input data, cloud server and output data. These monitor lettuce cultivation from anywhere through the internet by analyzing parameters, such as pH level, water, nutrient-rich water-based solution, room temperature, and humidity, on a real-time basis (Sundmaeker, Verdouw, Wolfert, & Pérez, 2016). The hydroponic system of the deep flow technique is a method for cultivating plants by placing roots in deep water layers, and ensuring the continuous circulation of plant nutrient solution. The plant growth elements data, such as pH, temperature, humidity, and water level in the hydroponic reservoir, are acquired by sensors integrated into Raspberry Pi, and data are processed and monitored automatically on a real-time basis to ensure proper water circulation (Wong, 2020).

Vertical Farming

The industrial-based agricultural farming practices damage soil quality at a faster rate than nature can reconstruct. The alarming erosion rate and use of fresh water for agriculture has led to the reduction of arable land, and increased the overburden on present water reservoirs (Wong, 2020). Vertical farming (VF) offers an opportunity to keep the plants in a precisely controlled environment, significantly reducing resource consumption and, at the same time, increasing production at varied times; and only a portion of the ground surface is needed depending on the number of stacks. VF is also extremely effective in higher yields and reducing water consumption compared to traditional farming (Sundmaeker, Verdouw, Wolfert, & Pérez, 2016). The carbon dioxide measurement is the most critical parameter; hence, nondispersive infrared (NDIR) CO2 sensors play a vital part in tracking and controlling the conditions in vertical farms.

Phenotyping

Phenotyping is an emerging crop engineering technique, relating plant genomics with ecophysiology and agronomy. The advancement of genetic and molecular tools is significant for crop breeding; however, quantitative analysis of crop behaviors, such as pathogen resistance, grain weight, etc., is inadequate due to the absence of effective technologies and efficient techniques. In this condition, Wong, (2020) reported that plant phenotyping is highly useful in investigating the quantitative characteristics responsible for growth, resistance to various stresses, yield quality, and quantity. The sensing technologies and image-based phenotyping describe screening of bio stimulants and an understanding of their mode of action (Viviano, 2017). IoT-based phenotyping is intended to observe the crop and related trait measurements, and offer facilities for the breeding of crops and digital agriculture (Viviano, 2017). The trait analysis algorithms and modelling support determine the relationships among genotypes, phenotypes, and their growing condition.

Conclusion and Suggestions

The world has been facing challenges in feeding the increasing population. This has prompted the agriculture sector to come up with innovative ways on how to produce in high quantity and quality. The unprecedented crisis, COVID-19, have led to disruptions in the supply chain which further challenge the agriculture sector. One of the ways to tackle this issue is by helping the farmers to be more connected through smart farming. Smart farming offers a path toward sustainable agriculture by providing innovative ways into a profitable, socially accepted agriculture that benefits the environment, sustain farmers' income and resilience and attract more youth into the sector. Smarter and more efficient crop production methodologies are needed to address the issues of shrinking arable land and the food demands of an increasing world population. There is a necessity for everyone to be aware of food security in terms of sustainable agriculture. The growth of new technologies for increasing crop yield and encouraging the adoption of farming by innovative young people as a legitimate profession. This paper emphasized the role of many technologies used for farming, particularly the IoT, in making agriculture smarter and more effective in meeting future requirements. Hence, every piece of farmland is important to enhance crop production by dealing with every inch of land using sustainable IoT-based sensors and communication technologies.

Barriers for many of Africa's smallholders in implementing smart farming is the lack of capital to finance smart farming, hence more intervention is needed in this area. The challenge is to ensure that revolution works for everyone, especially small-scale farmers. This can be done by conducting capacity building among farmers in order to avoid deepening the digital divide and ensuring a concise ecosystem is in place to support healthy growth and support for the relevant stakeholders in the agriculture industry. It has to be noted that transformation of agriculture in to smart farming in Africa will take some time as the nature of the sector is different and it was once a traditional sector. Issues such as communicating with older farmers, who could often not understand the technicalities of new technologies will also need to be addressed. However, with the rapid industrial revolution, every player in different industries will eventually need to embrace and adopt the change.

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