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Application of Smart Farming Technologies in Sustainable Agriculture Development: A Comprehensive Review on Present Status and Future Advancements

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Authors' contributions

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Review Article

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ABSTRACT

The pressure on agricultural food production to produce high-quality and sustainable food has increased dramatically as a result of global urbanization, population growth and climate change. Food shortage and population expansion are two of the world's major challenges to long-term sustainable development. So, in recent years technological development such as smart farming has resulted substantial changes in the agricultural production allowing for 3rd green revolution and progression in farming methods. Smart farming (SF) is a method of agricultural production that integrates information and communication technologies to maximise resource efficiency. Smart farming technologies such as automated tractors, artificial agricultural intelligence (AAI), automated irrigation and weather forecasting, Internet of Things (IoT), kisan drones and remote sensing (GIS

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and GPS) can provide realistic solutions to the world's challenges. The accurate application of this technology in conjunction with the Internet of Things (IoT) is expected to be a beneficial for the farmers to improve their living standards through increased production and profit which is a good indicator for sustainable food security. However, due to lack of internet access, high costs and lack of application knowledge there are still barriers to the adaptation and conversion of smart farming. As a result, more research is needed in this area.

Keywords: Climate change; smart farming; sustainable food production; technology.

1. INTRODUCTION

Globally, the agriculture sector is facing numerous issues like climate change, land degradation and extreme weather events such as heat waves, intense rainfall, cold waves, floods and droughts. Agriculture is particularly vulnerable to climate change because climate change and agriculture are inextricably linked, and both occur on a global scale [1]. Climate change causes a range of risks, including temperature, CO_2, and rainfall, which affect plant growth directly and indirectly through land availability, irrigation, weed growth, pest and disease outbreaks, and so on [1]. During the few past decades, crop yields have been reduced because of climate change and modelling studies indicate that climate change will reduce crop yield potential, particularly in many tropical and midlatitude countries [2]. Adverse influences of global warming include reduced crop quantity and quality due to the reduced growth period following high levels of temperature rise, reduced sugar content, and reduced storage stability in fruits, increase of weeds, blights, and harmful insects in agricultural crops, reduced land [1]. Short-term climatic fluctuations have profound implications on food security so, the Intergovernmental Panel on Climate Change (IPCC) suggests that improving our ability to assess climate-change impacts at national and subnational levels will necessarily require improvements in climate-variable monitoring [3].

On the other hand, farming has been greatly intensified since the 1560s i.e., after the green revolution, in order to increase the production. Agriculture, horticulture and livestock farming were all organised with the single goal of increasing production [4]. The successes of green revolutions have resulted in a slew of environmental issues, including deforestation, waterlogging, salinity, alkalinity, soil erosion, and the decline and rise of the ground water table linked to brackish water and others [5]. A lot of chemicals, as well as a lot of water and fertilizer, were used which increased the production but at the cost of sustainability. While these extensive monoculture systems may have been advantageous in enhancing food production efficiency, they exert an adverse influence on the environment. While these extensive monoculture systems may have been advantageous in enhancing food production efficiency, they exert an adverse influence on the environment. But nowadays crop productivity has been limited by declining nutrient-use efficiency, physical and chemical soil degradation, and inefficient water use, while monocultures, mechanisation, and an over-reliance on chemical plant protection have reduced crop, plant, and animal diversity in recent years [6].

For this reason, there is now a greater emphasis on using unconventional technologies (like smart farming) for better farming, decision-making, and policymaking in order to accelerate agricultural growth while maintaining sustainability. Smart farming is a very broad concept which is about the understanding of “what the system needs”, “when it needs this”, “how much it needs” and “where”. Subsequently, actions and input are provided in a precise manner [7]. Smart farming provides (in the future) technologies that allow the cultivation systems to be managed autonomously by machines/robots, transforming the sector into Climate Smart Farming. It converts “large-scale production technology” to “large-scale precise production technology” on an individual level with fewer resources. It also includes incorporating information and communication technologies (ICTs) into farm equipment and sensors for use in crop cultivation and food production systems [8]. Farmers can now use IoT to improve farm efficiency, such as fertilisation, irrigation, harvesting, threshing and climate forecasting, by monitoring with sensors and making better decisions (Fig. 1). This development enables farmers to make improved decisions about farm management by making better use of accessible resources, resulting in a higher yield and more income [9]. For these reasons, there is a growing awareness that Smart Farming can play that role, and governments, knowledge institutes, and businesses are increasingly seeking ways to collaborate.

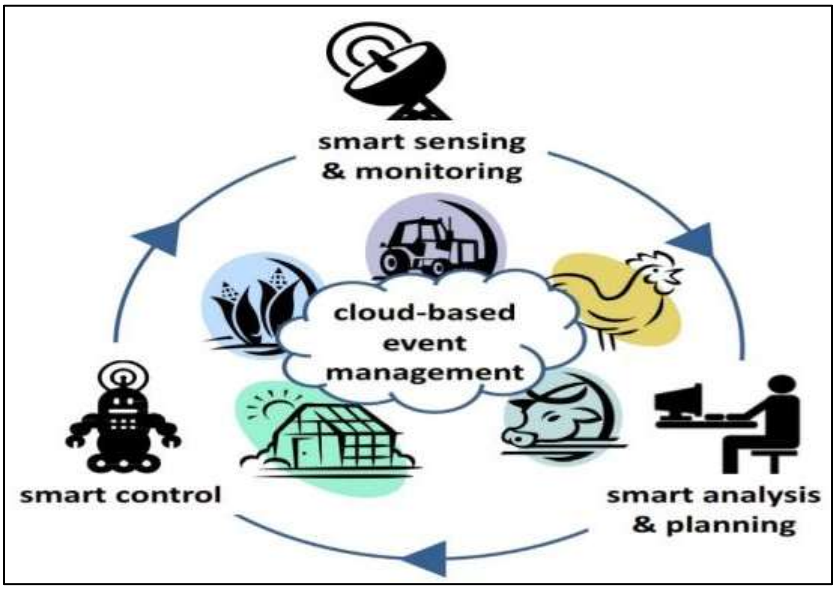


Fig. 1. Complete cycle of smart farming (Wolfert et al., 2014).

2. SIGNIFICANCE OF SMART FARMING

Smart farming is necessary to improve efficiency, make informed decisions, and promote sustainable and environmentally friendly agricultural practices. Agriculture is one of the most labour-intensive and resource using work. Farmers now confront a number of issues which forcing them to make the switch to smart farming.

- **Consumer preferences:** The abundance of fast food and other unhealthy meals on the market has resulted in a demand for healthier food products; and quality production is easily achieved through smart farming without any resource degradation.
- **Accurate evaluations of resources:** To measure different resource levels, farmers generally conduct manual tests on a regular basis but if they could use smart sensing technology, which is far more accurate, convenient and time efficient [10].
- **Advanced spraying:** Advanced spraying by variable rate technology using drone can boost enormous productivity.
- **Labour shortage:** Due to rapid urbanization, the farming community deal having an acute labour shortage. As a result, modern agriculture should be adopted using smart farming since the approach has less labour requirement.
- **Environmental concern:** Farm automation reduces chemical load significantly, improving ecological balance without hampering the production.

3. APPLICATIONS OF SMART TECHNOLOGIES

To effectively collect and utilize information for precision farming, it is crucial for individuals interested in this approach to have a good understanding of the available technological tools. These tools encompass hardware, software, and suggested methodologies. This chapter delves into various tools and techniques employed in the execution of precision farming which is described below.

3.1 Remote Sensing

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft) (Fig. 2) [9]. Remote sensing has recently been used to improve understanding of the climatic system and its changes. It allows for the monitoring of the ocean, Earth's surface and atmosphere at multiple spatiotemporal scales, allowing for observations of the climate system [11]. By increasing the study of the spatial variability of terrestrial and ocean ecosystems, remote sensing has contributed to the creation of global climate change strategies. Furthermore, remote sensing can be used to collect information and data in potentially hazardous (e.g., during fire

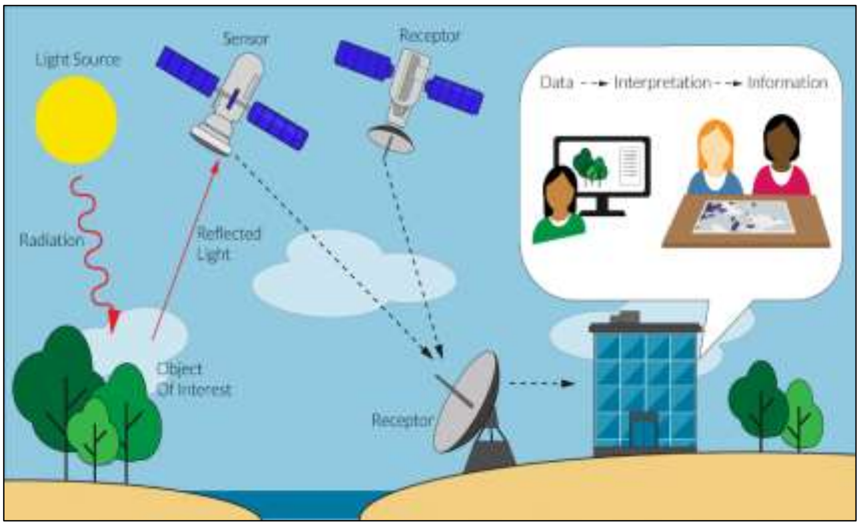
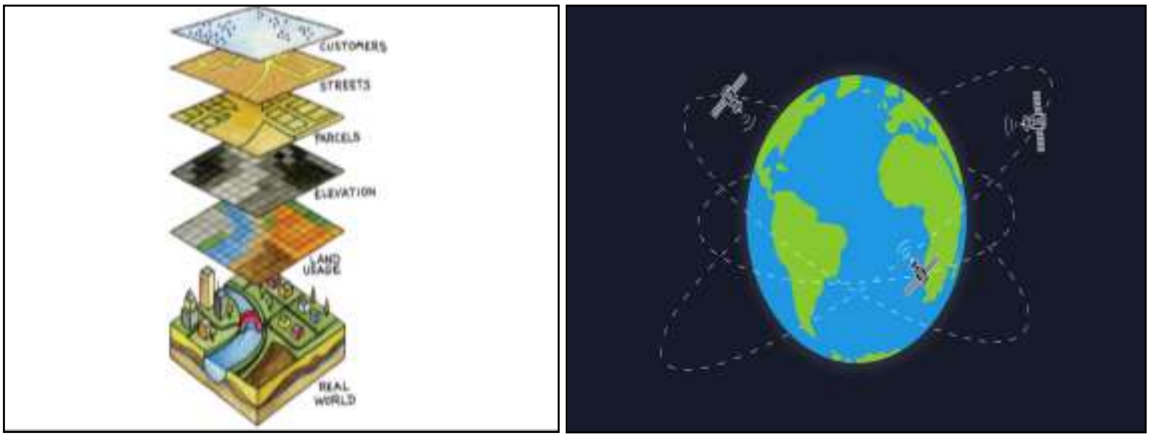


Fig. 2. A systematic view of remote sensing

events) or inaccessible areas (e.g., impervious areas) [7]. Accurate remote sensing investigates global temperature and trends to improve weather and climate forecasting. It can screen for aerosols (A colloid of fine solids in gas. e.g., Mist, smoke etc. Particle matter is 2.5), water vapour concentration, and changes in precipitation regime as well as examine earth temperature at both the ocean and atmospheric levels. The reduction of snow and ice coverage serves as a significant marker of global warming, and this can be gauged through the analysis of remote sensing images. Accurate data analysing sea-level temperatures is essential for establishing connections between global temperature shifts and their effects on overall marine life abundance, coastal alterations, and the identification of flood-prone areas, including the creation of hazard maps for vulnerable regions. To mitigate and manage the risks linked to climate-related disasters, the application of remote sensing allows for the development of early warning and forecasting systems. This technology is also beneficial in monitoring water resources and assessing the impact of droughts. Combining remote sensing with spatial analyses aids in gauging the wildfire threat. Evaluating the collected data is crucial for predicting climate change patterns, facilitating early warnings in the event of disasters, transitioning from point-based assessments to more spatially explicit estimations. Remote sensing becomes instrumental in guiding decision-making processes related to climate change adaptation. It is useful in soil mapping, agro-climate assessment, land suitability, crop condition assessment, and irrigation management.

3.2 Geographic Information System (GIS) & Global Positioning System (GPS)

GIS is an integrated system of computer hardware and software, along with procedures and a human analyst, that supports the capture, storage, management, manipulation, analysis, modelling, and display of spatially referenced data [12]. In summary, geographical information systems empower users to create maps, integrate information, visualise scenarios, solve complex problems, present powerful ideas, and develop effective solutions in ways never before possible (Fig. 3a) [8]. The Global Positioning System (GPS) provides unrivalled positioning accuracy and flexibility for navigation, surveying, and GIS data capture (Fig. 3b). With a constellation of 24 satellites, GPS provides continuous three-dimensional positioning around the world 24 hours a day. GPS measurements are three-dimensional so, we can determine both horizontal and vertical displacement at the same time and place [13]. Researchers are using GPS and GPS for climate change information in a variety of ways, including the water content of the atmosphere, Groundwater hydrology, resource management, environmental monitoring, and emergency response all benefit from the integration of remote sensing (RS), geographic information systems (GIS), and global positioning systems (GPS) [14]. It helps in measuring earthquakes. Computer-based GIS and GPS mapping and analysis is useful in geographic



(A) (B)

Fig. 3. A brief pictorial depiction of (A) GIS & (B) GPS respectively

planning, identifying environmental changes, where temperatures is abnormally high or irregular in comparison to the global average and implementing action plans. Striving to visualize a range of factors that could influence the growth of crops, impact the industry, and affect wildlife [7]. GIS and GPS techniques can aid in the collection and analysis of relevant data, allowing appropriate actions to be taken in advance of climate change occurrences [15]. It creates models to show how a warming climate might affect the ecology of various regions and these techniques can aid in the collection and analysis of relevant data, allowing appropriate actions to be taken in advance of climate change occurrences [15]. Helicopters utilise GPS to track the perimeter of forest fires, making it possible to use firefighting resources more efficiently [16] attempting to visualise a variety of factors that may have an impact on crop growth, industry, and wildlife.

3.3 Kisan Drone

A drone, in technological terms, is an unmanned aircraft. They are more formally known as unmanned aerial vehicles (UAVs) weighing up to 2-20 kg which is remotely controlled or fly autonomously through software-controlled flight plans in their embedded systems, working in conjunction with onboard sensors and GPS [7]. Drones can also help in ways that go beyond monitoring by human. It can accomplish a variety of functions that lead to better agricultural sustainability (Fig. 4). Drone operations include irrigation, crop health monitoring, planting, crop spraying, crop inspection, and soil analysis [18]. They can also aid in mitigating the effects of climate change and completing tasks that human is unable to complete due to changing environmental conditions. Drone technology, once primarily associated with film production or military applications, is now being creatively utilized to address human-induced climate change [5]. Drones can be used to map plastic waste, documenting the level of pollution and giving scientists insight into our litter habits collect data such as weather and soil moisture, allowing for more effective land management and help scientists to track the growth of the problem and are also help in planting trees in Myanmar. These drones can save up to 90% of the water [19]. Farmers create Vegetation Index (VI) maps from multispectral camera embedded in drone to disclose crucial crop health information, spot anomalies, and efficiently allocate resources. The drone is outfitted with a weed scanner and crop sprayer, allowing weeds to be scanned from the air and then specifically controlled, resulting in a 30 percent reduction in chemical use [20]. High rate of drone planting slows climate change and other environmental damage by sequestering carbon, improving air and water quality, and preventing erosion [21].Bees have been dying off in huge numbers due in part to climate change. Japan's National Institute of Advanced Industrial Science and Technology used a 1.5-inch drone to pollinate Japanese lilies [22]. Using drones to deliver packages instead of trucks could help reduce emissions associated with package delivery [21]. With the assistance of drone-enabled LiDAR sensors, scientists can now simulate shoreline changes to accommodate rising sea levels, run models predicting storm impacts and identify areas most susceptible to flooding.

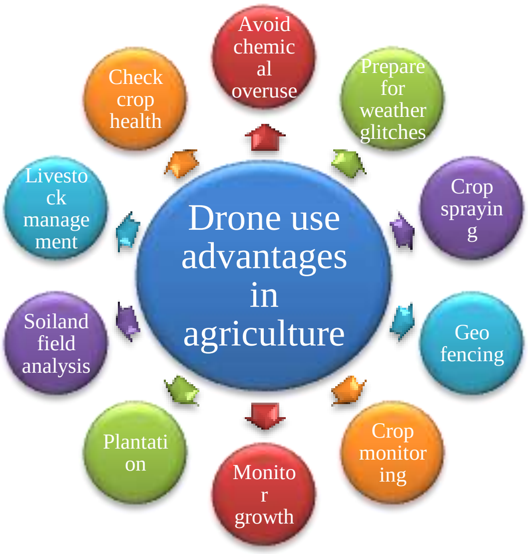


Fig. 4. Benefits of drone technology

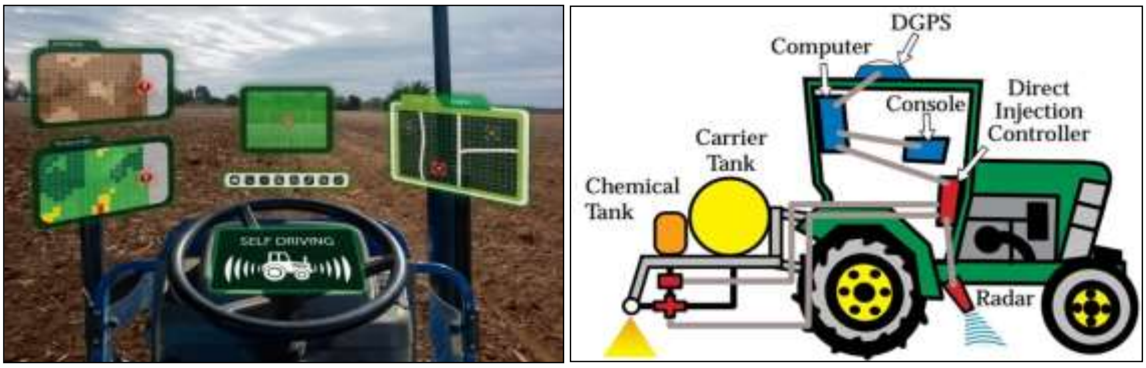


Fig. 5. Automated steering system and embedded variable rate technology of a tractor

3.4 Automated Tractor or Driverless Tractor

A driverless tractor is an autonomous farm vehicle that provides high tractive effort (or torque) at low speeds for tillage and other agricultural tasks (Fig. 5) [23]. Remote control is available for these tractors. With the advancement of technologies such as vision systems, light detection tools, GPS, and so on, smart tractors will become increasingly self-sufficient in agricultural use. It has an Auto-steer technology that is based on GPS and assists the tractor in travelling in a straight line [24]. The driverless tractors will do the planting automatically and with high accuracy, resulting in seed conservation and this could aid in the alleviation of farm labour shortages and this tractor can work with high efficiency thus reduce the diesel need hence reduce the CO_2 level indirectly. The tractors' sensors will be able to collect data on soil conditions, crop maintenance for already planted crops, and harvest data before and after cultivation. With variable rate technology embedded in tractor reduce the chemical load in environment as well as farmers will also be protected from health risks associated with chemical spraying.

3.5 IoT - based Agricultural Sensor

Internet of Things (IoT) is defined as the connection of network, hardware devices, software, and most importantly human beings exchanging data for specific purposes. According to the researchers, the ability of computers within a network to make decisions without human intervention has evolved over time with the help of IoT [25]. IoT has the potential to play a critical role in combating climate change by assisting us in reducing greenhouse gas emissions and living more sustainably. The smart systems improve the accuracy and efficiency of devices that monitor plant growth and even livestock raising. Wireless sensor networks (WSNs) collect data from various sensing devices (Fig. 6) [18]. Sensors used to monitor environmental conditions such as soil nutrients, air temperature, and humidity, defining the best time and location for planting, irrigation, fertiliser application, and so on, resulting in more efficient use of agricultural land and resources, improved output, and higher quality production [26]. Chand et al. (2021) succeeded in designing a multi-purpose smart farm robot (MpSFR) that can carry out water sprinkling, and pesticide spraying based on IoT and computer vision (CV) technology [18]. Automated sensors in Automated weather observing system (AWOS) measure meteorological operations, monitor of climatic conditions by weather stations, combining various smart farming sensors weather forecasting with 80-90% accuracy [27]. According to the report of the Food and Agriculture Organization (FAO 2017), about 20–40% of crops are lost annually due to pests and diseases and as a result of lack of good monitoring of the state of the crop [18]. Carbon savings are also possible in the developing countries. Low-cost, low-power IoT devices could deliver precision agriculture (which reduces fertiliser, pesticide, and water consumption) to developing countries much faster. Hence, the use of sensors and smart systems allows monitoring of weather factors, fertility status, and also determining the exact number of chemicals necessary for crop growth [18]. IoT-powered sensors can obtain accurate real-time information on greenhouse conditions and this IoT-smart services and industry could account for a 3 percent carbon reduction by increasing efficiency [28]. With IoT sensors, farmers can collect a plethora of metrics on every aspect of the field microclimate and ecosystem, including lighting, temperature, soil condition, humidity, CO_2 levels, and pest infections [10].The rain drops sensor and soil moisture sensor send SMS notifications to the farmer about the moisture content of the soil. Sensor-mounted devices used by individuals to monitor and warn about air quality levels and can detect the level of sustainability, CO_2, CH_4 measurement is critical. Sensors is a highly sensitive, near-infrared sensor for accurate and reliable measurement of CO, CO2, CH4 gas. Drone authorities have been successful in conserving some rare species by installing motion-sensing cameras throughout forests. Another important sensor for monitoring the tree in the continuous basis is tree talker (TT) (Fig. 7). This device is very useful for collecting data from the trees of agroforestry system and urban areas. It includes variety of sensors along with microcontrollers. It collects the data of several plant parameters like water transport in the xylem of the trunk (sap flow), wood temperature and humidity, multispectral signature of light transmitted through the canopy, tree trunk radial growth, accelerations along a 3D coordinate system used to detect tree movements, air temperature and relative humidity which can be additionally complemented by soil temperature and volumetric water content (SWC) [29].

Fig. 6. IoT based sensor used in field

Fig. 7. Tree talker sensor used to monitor the tree

3.6 Automatic Watering and Irrigation

An automated irrigation system is one that operates with no or very little manual intervention aside from surveillance [28]. Almost any system (drip, sprinkler, surface) can be automated using timers, sensors, computers, or mechanical devices (Fig. 8) [28]. It makes the irrigation process more efficient, which can result in savings for the end user, not only in monetary terms, but also in natural resources such as water and energy, resulting in a more sustainable environment [17]. Using Wireless Sensor Networks (WSN) directly in the field to collect real-time data on the current state of the garden and cross-referencing this information with weather forecast, evapotranspiration, and garden specifications, smart farming is able, using artificial intelligence algorithms, to predict/calculate the real water needs for that specific garden and adjust the irrigation controller without human intervention [30]. The smart irrigation system is entirely powered by the solar panel's photovoltaic (PV) cells. The generated power is stored in a battery pack and used to power the pumps at the water management and control station. The solar panels charge the battery during the day so that when there is no solar irradiance, the battery pack has enough power to keep the pumps running when needed [31]. Advantages of automatic watering and irrigation system. A rain sensor detects rainfall and prevents the irrigation system from operating during a rain event [4]. With this solution, it is possible to save up to 34% of water when using sensor data from temperature, humidity and soil moisture, or up to 26% when using only temperature inputs [30]. Soil moisture sensors measure the water content of the soil and are a management tool that can help determine when irrigation is required [4]. The sensors are placed at the crop rooting depth (typically, 15–30 cm). Moisture sensor triggers irrigation when 20% of available soil water is depleted [30]. Irrigation process starts and stops exactly when it needed thus reducing energy consumption, using water from numerous sources and increasing water and fertiliser efficiency. Furthermore, surface drip irrigation can be linked with fertigation (irrigation water plus fertiliser), which not only increases irrigation efficiency (20–305%) but also decreases fertiliser losses (20–40%) and increases crop yield (10–20%) depending on soil, crop, and environmental conditions [32]. This improved technology has the potential to increase water application efficiency and use water judiciously based on crop stage and requirement.

3.7 Automated Weather Forecasting

An automated weather station is an automated version of a traditional weather station. They can be single-site or part of a weather network [33]. Humans are heavily reliant on the weather; it plays a role in every aspect of our lives, from feeding us to providing power for our ever-increasing needs. Climate change has warmed the planet and altered our weather patterns, making extreme weather events like droughts and floods more likely [34]. High-tech weather forecasting technology can aid in the fight against climate change by monitoring meteorological conditions to aid decision making, whether in the aviation or shipping industries, or by assisting us in understanding and forecasting natural hazards and disasters, allowing us to reduce the risk of adverse events – and the costs, environmental, economic, and social (Fig. 9) [35]. At the farm level, an Automatic Weather Station (AWS) is used to provide real-time weather information. The AWS also provides information

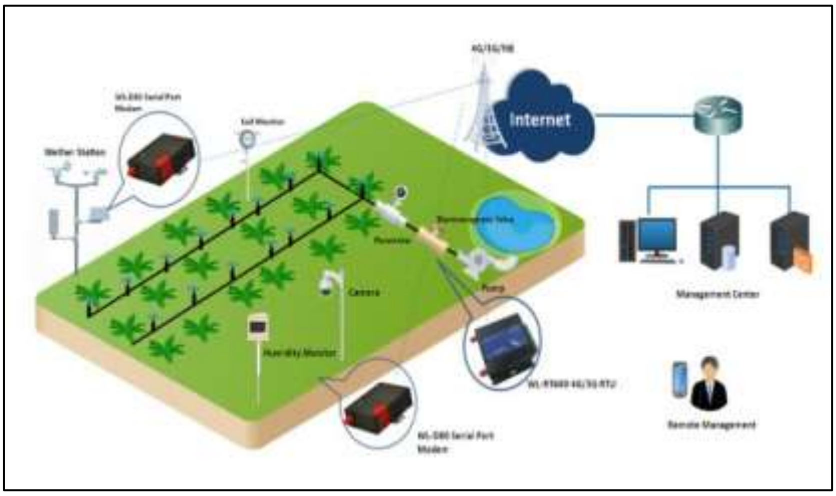


Fig. 8. Sensor based automatic irrigation system

Fig. 9. Automated weather observing system

on soil moisture and temperature, which helps to determine how much water is needed. Without a doubt, AWS is a valuable tool in the hands of farmers today. The main benefits of using a weather station in agriculture. AWS outperform traditional ones because they produce more precise and frequent measurements, require less power, and can function almost anyplace and Help farmers, scientist to take action quickly without any data leakage and quality deterioration. Another accurate measurement of current weather conditions for specific location and surroundings. The capacity to access historical data, conduct extended statistical analyses and generate graphs spanning up to a decade, incorporating computations for both minimum and maximum values. Operating the station incurs no extra costs or fees.

3.8 Use of Artificial Intelligence & Data Analytics

AI, or Artificial Intelligence, refers to the development of computer systems that can perform tasks that typically require human intelligence. These tasks include learning from experience (machine learning), understanding natural language, recognizing patterns, and problem-solving. Artificial intelligence (AI) is steadily emerging as a technological evolution in the agriculture industry. AI-powered solutions will not only help farmers improve efficiencies, but they will also increase crop quantity and quality while also ensuring a faster time to market [36, 37]. These robots are capable of eliminating 80 percent of the volume of chemicals normally sprayed on crops and reducing herbicide expenditure by 90 percent [38]. This method builds models that can "keep an eye" on plant health by using classification, detection, and image segmentation methods (Fig. 10) [36]. AI technology helps in detection of plant diseases and pests by using image recognition technology based on deep learning can analyse and Interpretate the images faster than humans, allowing it to assess crop health, anticipate yield, and detect crop malnutrition. AI sensors can detect and target weeds and then decide which herbicide to apply within the region [36] and it can improve agriculture efficiency, as they reduced operating costs and reduced operating time. In addition, the robots can reduce the environmental pollution of up to 80% of farm’s pesticides [39]. These intelligent AI sprayers can drastically reduce the number of chemicals used in the fields, improving the quality of agricultural produce while also reducing costs [38] The smartphone collects the image, which is compared to a server image, and then provides a diagnosis of that specific disease, which is then applied to the crop using an intelligent spraying technique [40] Scientists used A.I. analytics tool to determine the best time to sow the seeds for maximum yield and the ripening time of a particular tree. They can also advise farmers and governments on future price patterns, demand levels, crop type to sow for maximum benefit, pesticide usage, and so on [36]. To summarize, AI alleviates the scarcity of resources and labour to a large extent, and it will be a powerful tool that can assist organizations in dealing with the growing complexity of modern agriculture [40]. AI models can alert farmers to specific problem areas, allowing them to take immediate action.

3.9 Smart Decision Support Systems (SDSS)

Smart Decision Support Systems (SDSS) are being introduced in the agricultural industry to help farmers and anybody else interested in agricultural investment make educated decisions [41]. There are numerous decision support systems in agricultural management, such as irrigation management, fertilisation, and others for service operations. Furthermore, Giusti and Marsili-Libelli (2015) proposed a fuzzy decision support system for irrigation management, as the system includes spatial location data and crop characteristics such as crop growth stages, planting date and water requirements, precipitation, temperature, as well as soil characteristics and water requirements (Fig. 11) [42]. It also contains an interpretation system that regulates irrigation timing to maintain soil moisture within the suitable limits; this system increase water use efficiency (WUE) and quality of crop yield.

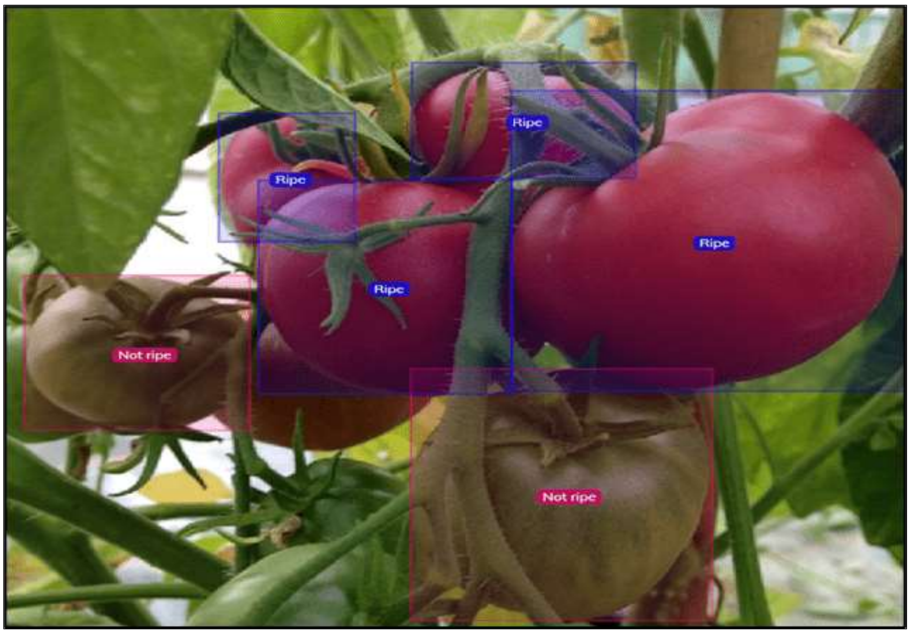


Fig. 10. AI technology helps in detecting ripening status in plants

Fig. 11. Graphical user interfaces (GUI) for agricultural DSS

3.10 SaaS-Based Cloud Software

Farmers will be pushed to make data-driven decisions since global food consumption is predicted to rise significantly in the near future. Changing weather patterns, increasing pest infestations, and unproductive soils, on the other hand, all have an impact on data collection methods and, ultimately, agricultural outcomes. This has increased the demand for Software as a service (SaaS) based agriculture that can provide precise data to assist farmers in effectively dealing with these changes (Fig. 12) [43]. Cloud computing can help farmers make better farming decisions by collecting data from sensors, weather stations, and satellite photographs. Farmers, for example, can use a SaaS platform and powerful AI/machine learning algorithms to evaluate a combination of satellite data and ground truth data for better decision making and farming practises. In addition to data collection, cloud computing can assist farmers in better understanding their farm environment (Fig. 13). Cloud computing in farming can give agribusinesses with actionable insights that can aid them in making key financial and strategic choices. It enables effective farm management through digitization by providing total view of people, processes, and performance across the field. As a result, SaaS solutions can aid in precisely mapping and monitoring farm conditions in order to ensure effective agricultural activities with data-driven decision making [44].

Fig. 12. Benefit of SaaS-based cloud software

Among different cloud-based software system one of the most user-friendly autonomic information systems is Agriculture-as-a-Service (AaaS). AaaS has the ability to manage all types of agricultural data based on different based on different domains. It provides mainly 3 types of services like – i) Software as a service (SaaS), ii) Platform as a Service (PaaS), and iii) Infrastructure as a Service (IaaS). SaaS is the interface where the user interacts with software. PaaS work as interlink between cloud subsystem and user subsystem. IaaS is a resource manager which automatically manages the data based on the particular request [45].

3.11 Cloud Based System for Livestock Monitoring

Nowadays application of smart farming became very popular in the livestock farming also. precise livestock farming (PLF) indicates the advanced management of farm animals u8sing IT and IoT and Wireless Sensor Network (WSN) technologies [46]. Livestock monitoring can be done mainly inn three ways First, monitoring the individual animal for analysing their health status and this reduces the chances of collective infections caused by illness. Second, tracking the animal location during the time

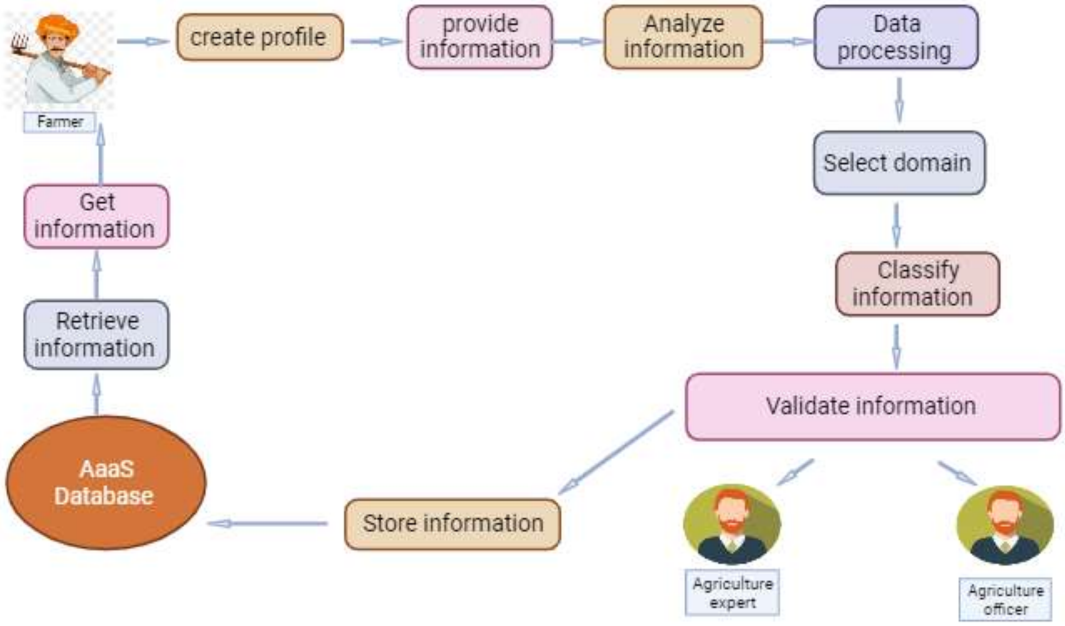


Fig. 13. Functional aspects of SaaS

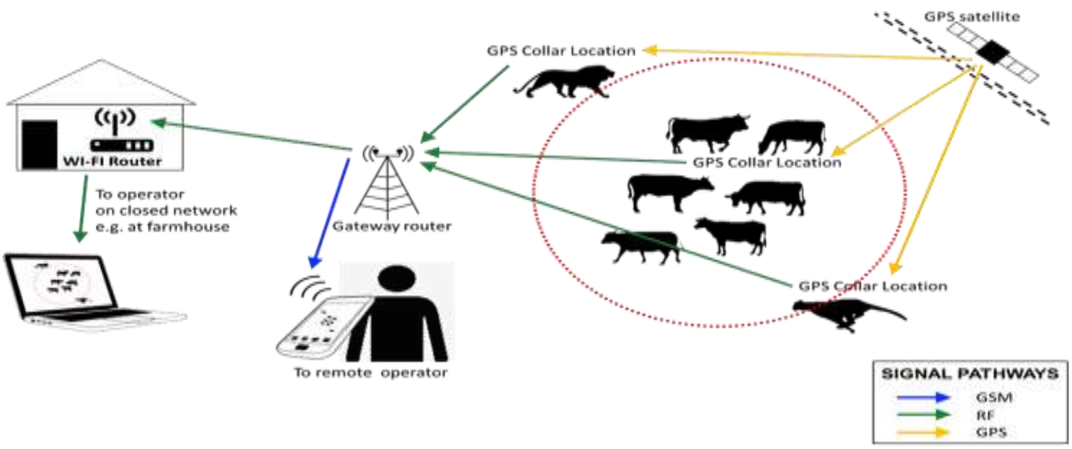


Fig. 14. Remote livestock management

of grazing. Third, maintaining the optimum environmental condition for the animal by monitoring the farm environment. From Vaughan's research, the body weight of animals on a livestock farm is measured by using different IOT application. A sensor is installed on the farm floor which measure the weight and the gait data of the livestock. The cloud-based system has three components [47]. First, network layer where, data are collected from the node is send to cloud platform. Each animal wearing a sensor containing neckless considered as nod. Second, is the cloud platform where the manipulation of collected data happens. Third, component is user interface. On the screen, you can find details regarding the nod and its location status (Fig. 14) [46].

4. THE BENEFITS OF SMART FARMING

Benefits of smart farming include:

- **Increased Efficiency:** Farmers can increase their efficiency through smart farming. Farmers can now produce more products in a shorter period of time. inspect the condition of the crop and anticipate concerns for immediate decision-making.
- **Higher crop quality:** IoT monitoring systems aid in the maintenance of optimal conditions, resulting in higher crop quality. Weather monitoring in agriculture, for example, aids in estimating the precise supply of water, chemicals, and nutrients required to produce high-quality crop yields. Farming products grown with IoT monitoring systems can also meet market specifications better than other products [48]
- **Less reliance on pesticides:** Pesticides are not only toxic, but their use also incurs costs. Smart pest monitoring systems reduce the need for pesticides, the costs associated with them, and the hazardous effects of chemicals on the environment and human health [48]
- **Higher sales price and lower costs:** Obviously, greener, healthier products grown with cutting-edge Agri-technologies will have higher sales prices and, as a result, bring in more revenue. Smart farming leaders will reduce crop labour, water, and nutrient costs [4]
- **Labour shortage is easing:** Labour in some farming branches can account for up to 50% of total costs. This situation is exacerbated by a labour shortage. The use of robots for seeding, harvesting, watering, and monitoring reduces the need for employees to perform a variety of monotonous tasks.
- **Eco-friendly Agriculture:** The use of pesticides scares many people, which is why agriculture is gaining a bad reputation. Robots are changing the game to be more environmentally friendly: they can add pesticides with great precision, which is nearly impossible for a human to do.
- **Save time and be more organised:** Remote monitoring of water levels and weather conditions saves time that would otherwise be spent physically going out to the fields. Furthermore, knowing weather trends allows you to better plan your day's activities while avoiding rain or other bad weather.
- **More efficient crop monitoring with less human error:** Automated crop monitoring will result in more accurate data in less time and with less labour.

5. ECONOMIC OPPORTUNITIES IN SMART FARMING

Smart farming is important in addressing social challenges and moving toward more sustainable food systems and nutritious foods while also providing farmers with economic opportunities. Accurate measurement and appropriate plant growth factor adjustment result in higher product quality and productivity is higher than conventional cultivation due to cost savings from resource use (water and fertilization) and a higher price. Increasing the product weight per unit and reducing the amount of labour increases the return per unit area.

6. ROLE OF SMART TECHNOLOGIES IN SUSTAINABILITY

Sustainable development is becoming increasingly important in the agriculture sector because the current underutilization of resources and energy, as well as the pollution caused by toxic chemicals, cannot be sustained at current rates. Agriculture can be more sustainable by using fewer (or no) toxic chemicals, conserving natural resources, and lowering greenhouse gas emissions. Technology applications could assist farmers in making better decisions based on accurate data, resulting in low-input agriculture

[49]. Agriculture can be made more sustainable by making better use of data in decision making. Indeed, innovative farming is regarded as a subset of data analysis and mathematics. Farmers are subjected to a variety of variables on a daily basis, ranging from soil diversity to climate change [3]. Such variations necessitate careful examination in order to implement the best farming practices. Smart farming, which highlights the use of big data in decision making, can help with some of these challenges as well as fulfilling any production targets. Unlike in the past, farmers can now collect data and make informed decisions using smart farming approaches. Farmers can use a variety of data analysis techniques. Farmers, for example, can determine the fertility of their farmland using smart technology by analyzing and comparing satellite images, and then using the data to determine the yield potential of a given land. Farmers who use smart farming find it simple to measure variables and process data with precision. This is done to make tasks easier, increase yields, cut costs, and move toward more sustainable agriculture [49].

7. CONCLUSION

The Food and Agricultural Organization of United Nations (FAO) recommends the use of digital technologies that boost productivity, as the increased output can help to lower the risk of global food security. Farmers use drones and sensors to improve their farming techniques. Pesticide and fertiliser consumption will decrease in the future, according to this smart agricultural revolution and total efficiency will increase in many folds. In addition to breeding, introduction and selection in the post-green revolution era, smart farming appears to be the gateway of the 3rd green revolution in near future in India by utilising these smart farming technologies and instruments. This method, in general, comprises the use of network and communication technology to fulfil specific production goals while simultaneously promoting sustainable agriculture. Continuing to adopt smart farming in agriculture, according to current trends, can help to alleviate the risk of unsustainability in agriculture.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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