# Application of Digital Technologies for the Next Level of Agriculture Growth and Transformation under Changing the Indian Agriculture: A Critical Review

## R. K. Naresh[1], Sunil Kumar[2], M. Sharath Chandra[1*], Shakti Om Pathak[3], S. K. Gupta[4], Sandeep Gawdiya[5] and Pradeep Kumar Singh[1]

[1]*Department of Agronomy, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, U. P., India.*
[2]*ICAR-Indian Institute of Farming System Research (IIFSR), Modipuram, Meerut, U. P., India.*
[3]*Department of Soil Science & Agricultural Chemistry, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, U. P., India.*
[4]*Department of Agronomy, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India.*
[5]*Department of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi, India.*

***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

*Review Article*

## ABSTRACT

The rapid population growth has driven the demand for more food, fiber, energy, and water, which is associated to an increase in the need to use natural resources in a more sustainable way. The growing connectivity in the rural environment, in addition to its greater integration with data from sensor systems, remote sensors, equipment, and smart-phones have paved the way for new concepts from the so-called digital agriculture. The information that crops offer is turned into profitable decisions only when efficiently managed. Current advances in data management are making Smart Farming grow exponentially as data have become the key element in modern

_____

*\*Corresponding author: E-mail: sharathagrico@gmail.com;*

agriculture to help producers with critical decision-making. Valuable advantages appear with objective information acquired through sensors with the aim of maximizing productivity and sustainability. These kind of data-based managed farms rely on data that can increase efficiency by avoiding the misuse of resources and the pollution of the environment. Data-driven agriculture, with the help of robotic solutions incorporating artificial intelligent techniques, sets the grounds for the sustainable agriculture of the future. Digital agriculture offers far-reaching opportunities for accelerating agricultural transformation. Although there are concerns that digital agriculture will enhance the market power of large agribusiness enterprises and increase the digital divide, a combination of new actors and public action can help accelerate the supply of digital agricultural technology, manage threats of market concentration, and harness the opportunities of digital agriculture for all.

The agriculture industry has radically transformed over the past 50 years. Advances in machinery have expanded the scale, speed, and productivity of farm equipment, leading to more efficient cultivation of more land. Seed, irrigation, and fertilizers also have vastly improved, helping farmers increase yields. Now, agriculture is in the early days of yet another revolution, at the heart of which lie data and connectivity. Artificial intelligence, analytics, connected sensors, and other emerging technologies could further increase yields, improve the efficiency of water and other inputs, and build sustainability and resilience across crop cultivation and animal husbandry. This paper reviews the current status of advanced farm management systems by revisiting each crucial step, from data acquisition in crop fields to variable rate applications, so that growers can make optimized decisions to save money while protecting the environment and transforming how food will be produced to sustainably match the forthcoming population growth.

**Graphical Abstract**



**Image 1. Indian agricultural farms**

## 1. INTRODUCTION

The world population is projected to reach 9.6 billion by 2050. This would lead to a significant increase in food demand, even as arable land and freshwater resources are decreasing rapidly. Therefore, it becomes pertinent to upscale, upgrade, and modifies the agriculture sector [1]. Agriculture is the life of the Indian economy. It contributes to 16% of India's gross domestic product (GDP) and employs 43% of the Indian workforce. Several industries such as consumer packaged goods; retail, chemicals and e-commerce are heavily dependent on the output

produced through agriculture, thereby magnifying the impact of agriculture on the country's economy. Multiple structural challenges are inhibiting Indian agriculture sector from reaching its full potential. Yields on crops such as cereals are lower in India by 50% compared to developed countries. Presence of numerous intermediaries throughout the value chain contributes to a reduction in farmers' income. Limited access to technology, credit and marketplaces are some of the other challenges that India's agriculture sector is grappling with. It is imperative to recognize that small and marginal farmers constitute the lion's share of India's farm holdings (86%). As a result, solutions to challenges in Indian agriculture need to be inclusive of the needs of these small and marginal farmers [2].

To feed the growing population; agriculture productivity has to be increased using digital technologies for the next level of agriculture growth. The technology deficit gap needs to be filled on fast track basis to match productivity ratios with the rest of the world. Increasing population, increasing average income and globalization effects in India will increase demand for quantity, quality and nutritious food, and variety of food. Therefore, pressure on decreasing available cultivable land to produce more quantity, variety and quality of food will keep on increasing [2].

New technologies are needed to push the yield frontiers further, utilize inputs more efficiently and diversify to more sustainable and higher value cropping patterns. These are all knowledge intensive technologies that require both a strong research and extension system and skilled farmers but also a reinvigorated interface where the emphasis is on mutual exchange of information bringing advantages to all [3]. Digitalization will change every part of the agri-food chain. Management of resources throughout the system can become highly optimized, individualized, intelligent and anticipatory. It will function in real time in a hyper-connected way, driven by data. Value chains will become traceable and coordinated at the most detailed level whilst different fields, crops and animals can be accurately managed to their own optimal prescriptions. Digital agriculture will create systems that are highly productive, anticipatory and adaptable to changes such as those caused by climate change. This, in turn, could lead to greater food security, profitability and sustainability [4].

When applying these new technologies, the challenge for retrieving data from crops is to come out with something coherent and valuable, because data themselves are not useful, just numbers or images. Farms that decide to be technology-driven in some way, show valuable advantages, such us saving money and work, having an increased production or a reduction of costs with minimal effort, and producing quality food with more environmentally friendly practices [5]. However, taking these advantages to the farm will depend, not only on the willingness of producers for adopting new technologies in their fields, but also on each specific farm potential in terms of scale economies, as profit margin increases with farm size. A greater use of Smart Farming services is vital to not only improving a farm's financial performance, but also to meet the food needs of an expanding population.

The use of digital tools is not only confined to the farming process, but also aids the farmer in the post-harvest process that includes pricing, storage, transportation, and logistics. Along with market insights, these tools help in maximizing the produce value and ensure the efficient and sustainable use of resources. Although efforts to digitalize Indian agriculture have been initiated, the adoption of digital technology remains at a nascent stage as of now. The scientists identify the prominence of segregated small-holder farms in the country, which makes data gathering a complicated activity, as the prime factor behind the slow adoption process. Limited percolation of mechanization tools and recurring natural phenomena like floods, droughts, etc. have also worked against the deployment of digital solutions in the sector. The absence of a centralized repository of different varieties of data stacks to be used in agriculture also makes it difficult for the efficient functioning of the AI/ML tools. The use of technology has defined the 21st century. As the world moves toward quantum computing, AI, big data, and other new technologies, India has a tremendous opportunity to reap the advantage of being an IT giant and revolutionize the farming sector. While the green revolution led to an increase in agricultural production, the IT revolution in Indian farming must be the next big step.

The digital agriculture can be understood and encompasses communication, information, and spatial analysis technologies that allow rural producers to plan, monitor, and manage the operational and strategic activities of the production system. In addition to the technologies already consolidated, such as field

sensors [6,7] orbital remote sensors [8] and also embedded in UAV-Unmanned Aerial Vehicle global positioning systems telemetry and automation [9] digital maps-soil relief, production, productivity [9] digital agriculture also involves the Internet and connectivity in crops [10] cloud computing, big data, blockchain and cryptography [11,12] deep learning [13] Internet of Things (IoT) [14] mobile applications and digital platforms [15,16] and artificial intelligence [17]. All these technologies support pre and post-production decisions and greater sustainability of production systems [18] in addition to access to a differentiated market benefiting short marketing chains.

Digitalization may cause the next agricultural revolution as it has a unique potential to make crop and livestock production more efficient and environmentally friendly, thereby creating substantial benefits for farmers, consumers, and society at large [19]. Promising digital tools exist not only for farmers in industrialized countries but also for farmers, including smallholders, in developing countries. Given its transformative power, there are, however, also concerns related to digital agriculture. Critics warn of digital divides between urban and rural areas, large and small farms, male and female farmers, and farmers in industrialized and developing countries [20].

Advances in machinery have expanded the scale, speed, and productivity of farm equipment, leading to more efficient cultivation of more land. Seed, irrigation, and fertilizers also have vastly improved, helping farmers increase yields. Now, agriculture is in the early days of yet another revolution, at the heart of which lie data and connectivity. Artificial intelligence, analytics, connected sensors, and other emerging technologies could further increase yields, improve the efficiency of water and other inputs, and build sustainability and resilience across crop cultivation and animal husbandry.

Demand for food is growing at the same time the supply side faces constraints in land and farming inputs. The world's population is on track to reach 9.7 billion by 2050 [21] (FAO, 2016c) requiring a corresponding 70 percent increase in calories available for consumption, even as the cost of the inputs needed to generate those calories is rising [22]. By 2030, the water supply will fall 40 percent short of meeting global water needs [23] and rising energy, labor, and nutrient costs are already pressuring profit margins. About one-quarter of

arable land is degraded and needs significant restoration before it can again sustain crops at scale [24] and then there are increasing environmental pressures, such as climate change and the economic impact of catastrophic weather events, and social pressures, including the push for more ethical and sustainable farm practices, such as higher standards for farm-animal welfare and reduced use of chemicals and water.

To address these forces poised to further roil the industry, agriculture must embrace a digital transformation enabled by connectivity. Yet agriculture remains less digitized compared with many other industries globally. Past advances were mostly mechanical, in the form of more powerful and efficient machinery, and genetic, in the form of more productive seed and fertilizers. Now much more sophisticated, digital tools are needed to deliver the next productivity leap. Some already exist to help farmers more efficiently and sustainably use resources, while more advanced ones are in development. These new technologies can upgrade decision making, allowing better risk and variability management to optimize yields and improve economics. Deployed in animal husbandry, they can enhance the well-being of livestock, addressing the growing concerns over animal welfare.

Feeding 10 billion people *sustainably* by 2050, then, requires closing three gaps:

- **A 56 percent food gap** between crop calories produced in 2010 and those needed in 2050 under "business as usual" growth;
- **A 593 million-hectare land gap** (an area nearly twice the size of India) between global agricultural land area in 2010 and expected agricultural expansion by 2050; and
- **An 11-gigaton GHG mitigation gap** between expected agricultural emissions in 2050 and the target level needed to hold global warming below $2^{\circ}C$ ($3.6^{\circ}F$), the level necessary for preventing the worst climate impacts.

Mobile computing has affected lots in number in our day to day life due to its availability and has a cheaper cost of communication. It is in use in almost every field including agriculture sector. System based on mobile computing has been proposed for sending daily, seasonal messages to farmers regarding the product information and

weather information [25]. This review paper aims at making agriculture smart using automation and IoT technologies based on real time field data. Smart warehouse management are temperature maintenance, humidity maintenance and theft detection in the warehouse. Controlling of all these operations will be through any remote smart device or computer connected to Internet and the operations will be performed by interfacing sensors, Wi-Fi or ZigBee modules, camera and actuators with micro-controller and raspberry pi. Then it will be stored in the cloud and big data analytics concepts are used to analyze the data. Finally, the report will be sent to the farmer through mobile computing technologies.

Thus, this review work aimed to gather information through an online consultation with rural producers about the digital technologies used today, their applications, challenges, and future perspectives. The paper identifies the problem at the decision-making stage by the farmer. Farmers in India primarily rely on their traditional knowledge to select their crops. Meanwhile, the suitability of the crop is dependent on the soil type & quality, market demand, and weather pattern, among other factors. The report advises deploying AI-based technology that could factor in all these conditions and suggest the best crop to plant. The paper further addresses the second most crucial aspect of farming, i.e., the cost of production. Here comes the role of digital technologies that can zero down on the type of seed, quality of soil preparation, soil health analysis, moisture percentage estimation, real-time crop analysis, and others to provide reliable information to the farmers. The third stage of farming, i.e., the harvesting, can also be optimized with the help of IoT and analytical tools. The optimum time to harvest a crop ensures that the nutritional content of the crop is highest.

**Internet of Things (IoT) in Agriculture for Smart Farming:** Internet of things (IoT) is a promising technology which provides efficient and reliable solutions towards the modernization of several domains. IoT based solutions are being developed to automatically maintain and monitor agricultural farms with minimal human involvement. IoT technology in agricultural area to develop smart farming solutions [26]. IoT has brought a great revolution in agriculture environment by examining multiple complications

and challenges in farming [27]. Now days, with the advancement of technology it has been expected that by using IoT agriculturalists and technologists are finding out the solution of those problems which farmer are facing such as shortages of water, cost management and productivity issues [28,29] efforts made on wireless sensors networks enable us to collect data from sensing devices and send it to the main servers [30]. Data collected through sensors gives information about different environmental condition to monitor the whole system properly. Agarwal et al. [31] revealed that monitoring the environmental conditions or crop productivity is not only the factor for the evaluation of crop but there are many other factors which effect the crops' productivity, e.g. field management, soil and crop monitoring, movement of an unwanted object, attacks of wild animals, and thefts etc.

The agricultural trends which provide easy and cost effective interactions through a secure and unblemished connectivity across individual Greenhouse, Livestock, Farmer, and Field monitoring. Whereby, the IoT agricultural networks using the wireless devices enable real time crop and animal monitoring. The Fig. 1a shows that two sensor kits (Libelium Smart Agriculture Xtreme IoT Vertical Kit and Crop/ Plant Monitoring Sensor Kit) have been implemented which monitor the soil moisture, leaf wetness, temperature, humidity, productivity, and air flow. While, MooMonitor sensor monitors the animal health, fertility, feeding, ruminating and resting. The agricultural servers, gateways, and agriculture database play an important role to store agriculture records and provide on demand agricultural services to authorized users [32].

Jayaraman et al. [33]; Koksal and Tekinerdogan, [34] reported that IoT agriculture research trends include network platform, network architecture, applications, security, and challenges among others. However in IoT agricultural environment a reasonable amount of work has been done and there is a need of thorough study on IoT in agriculture context to understand the current research status.

Alahi et al. [35]; Balaji et al. [36] also found that IoT based smart farming consist of four major components Fig. 1b. These four major components are physical structure, data acquisition, data processing, and data analytics.

**Fig.1a. Agricultural trends**
**Fig. 1b. Major components of IoT based smart farming [32]**



**Fig. 2a. IoT agricultural network platform based on cloud**
**Fig. 2b. Conceptual illustration of IoT-based ubiquitous agricultural solutions**

IoT enables farmers to monitor livestock via multiple sensors which are used to monitor different animal's diseases like temperature, heart rate, and digestion etc. Whereas field monitoring applications intend to report different conditions of field like soil richness, temperature, humidity, and crop disease monitoring.

Khattab et al. [37] revealed that cloud provides a large amount of storage through large virtualized servers which are connected together to perform necessary action (Fig. 2a). In which IoT techniques are applied to analyze and manage data from farms through sensors and devices to generate information for decision making. Platform has been proposed on the basis of four layers which are Cloud Storage, Gateway, Fog Computing and hardware modules. Cloud storage layer centralized the all agricultural related data such as weather related, soil, fertilization, crop and agricultural marketing in the cloud and provides on demand resources

through networked infrastructure. Analytics resources and web services are also installed on cloud or internet which is accessible by cloud services. Most of the devices or sensors are not designed in such a way which can connect with internet for the purpose of data sharing. To resolve this data sharing problem local gateways are designed which act as bridge between all hardware devices and sensors for connectivity, security and controllability. Implementation of gateway in greenhouse or field improves the ability of automation and control the real time greenhouse monitoring system.

For the implementation of smart farming fast response time and capability to exchange information is necessary. Both of these requirements (fast response time and capability to exchange information) are fulfilled by two protocols that are Representational State Transfer (REST) and Message Queuing Telemetry Transport (MQTT). Instead of using big data center distributed system is more effective for smart farming because it breaks up large computation into easy and smaller tasks like: Crop, Temperature, nutrients, energy, climate, moisture of soil etc.

However, IoT agricultural network topology shows the arrangement of multiple elements of an IoT Agricultural network and represents an ideal scenario for smart farming (Fig. 2b) and described how heterogeneous computing grid collects necessary sensor data by using multiple sensing devices such as moisture sensor,

humidity sensor, temperature sensor, gas sensor, ph sensor, ultra violet sensor etc and forms an IoT agricultural network topology. This ubiquitous Agricultural solution transforms the storage capacity of multiple electronic devices like Smartphone, Laptops, and agricultural terminals into hybrid computing grids.

Farooq et al. [32] reported that a scenario in which multiple crop parameters is monitored by implementing agricultural devices and sensors in all over the field (Fig. 3a). Sensed data is then analyzed and stored, and stored data from multiple sensors and devices becomes useful for aggregation.

On the basis of aggregation and analysis agriculturists/ farmer can monitor the different crop variables in all over the field from anywhere. Moreover, topology consists of a proper network configuration for the streaming of agricultural videos i.e. Fig. 3a support the streaming of pests via an interconnected network with an internet protocol (IP), GSM, WiMAX and access service network gateway.

The sensor-based management of herbicides and other pesticides is another promising implementation of precision agriculture [38]. Sensors under development for weed detection vary from simple colour detectors to complex machine vision systems, aimed at using colour, shape and texture features of plant materials, in order to distinguish weeds from crops, as well as to identify different weed species [39].
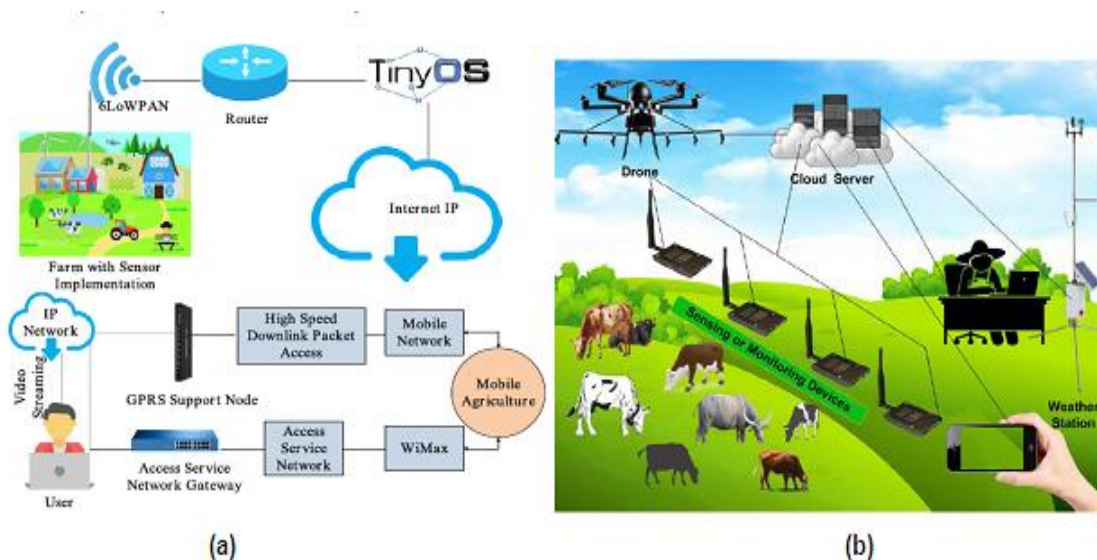


**Fig. 3a. Farm remote monitoring in agriculture**
**Fig. 3b. IoT based livestock scenario**

Hi et al. [40] revealed that an Identification of disease symptoms and prevention is the major function for animal health monitoring. Normal body temperature of dogs is $38.3^0$C-$39.2^0$C and cow's is $38.5^0$C-$39.5^0$C. When the body temperature is increased or decreased from the normal body temperature then it indicates that animal is suffering from any disease. Different livestock monitoring sensors are also attached to the animals to monitor their log performance. Livestock monitoring factors varies on the categories of animals under consideration such as conductivity of milk, pest attack, humidity, and water quality. By tagging RFID to individual animal allow farmers to track their location, thereby preventing animal from theft. Connected sensors and wearable in the livestock allow the farmer to monitor overall animals' activities and data streamed to the cloud directly helps the farmers to identify the issues (Fig. 3b). Cowlar and SCR by Allflex are using smart agriculture sensors to monitor animals health, activity, temperature, nutrition and collect information on each individual as well as about the herd. In the field of livestock several studies have been realized. Wireless Sensor have been used which are most advantageous for large farm as well as for hazardous gas monitoring.

Sawaitul et al. [41] have proposed a novel method for Classification and Prediction of future weather by using Back Propagation Algorithm and the weather parameters like speed of the wind, wind direction, rainfall, temperature and forecasting the climatic conditions are recorded. The artificial neural network back propagation algorithm is used to predict the weather conditions. The Author has tried three models to predict the weather conditions. The first model is used to collect the weather forecasting techniques. The second model is used to introduce the WSN tool kit for collect the data and then third model is used the Back Propagation Algorithm can be applied on different parameters of weather forecast.

Rajesh et al. [42] reported that integrated the sensor information and cloud computing. The service oriented architecture is used to integrate and control the sensor node. The data can be used store and available to the users by the cloud computing technology. They offer the new application and also the new database. The sensor networks are integrate with the in the cloud model and internet. The industrial processes are recorded by using the sensor network. The collected information is very important for the industry and delivers the data as fast.

Cloud technology is while effectively mediating multiple sources of modularizing architectures that delivering a complete service [43]. The new and emerging mobile computing technology also used to integrate the IoT, cloud base big data analytics. The mobile computing technology is used for deliver the prediction results are sent to the farmer's mobile and also they know the facilities provide by the ICT and the cost of the crop in the market, cost of the agricultural products etc [44].
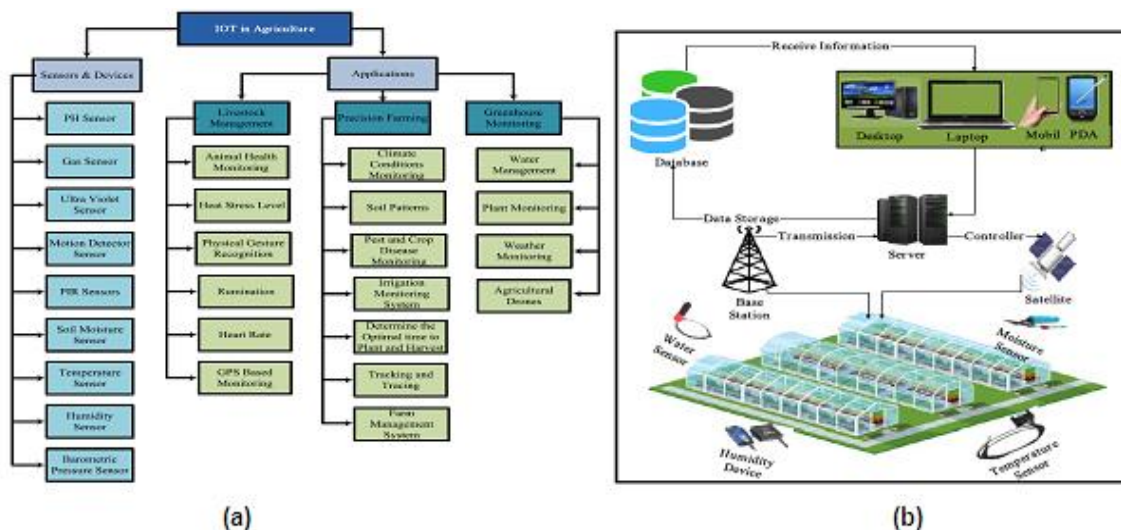


**Fig. 4a. IoT structure in agriculture**
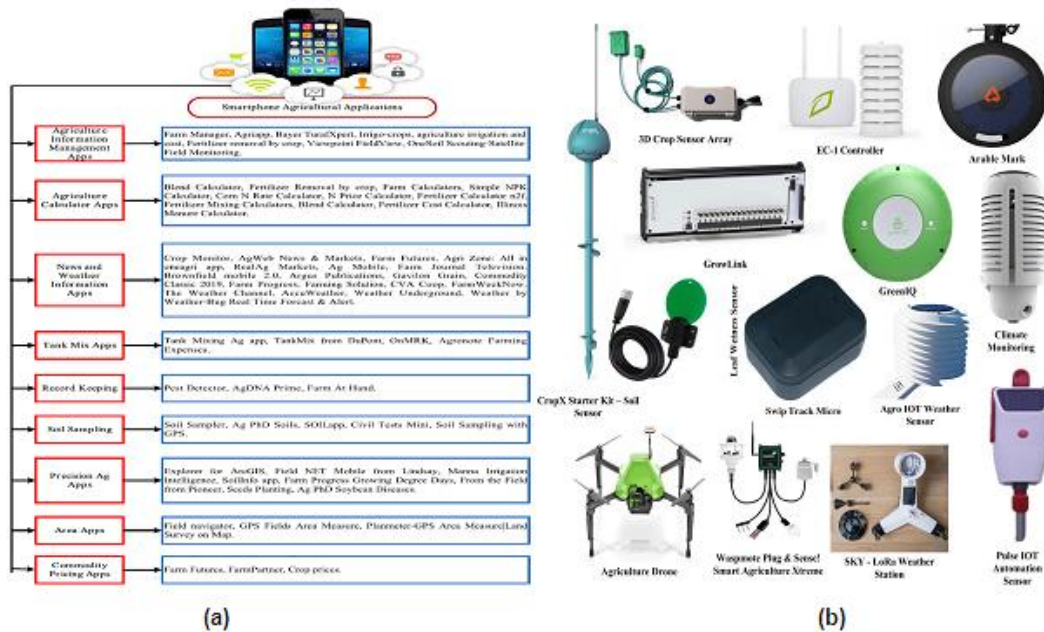**Fig. 4b. WSN for monitoring greenhouse environment**

**Fig. 5a. Smartphone applications for agriculture**
**Fig. 5b. Selected IoT agricultural products**

Reddy at el. [45] proposed GIS based DSS (Decision Support System) framework in which Spatial DDS has been designed for watershed management and management of crop productivity at regional and farm level. GIS is used to gather and analyze the graphical images for making new rules and decisions for effective management of data. Shitala et al. [46] presented mobile computing based framework for agriculturists called AgroMobile for cultivation and marketing and analysis of crop images. Further, AgroMobile is used to detect the disease through image processing and also discussed how dynamic needs of user affects the performance of system. Seokkyun et al. [47] proposed cloud based Disease Forecasting and Livestock Monitoring System (DFLMS) in which sensor networks has been used to gather information and manages virtually.

Ranya et al. [48] presented ALSE (Agriculture Land Suitability Evaluator) to study various types of land to find the appropriate land for different types of crops by analyzing geo-environmental factors. ALSE used GIS (Global Information System) capabilities to evaluate land using local environment conditions through digital map and based on this information decisions can be made. Raimo et al. [49] proposed FMIS (Farm Management Information System) used to find the precision agriculture requirements for information systems through web-based approach. Moreover, the management of GIS

data is a key requirement of precision agriculture. Sorensen et al. [50] studied the FMIS to analyze dynamic needs of farmers to improve decision processes and their corresponding functionalities. Further they reported that identification of process used for initial analysis of user needs is mandatory for actual design of FMIS. Zhao [51] presented an analysis of web-based agricultural information systems and identified various challenges and issues still pending in these systems. Due to lack of automation in existing agriculture system, the system is taking longer time and is difficult to handle dynamic needs of user which leads to customer dissatisfaction.

Sorensen et al. [52] identified various functional requirements of FMIS and information model is presented based on these requirements to refine decision processes. They identified that complexity of FMIS is increasing with increase in functional requirements and found that there is a need of autonomic system to reduce complexity. Hu et al. [53] proposed WASS (Web-based Agricultural Support System) and identified functionalities (information, collaborative work and decision support) and characteristics of WASS. Based on characteristics, authors divided WASS into three subsystems: production, research-education and management.

IoT agriculture system applied as an array of wide variety of fields such as, Precision farming,

livestock monitoring, and greenhouse monitoring. Agriculture applications have been categorized into three sections: IoT agricultural applications, Smartphone based applications and sensor based applications (Fig. 4a). Different IoT sensors are deployed to measure soil quality, weather conditions, moisture level, and effectively plan to optimize harvesting techniques. To enhance the crop production a correlation analysis between agricultural environment information and crop statistical analysis has been developed to collect crop data [54]. Khanna and Kaur, [55] reported that an IoT based platforms has been developed for precision agriculture and ecological monitoring. IoT based weather forecasts helps to optimize productivity and take anticipatory analysis to prevent the crop from damage. Multiple monitoring devices/sensors are used to predict pest behavior, plant or crop growth and address any pending pest issue before they damage crop. Nakutis et al. [56] also found that a remote agricultural monitoring platform has been presented on the basis of monitored data. IoT base Precision farming consist of multiple monitoring and controlling applications such as climate conditions monitoring, soil patterns monitoring, pest and crop disease monitoring, irrigation, determine optimal time to plant and harvest and tracking/ tracing.

Ibrahim et al. [57] reported that the cultivation of greenhouse is more intense, therefore in terms of controlling and monitoring it requires high precision. To monitor environmental or weather conditions there have been several studies on the applications of WSN's in greenhouse. Recent studies shows that how IoT can be implemented in greenhouse to minimize the human resources accumulate energy and provides direct link of greenhouse from ranchers to customers. Most of the studies have focused only on remote monitoring and localized. González-Amarillo et al. [58] revealed that the purpose of high precision there have been a lot of studies which integrates meta-processing structure with data to transfer it on remote infrastructures through internet. By applying well evaluated crop models, assessment of the crop status helps the ranchers to take better decisions. In Fig. 4b a Wireless Sensor Network (WSN) has been implemented to monitor the greenhouse environment. Whole network is divided into multi parts which processes the data and gives feedback.

Data can be obtained by corresponding sensors and detectors and then transferred to the main server for processing. In physical implementation the major components are the sensors and network for accurate data transmission. Growers setup the different monitoring devices and sensors according to the specific requirements and track or record the required information. Agriculturists make better decisions by analyzing the received information and achieve specific goals by obtaining optimal data. There are many IoT based greenhouse applications such as water management, plant monitoring, and climate monitoring etc.

Windsperger et al. [59] also found that the exact amount of required water in greenhouses is a key problem. Smart sensors are implemented which are controlled by applying multiple IoT techniques to avoid from excessive use of water. In greenhouses water management is carried out by using automatic drip irrigation which works by following soil moisture threshold that is set accordingly. Shirsath et al. [60] reported that an IoT sensors and cameras creates ideal environment for plants by monitoring the state of plants regularly and generates an alert if any problem is recognizable. On the other side, cloud based IoT solutions store the sensed data and view it periodically which is helpful for growers to ensure that all plants obtains ideal attention in the greenhouse.

Barh and Balakrishnan, [61] observed that integration of electronic devices with smart-phones innovate the technology world and smart-phones are taken as a driver of IoT. To make smart phones versatile in agriculture field various hardware and software have been designed. A good (but not complete) survey of smart phone apps providing agricultural solutions has been presented. Fig. 5a showing a classification illustration of smart phone apps for smart farming. Moreover, there are a number of recent apps which are serving similar functionalities. All smart phone apps which are elaborated in Fig. 5a discussed in tabular form with a small description of each. These smart phone apps are not limited; developers from all over the world have developed many e-Farming apps therefore, this paper highlighted some selected apps which have been discussed according to their popularity.

**IoT Agricultural Industry Trends and Practices:** The IoT in agriculture field has experienced a burst of creativity, activity, venture capital forms and exciting entrepreneurs (Fig. 5b).

The space becomes visible as an active group of large forms and new start ups that are willing to become the part of what may be a giant market and technologies. In this section an extensive record of some products and technologies has been provided for a good understanding of IoT position in agriculture field.

3D Crop Sensor Array with PAR Addon can be mounted on any location, to monitor temperature, humidity and carbon dioxide in the farm. EC-1 Controller monitors the environmental conditions and then programs them to control the environment by turning off and on devices. Arable Mark is the first device which links the global weather data within the field observations developed by Arable. With the unprecedented ground truth accuracy device makes informed decisions and delivers real time monitoring information to the palm of user's han.

Growlink designed Growlink one controller to deliver smart farming experience. It has highest processing power and components quality to coordinate with multiple sensors and devices in all over the farm.

This device is simply all in one and farmers can expand the system according to their requirements by adding additional microcontroller via IP networks.

Easternpeak offers an IoT GreenIQ agricultural device which control irrigation and saves water of your garden's lawn from anywhere. Growers can save up to 50% outdoor water bills by using a Green IQ smart sprinklers controller. Grofit provides a climate monitoring device based on Bluetooth and its transmission range is up to 200 m in all over field. This device also provide data log which store maximum 30 days measurements. Growers can monitor air humidity, real time air temperature and sun radiations by using this device.

MeteoHelix weather station designed by allmeteo which provides reliable, stable and open meteorological solutions according to weather requirements. This weather station provides multiple features like temperature, humidity, atmospheric pressure, dew point, sun radiations, and solar radiations measurement. Leaf Wetness sensor is developed by Smart Element which determine the wetness of leaf by electrical resistance on the surface of sensor. It is used to measure wet and dry time on the leaf surface. Swip Track Micro locates any moving object in all

over the field that may be any farming machine, vehicle or engines. Waspmote Plug & Sense! Smart Agriculture Xtreme is a sensor node which provides more reliable and accurate information about weather. This sensor measures the wind and rainfall condition via optical technology. The presence of fertilizers and soil morphology can be analyzed through this sensor by measuring the oxygen level, water content, and soil water potential.

SKY _ Lora Weather Station can easily communicate to nearby master sensor through LoRa. This is suitable for those locations where there is nearby connectivity. This weather station can send data up to 600 meter away to a master sensor which has WIFI connection. Pycno has been developed a Pulse IoT automation sensor which comes in a self-sustained package powered by a tiny solar panel. Sensor is WIFI and LoRa enabled device which has multiprotocol port in the bottom. In future Pulse Automation Sensor and Pycno soil sensor will be integrated to actuate devices and talk with each other in the field. CropX Starter Kit _ Soil Temperature 24/7 is a real-time soil-temperature monitoring Sensor. This sensor has direct cellular connection and better accuracy which provides advance sensing capabilities.

## 1.1 Cloud-based Agriculture Service

AaaS to provide and get useful information about agriculture based on different domains. Nine types of information of different domains in agriculture have been considered: crop, weather, soil, pest, fertilizer, productivity, irrigation, cattle, and equipment. Users are basically classified in three categories: i) agriculture expert, ii) agriculture officer, and iii) farmer. The agriculture expert shares professional knowledge by answering farmer queries and updates the AaaS database based on the latest research done in the field of agriculture with respect to their domain. Agriculture officers are the government officials that provide the latest information about new agriculture policies, schemes, and rules passed by the government. Farmer is an important entity of AaaS who can take maximum advantage by asking his queries and getting automatic reply after analysis. Users can monitor any data related to their domain and get their response without visiting the agriculture help center. It integrates the different domains of agriculture with AaaS. The queries received from user(s) are forwarded to cloud repository for updates and response sends back to particular

user on their preconfigured devices (tablets, mobile phones, laptops etc) via internet.

The subsystem contains the platform in which agriculture service is hosted on a cloud. Details about users and agriculture information are stored in a cloud repository in different classes for different domains with unique identification number. The information is monitored, analyzed, and processed continuously by AaaS. The analysis process consists of various sub processes: selection, data preprocessing, transformation, classification and interpretation Fig. 6a. Different classes for every domain and sub classes for further categorization of information have been designed. In storage repository, user data is categorized based on different predefined classes of every domain. This information is further forwarded to agriculture experts and agriculture officers for final validation through preconfigured devices. Further, a number of users can use cloud-based agriculture service so the QoS manager and autonomic resource manager in cloud subsystem have been integrated. Based on QoS requirements, autonomic resource manager identifies resource requirements automatically and allocates and executes the resources at infrastructure level. Performance monitor is used to verify the performance of system and also maintain it automatically. If the system will not be able to handle the request automatically then the system generates an alert.

Cloud-based agriculture service provides a user platform through which user can access agriculture service Figure 6b. Firstly, agriculture service allows user to create profile for interaction with AaaS. After profile creation, the user is required to provide his personal details along with the details of information domain. AaaS analyses the information to verify whether the data is complete or not for further processing by performing various checks. Further data is processed and redundancy of data is removed and data is used to select domain to which data belongs. Information is classified properly in order with unique identification number. This information is forwarded to agriculture experts and agriculture officers for final validation through preconfigured devices. After successful validation of information, it is stored in *AaaS* database. If user wants to know the response of their query, then system will automatically diagnose the user query and send the response back to that user.
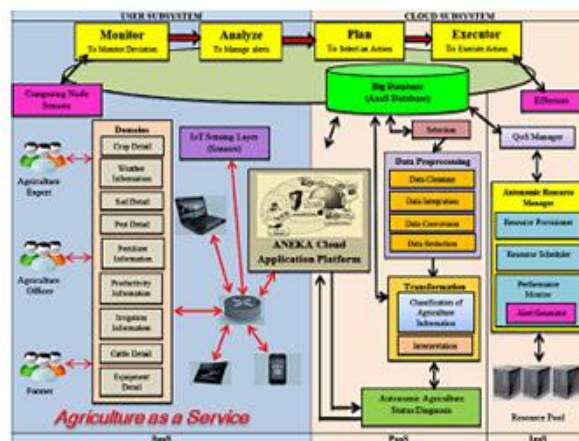


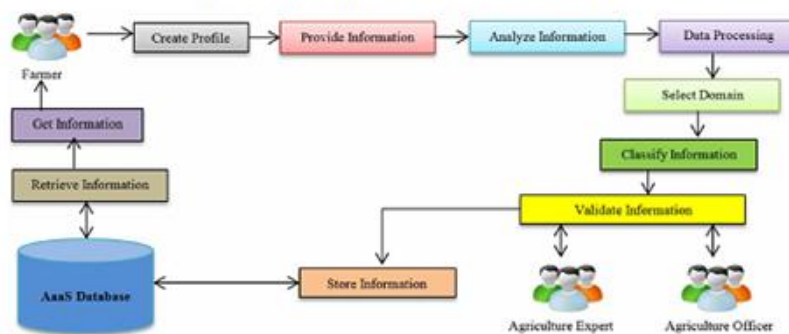Fig. 6a: Agriculture-as-a-Service architecture



Fig. 6b: Functional aspects of AaaS

## 1.2 Agricultural Robots, Drones and AI 2020-2040 Technologies

The developments in agricultural robotics, machine vision, and AI will drive a deep and far-reaching transformation of the way farming is carried out. Yes, today the fleet sizes and the total area covered by new robots are still vanishingly small compared to the global agricultural industry. Yet, this should not lull the players into a false sense of security because the ground is slowly but surely shifting. Robotics and AI are enabling a revolution in affordable ultra-precision, which will eventually upend familiar norms in agrochemical supply, in agricultural machine design, and in farming practices.

Digitalization has also enabled new types of equipment such as drones and robots to be used for precision farming in both crop and livestock production (Fig. 7a). Both types of equipment have benefitted from advances in sensor and positioning technologies and computing power. Drones may be used to apply inputs such as agrochemicals or to monitor grazing animals [62]. Small field robots are especially suitable for crop-care and monitoring activities and may be used in a swarm concept. In livestock production, milking robots were introduced in the 1990s and are now widely used in industrialized countries [63]. However, there are hundreds of small firms that are essential to the development and supply of digital innovations for agribusinesses and farmers. Fig. 7b shows examples of the many types of firms that supply digital technology to the farm in the middle. At the top are examples of Farm Management Software firms then moving clockwise there are the precision agriculture firms, suppliers of market places for business to business transactions, robotics, etc? As with other types of firms supplying digital technology, data on investments by small firms are scarce.
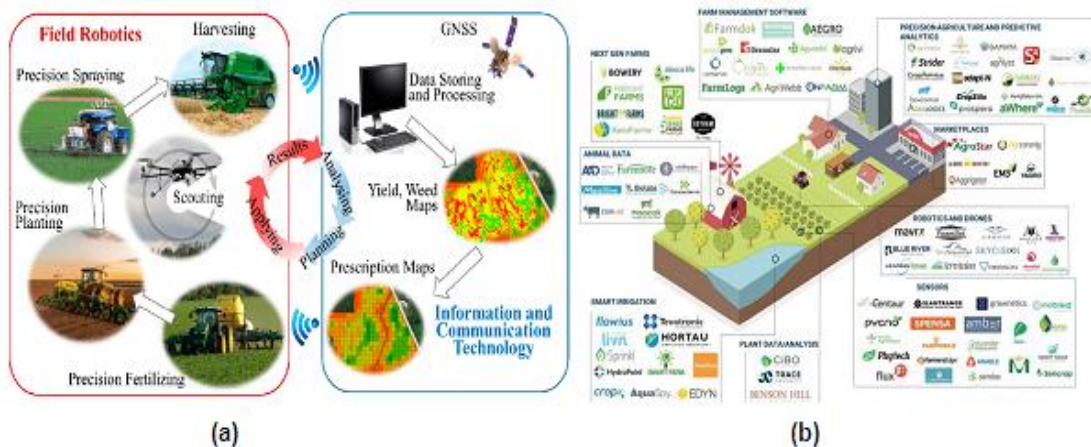


**Image 2. Agricultural Robots, Drones, and AI**



**Fig. 7a.  Technologies involved in precision agriculture**
**Fig. 7b. Some companies supplying digital technologies and services**

59

Many firms supply digital technology for agriculture. The most popular suppliers of these services are commercial enterprises (54% of registered users), mobile network operators (20%), governments (20%), NGOs (5%), and large agribusiness such as Mars and Olam (1%). The main types of digital technology accessed are advisory services with 22.6 million registered users, financial access (5.6 million users), market linkages (2.5 million users), and value chain management (2.4 million users) [64].

Jadeja and Modi, [65] reported that managing big datasets requires special computing and storing tools, and cloud computing techniques provide comfortable, fast, economical, and secure mechanisms for doing so (Fig. 8b). Cloud computing is defined by The National Institute of Standards and Technology as "a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources—e.g., networks, servers, storage applications and services—that can be rapidly provisioned and released with minimal management effort or service provider interaction. A cloud computing solution can be implemented as (1) a public cloud where the access is provided via interfaces in a pay-per-use procedure; (2) a private cloud, which is similar to an organization's Intranet; and (3) a hybrid cloud, which combines public and private cloud features. Cloud providers operate hardware and software computing infrastructures to provide services to demanding users over the Internet offering three types of services: software as a service (SaaS), platform as a service (PaaS), and infrastructure as a service (IaaS).

Shamshir et al. [66] revealed that digital farming is the practice of modern technologies such as sensors, robotics, and data analysis for shifting from tedious operations to continuously automated processes. The concepts of multi-robots, human-robot collaboration, and environment reconstruction from aerial images and ground-based sensors for the creation of virtual farms were highlighted as some of the gateways of digital farming (figure 8a). It was shown that one of the trends and research focuses in agricultural field robotics is towards building a swarm of small scale robots and drones that collaborate together to optimize farming inputs and reveal denied or concealed information. For the case of robotic harvesting, an autonomous framework with several simple axis manipulators can be faster and more efficient than the currently adapted professional expensive manipulators. The trend in food production is towards automated farming techniques, compact Agri-cubes, and cultivation systems that have the minimum human interface where skilled workforce are being replaced with robotic arms and mobile platforms. This system of computer-to-robot communication combined with the sophisticated simulation software, analytics applications, and data sharing platforms offers a much smoother control over farming operations. In addition, it provides farmers with details of historical field data for improving their performances and optimizing crop yields for specific plots, or even developing new business models.

An agricultural drone, otherwise known as an unmanned aerial vehicle (UAV), is used to monitor the health of their trees, land, and crops using high-tech sensors and digital and satellite imaging to provide comprehensive information about land. These clever flying bots can remotely detect land and crop damage from insects, weather conditions, wildfire and construction; they can indicate which crops need more or less nutrients, estimate yields and count cattle.

Staring from collecting insightful crop data from fields with automated sensors to interpretation of the data, analyzing and making real-time, more accurate assessments and decisions on the field, these technologies have revolutionized farming. The full or partial replacement of human labor on the farms is a clear indication of the atomization in the sector. This helps to bring greater level of accuracy, consistency, safety and reliability.

Drones are now a vital part of agriculture given the cost competitiveness of the industry in general, the use of a drone services opposed to traditional methods of manned aircraft, satellite imagery or man power on the ground has a colossal positive impact on finances in agriculture due to the ground coverage that can be achieved using a drone, not to mention the operational readiness and organizational benefits. A drone can be off the ground on a planned mission in minutes after arriving on site. Compare that to any of the traditional methods and the time saved is enormous. This alone is a huge benefit to agriculture allowing them to assign their time to other projects.
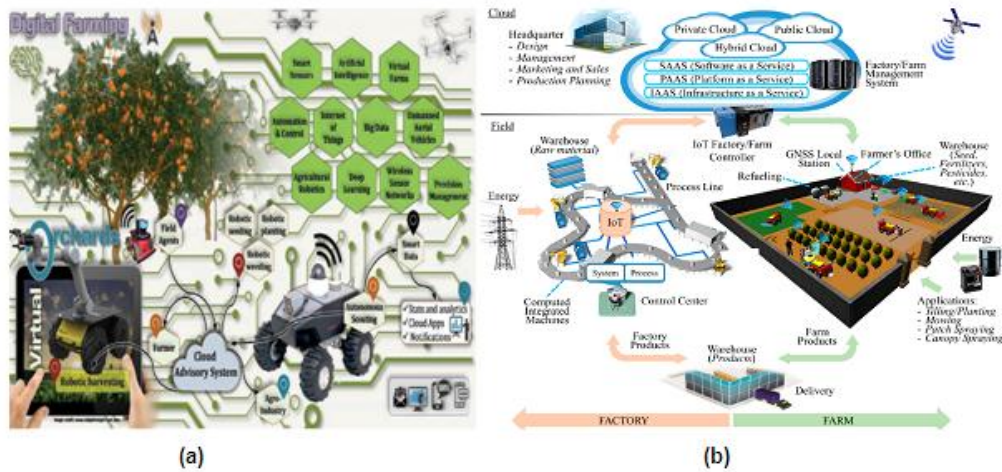
**Fig. 8a. Digital farming with emphasize on the role of agricultural robotics**
**Fig. 8b. Smart factory (left) and smart farm (right) with their common elements (center)**



**Fig. 9. A small agricultural drone equipped with a camera**

**Table 1. Some agricultural applications of remote optical imaging**

| Wavelengths | Applications |
|---|---|
| RGB (red-green-blue ) | Visual inspection, elevation modeling and plant counting |
| NIR | Soil properties, moisture analysis, crop health/stress analysis, water management, erosion monitoring and plant counting |
| RE (red-edge) | Crop health analysis, plant counting and water management |
| Multispectral | NIR and RE applications (but excluding plant counting) |
| Hyper-spectral | Nutrient stress, draught monitoring, disease detection etc. |
| Thermal infrared | Plant physiology analysis, irrigation scheduling, crop maturity evaluation and yield forecasting |

**Table 2. IoT sensor based applications in agriculture**

| Infirmity/ Conditions | Sensor/ Devices Used; Operations; IoT Roles/ Connections |
|---|---|
| $P^H$ Sensor | $P^H$ sensor is used to monitor the accurate amount of nutrients in the soil which is necessary for irrigation. By monitoring value of $P^H$ required quantity of nutrients is supplied to the plants or crop for healthy growth [67] |
| Gas Sensor | By observing the amount of infrared radiations consumed gas sensor measures the quantity of toxic gases in the greenhouses and livestock. It consists of two factors low range and high range. Typically low range start |

| Infirmity/ Conditions | Sensor/ Devices Used; Operations; IoT Roles/ Connections |
|---|---|
| | from 0 to 10, 000 and high range from 0 to 100, 000 [68] |
| Ultra Violet Sensor | UV sensors are used to monitor the ultra violet rays by converting photo current to voltage. It is equipped with an external circuit that is analogue signals to digital signal converter. This sensor detects light rays most efficiently for effective crop growth [69] |
| Motion Detector Sensor | This sensor is very useful at the night especially for animals and theft detection in the field. When an unwanted movement happened in farm an alert message is delivered on the farmer mobile. In this way farmer can take corrective action by detecting the motion of an unwanted object or animal around the field [70] |
| Passive Infrared Sensors | A motion detector is fixed in Passive Infrared (PIR) Sensor to detect which is used to check rang of a person movement. PIR sensor made up of Pyro Electric sensor and used to detect the levels of infrared radiation emitted from an object. Mainly PIR sensors are used for automatic light detection or in burglar alarm. When an unwanted object moves into field at that point temperature rise and PIR changes it into output voltage for detection purpose [71] |
| Soil Moisture Sensor | This sensor is used to measure the moisture content and water quality in the soil. Sensor consists of two large exposed pads and work on the key of electrical conductivity. Resistance of soil moisture sensor is inversely proportional to moisture content which is the major factor to determine plant growth. If water quantity less than required than analogue voltage will become low which helps the farmer to identify the deficiency of water. This sensor is used in all over the field to maintain the water quantity and any other automation that is required [72]. Sicari et al. [73] revealed that a wireless moisture sensor network has been used to improve the irrigation system in greenhouse. Losant platform also used to measure the soil content which informs the farmer via email or message. The sensed values are transmitted via WIFI to a field manager for proper analysis. |
| Temperature Sensor | Soil temperature plays an important role in the productivity of crop. Change in the soil temperature directly effect on soil moisture and nutrient absorption. Alahi et al. [74] reported that a novel sensing system has been developed to measure the balance of nutrients in ground and surface water. Electrochemical impedance also applied to monitor and detect the concentration of nitrates in the soil. The test samples have been calculated by LCR meter. In this research results has been evaluated by using standard library measurements to evaluate the nutrients concentration in water. |
| Humidity Sensor | This sensor is utilized to sense and measures the comparative humidity level in air. It measures the actual air temperature and moisture ratio in air. Humidity influence directly and indirectly in multiple ways of plants leaf growth, pollination and photosynthesis. Leaf development does not only depend on photosynthesis process it also depends upon physical process of cell growth which can be monitored via humidity sensor [75] |
| Barometric Pressure Sensor | Pressure sensor measure the atmospheric pressure when it is low then rainfall can be expected but it is expected that when pressure is high then there will be less chances of rainfall. Barometric pressure sensor also used to control the water flow. When pressure is less than a threshold value at that point water flow is controlled by stopping the water supply. Multiple small size sensors are installed at different points in all over the field to measure the average value of pressure [76] |

## 2. CONCLUSION

Recent years have seen dramatic changes in agricultural practices, driven largely by efficiency, economic and environmental considerations. These practices, mainly forms of precision agriculture, have allowed growers to gain a hitherto unprecedented understanding of a crop's

condition and requirements and its growing environment, allowing informed decision to be made regarding key functions such as irrigation and the application of fertilizers, herbicides and pesticides. Yields are increased, whereas the costs and environmental impact are reduced. This understanding arises from quantified information from sensors based on optical and other technologies deployed from the air, on agricultural machines and in the field and made possible by recent developments in imaging, image processing, sensing and communications technologies. This trend is set to continue for the foreseeable future, and as the demand for food continues to grow, agriculture will undoubtedly constitute a significant sector of the overall sensor market.

Digital agriculture technology has the potential to create an agricultural revolution, making crop and livestock production more efficient and more environmentally friendly and contributing to higher productivity. Connectivity, mobile apps, digital platforms, software, global satellite positioning systems, remote sensing, and field sensors are the main technologies used. In this review article, we have presented a comprehensive survey on the state-of-the-art for IoT in agriculture. To this end, we discuss agricultural network architecture, platform, and topology which help to access to IoT backbone and facilitates farmers to enhance the crop productivity. Furthermore, many important dimensions of IoT based agricultural including technologies; industries trends have also been presented to facilitate various stake holders. Government has started patronizing IoT in agriculture and it is anticipated that soon IoT in agriculture will revamp the conventional farming method. The use of such digital technologies has the potential to increase the sustainable management of natural resources (soil and water) and to reduce the use of agricultural inputs, making agricultural areas more productive and reducing their environmental impact. However, important difficulties to amplify its use were pointed out. The cost of purchasing machines, equipment and applications, problems with/or lack of connectivity in rural areas were the main issues presented. It is suggested that future studies focus on the new research questions from this work, more specifically on farmers' social and economic behavior towards adoption of new technologies and whether the adopters have a competitive advantage compared to non-adopters. Further research could also consider the way technology adoption will occur by the

new generation, accordingly to the level of Internet access in the rural areas and hoping that they will continue to run the family business.

It should be noted that development of an affordable and effective agriculture robot requires a multidisciplinary collaboration in several areas such as horticultural engineering, computer science, mechatronics, dynamic control, deep learning and intelligent systems, sensors and instrumentation, software design, system integration, and crop management. We highlighted some of the facing challenges in the context of utilizing sensors and robotics for precision agriculture and digital farming as: object identification, task planning algorithms, digitalization, and optimization of sensors. It was also mentioned that for an autonomous framework to successfully execute farming tasks, research focus should be toward developing simple manipulators and multi-robot systems. This is in fact one of the academic trends and research focuses in agricultural robotics for building a swarm of small-scale robots and drones that collaborate together to optimize farming inputs and reveal denied or concealed information. Some forms of human-robot collaboration as well as modification of the crop breeding and planting systems in fields and greenhouses might be necessary to solve the challenges of agricultural robotics that cannot yet be automated. For example, in a collaborative harvesting system using human-and-robot, any fruit that is missed by the robot vision will be spotted by the human on a touch-screen interface. Alternatively, the entire robot sensing and acting mechanism can be performed by a human operator in a virtual environment. Nevertheless, an agricultural robot must be economically viable which means it must sense fast, calculate fast, and act fast to respond to the variability of the environment.

## DISCLAIMER

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Confederation of Indian Industry (CII). Digital Agriculture: The Future of Indian Agriculture; 2020.
Available:https://www.ciiblog.in/digital-agriculture-the-future-of-indian-agriculture.
2. Pahwa A. Agritech – towards transforming Indian agriculture; 2020.
3. Kumari S. New ways of improving agriculture. Kurukshetra. 2014;62(8):1-52.
4. Trendov NM, Varas S, Zeng M. Digital technologies in agriculture and rural areas. Food and Agriculture Organization of the United Nations, Rome; 2019.
5. Díez C. Hacia una agricultura inteligente (Towards and intelligent Agriculture). Cuaderno de Campo. 2017;60:4–11.
6. Reyns P, Missotten B, Ramon HJ, De Baerdemaeker J. A review of combine sensors for precision farming. Precis. Agric. 2002;3:169–182.
7. Kayad A, Paraforos DS, Marinello F, Fountas S. Latest Advances in Sensor Applications in Agriculture. Agriculture. 2020;10:362.
8. Mogili U, Deepak B. 2018. Review on application of drone systems in precision agriculture. Procedia Comput. Sci.133: 502–509.
9. Suciu G, Marcu I, Balaceanu C, Dobrea M, Botezat E. Efficient IoT system for precision agriculture. Int. Conf. Eng. Mod. Electr. Syst. 2019;173–176.
10. McKinion JM, Turner SB, Willers JL, Read JJ, Jenkins JN, McDade J. Wireless technology and satellite internet access for high-speed whole farm connectivity in precision agriculture. Agric. Syst. 2004;81:201–212.
11. Chen Y, Li Y, Li C. Electronic agriculture, blockchain and digital agricultural democratization: Origin, theory and application. J. Clean. Prod. 2020;268:122071.
12. Wolfert S, GE L, Verdouw C, Bogaardt MJ. Big Data in Smart Farming—A review. Agric. Syst. 2017;153:69–80.
13. Liakos KG, Busato P, Moshou D, Pearson S, Bochtis D. Review machine learning in agriculture: A Review. Sensors. 2018;18: 2674.
14. Verdouw C, Sundmaeker H, Tekinerdogan B, Conzon D, Montanaro T. Architecture framework of IoT-based food and farm systems: A multiple case study. Comput. Electron. Agric. 2019;165:104939.
15. Michels M, Bonke V, Mussho O. Understanding the adoption of herd management smartphone apps. J. Dairy Sci. 2019;102:9422–9434.
16. Michels M, Bonke V, Mussho O. Understanding the adoption of smart-phone apps in crop protection. Precis. Agric. 2020;21:1209–1226.
17. Ampatzidis Y, Partel V, Agroview CL. Cloud-based application to process, analyze and visualize UAV-collected data for precision agriculture applications utilizing artificial intelligence. Comput. Electron. Agric. 2020;174:105457.
18. Saiz RV, Rovira MF. From smart farming towards agriculture 5.0: A review on crop data management. Agronomy. 2020;10:207.
19. Basso, Bruno, Antle JM. Digital Agriculture to Design Sustainable Agricultural Systems. Nature Sustainability. 2020;3:245–56.
20. Aker, Jenny C, Ishita Ghosh, Jenna Burrell. The Promise (and Pitfalls) of ICT for Agriculture Initiatives. Agricultural Economics. 2016;47:35–48.
21. FAO. The State of Food and Agriculture 2016. Climate change, agriculture and food security. Rome, FAO; 2016a.
22. Alexandratos N, Bruinsma J. World agriculture towards 2030/2050: the 2012 revision. ESA Working Paper No. 12–03. Rome, FAO; 2012.
23. FAO. The state of the world's land and water resources for food and agriculture (SOLAW); 2011b.
24. Lambin EF, Meyfroidt P. Global land use change, economic globalization, and the looming land scarcity. Proceedings of the National Academy of Sciences of the United States of America. 2011.108(9):3465–3472.
25. Khandakar E, Ahmed U, Gregory MA. Integrating Wireless Sensor Networks with Cloud Computing 7th Int Conf on Mobile Ad-hoc and Sensor Networks (MSN), Beijing; 2011.
26. Stoes M, Vank J, Masner J, Pavlik J. Internet of Things (IoT) in agriculture-selected aspects,' Agris On-Line Papers Econ. Inform. 2016;8(1):83-88.

27. Ray PR. Internet of Things for smart agriculture: Technologies, practices and future direction,' J. Ambient Intell. Smart Environ. 2017;9(4):395-420.

28. Kamienski C, Soininen JP, Taumberger M, Dantas R, Toscano A, Cinotti TS, Maia RF, Neto AT. Smart water management platform: IoT-based precision irrigation for agriculture,' Sensors. 2019;19(2): 276.

29. Elijah O, Rahman TA, Orikumhi I, Leow CY, Hindia MN. An overview of Internet of Things (IoT) and data analytics in agriculture: Benefits and challenges,IEEE Internet Things J. 2018;5(5):3758-3773.

30. Ojha T, Misra S, Raghuwanshi NS. Wireless sensor networks for agriculture: The state-of-the-art in practice and future challenges, Comput. Electron. Agricult. 2015;118:66-84.

31. Agrawal H, Dhall R, Iyer KSS, Chetlapalli V. 2019. An improved energy efficient system for IoT enabled precision agriculture," J. Ambient Intell. Hum. Comput., pp. 1-12, Jun. 2019.

32. Farooq MS, Riaz S, Abid A, Abid K, Naeem MA. A Survey on the Role of IoT in Agriculture for the Implementation of Smart Farming. IEEE Access. 2019;7:156237-156270.

33. Jayaraman PP, Yavari A, Georgakopoulos D, Morshed A, Zaslavsky A. Internet of Things platform for smart farming: Experiences and lessons learnt," Sensors. 2016;16(11):1884.

34. Koksal O, Tekinerdogan B. Architecture design approach for IoT based farm management information systems," Precis. Agricult. 2018;20(5):926-958.

35. Alahi MEE, Li X, Mukhopadhyay S, Burkitt L. A temperature compensated smart nitrate-sensor for agricultural industry," IEEE Trans. Ind. Electron. 2017;64(9):7333-7341.

36. Balaji S, Nathani K, Santhakumar R. IoT technology, applications and challenges: A contemporary survey," Wireless Pers. Commun. 2019;108(1):363-388.

37. Khattab A, Abdelgawad A, Yelmarthi K. Design and implementation of a cloud-based IoT scheme for precision agriculture," in Proc. 28th Int. Conf. Microelectron. (ICM). 2016;201-204.

38. Timmermann C, Gerhards R, Kühbauch W. The economic impact of site specific weed control. Precision Agriculture. 2003;4:249-260.

39. Felton WL, Alston CL, Haigh BM, Nash PG, Wicks GA, Hanson GE. Using reflectance sensors in agronomy and weed science. Weed technology. 2002;16:520-527.

40. Hi X, An X, Zhao Q, Liu H, Xia L, Sun X, Guo Y. Internet of Things in protected agriculture," Sensors. 2019;19(8):1833.

41. Sawaitul SD, Wagh KP, Chatur PN. Classification and Prediction of Future Weather by using Back Propagation Algorithm- An Approach. Int J Emerg Tech Adv Engg. 2012;2(1):110-113.

42. Rajesh V, Gnanasekar JM, Ponmagal RS, Anbalagan P. Integration of Wireless Sensor Network with Cloud. Recent Trends in Information, Telecommunication and Computing (ITC), IEEE Explore access; 2010.

43. Kumar RG, et al. Crop selection method to maximize crop yield rate using machine learning technique. Int Conf on Smart Technologies and Management for Computing, Communication, Controls, Energy and Materials; 2015.

44. Zhang P, Yan Z, Sun H. A Novel Architecture Based on Cloud Computing for Wireless Sensor Network", 2nd Int Conf on Computer Science and Electronics Engineering [ICCSEE]. 2013;472-475.

45. Reddy NM, Rao NH. GIS Based Decision Support Systems in Agriculture. National Academy of Agricultur al Research Management Rajendranagar; 1995.

46. Shitala Prasad, Peddoju SK, Ghosh D. AgroMobile: A Cloud-Based Framework for Agriculturists on Mobile Platform, International Journal of Advanced Science and Technology. 2013;59:41-52.

47. Seokkyun J, Jeong H, Kim H, Yoe H. Cloud computing based livestock monitoring and disease forecasting system. International Journal of Smart Home. 2013;7(6):313-320.

48. Ranya E, Abdul Rashid B, Mohamed Shariff, Fazel Amiri, Ahmad NB, Siva Kumar Balasundram SK, Mohd Soom MA. Agriculture Land Suitability Evaluator (ALSE): A decision and planning support tool for tropical and subtropical crops", Computers and Electronics in Agriculture. 2013;93:98-110.

49. Raimo Nikkila, Ilkka Seilonen, Kari Koskinen. Software architecture for farm management information systems in precision agriculture, Computers and

Electronics in Agriculture. 2010;70(2):328-336.

50. Sorensen CG, Fountas S, Nash E, Pesonen L, Bochtis D, Pedersen SM, Blackmore SB, et al. Conceptual model of a future farm management information system. Computers and Electronics in Agriculture. 2010;72(1):37–47.

51. Zhao R. Study on Web-based Agricultural Information System Development Method, In Proceedings of the Third Asian Conference for Information Technology in Agriculture, China. 2002;601-605.

52. Sorensen CG, Pesonen L, Bochtis DD, Vougioukas SG, Suomi P. Functional requirements for a future farm management information system. Computers and Electronics in Agriculture. 2011;76(2):266–276.

53. Hu Y, Quan Z, Yao Y. Web-based Agricultural Support Systems. Conference: Proceedings of the 2nd International Workshop on Web-based Support Systems, September 20, Beijing, China; 2004.

54. Jayaraman PP, Yavari A, Georgakopoulos D, Morshed A, Zaslavsky A. Internet of Things platform for smart farming: Experiences and lessons learnt. Sensors. 2016;16(11):1884.

55. Khanna A, Kaur, S. Evolution of Internet of Things (IoT) and its significant impact in the field of precision agriculture," Comput. Electron. Agricult. 2019;157(1):218-231.

56. Nakutis Z, Deksnys V, Jaruevicius I, Marcinkevicius E, Ronkainen A, Soumi P, Nikander J, Blaszczyk T, Andersen B. Remote agriculture automation using wireless link and IoT gateway infrastructure,' in Proc. 26th Int.Workshop Database Expert Syst. Appl. (DEXA), Sep. 2015;99-103.

57. Ibrahim H, Mostafa N, Halawa H, Elsalamouny M, Daoud R, Amer H, Adel Y, Shaarawi A, Khattab A, ElSayed, H. A layered IoT architecture for greenhouse monitoring and remote control, SN Appl. Sci. 2019;1(3):223.

58. Gonzalez-Amarillo CA, Corrales-Muñoz JC, Mendoza- Moreno MA, Hussein AF, kumar NK, Ramirez-González G. An IoT-based traceability system for greenhouse seedling crops,' IEEE Access. 2018;6:67528-67535.

59. Windsperger B, Windsperger A, Bird DN, Schwaiger H, Jungmeier G, Nathani C, Frischknecht R. Greenhouse gas emissions due to national product consumption: From demand and research gaps to addressing key challenges, Int. J. Environ. Sci. Technol. 2019;16(2):1025 - 1038.

60. Shirsath DO, Kamble P, Mane R, Kolap A, More RS. IoT based smart greenhouse automation using Arduino, Int. J. Innov. Res. Comput. Sci. Technol. 2017;5(2):234-238.

61. Barh A, Balakrishnan M. Smart phone applications: Role in agri-information dissemination, Agricult. Rev. 2018;39(1):82-85.

62. Vayssade JA, Arquet R, Bonneau M. Automatic Activity Tracking of Goats Using Drone Camera. Computers and Electronics in Agriculture. 2019;162:767–772.

63. Rodenburg J. Robotic Milking: Technology, Farm Design, and Effects on Work Flow. J Dairy Sci. 2017;100(9):7729–38.

64. Birner R, Daum T, Pray C. Who drives the digital revolution in agriculture? A review of supply-side trends,players and challenges. Appl. Econ. Perspect Policy. 2021;1–26.

65. Jadeja Y, Modi K. Cloud computing—concepts, architecture and challenges. In Proceedings of the 2012 Int Conf on Computing, Electronics and Electrical Technologies (ICCEET), Kumaracoil, India. 2012;877–880.

66. Shamshiri RR, Weltzien C, Hameed IA, Yule IJ, et al. Research and development in agricultural robotics: A perspective of digital farming. Int J Agric & Biol Eng. 2018;11(4):1-14.

67. Garcia-Sanchez AJ, Garcia-Sanchez F, Garcia-Haro J. Wireless sensor network deployment for integrating video-surveillance and data monitoring in precision agriculture over distributed crops, Comput. Electron. Agricult. 2011;75(2):288-303.

68. Bapat V, Kale P, Shinde V, Deshpande N, Shaligram A. WSN application for crop protection to divert animal intrusions in the agricultural land, Comput. Electron. Agricult. 2017;133:88-96.

69. Patil GL, Gawande PS, Bag RV. Smart agriculture system based on IoT and its social impact, Int. J. Comput. Appl. 2017;176(1):0975-8887.

70. Mat I, Kassim RM, Harun AN, Yusoff IM. IoT in precision agriculture applications using wireless moisture sensor network, in Proc. IEEE Conf. Open Syst. (ICOS). 2016;24-29.

71. Berni JAJ, Zarco-Tejada PJ, Sepulcre-Canto G, Fereres E, Villalobos, F. Mapping canopy conductance and CWSI in olive orchards using high resolution thermal remote sensing imagery, Remote Sens. Environ. 2009;113(11):2380-2388.

72. Brewster C, Roussaki I, Kalatzis N, Doolin K, Ellis K. IoT in agriculture: Designing a Europe-wide large-scale pilot," IEEE Commun. Mag. 2017;55(9):26-33.

73. Sicari S, Rizzardi A, Grieco A, Coen-Porisini A. Security, privacy and trust in Internet of Things: The road ahead, Comput. Netw. 2015;76:146-164.

74. Alahi MEE, Li X, Mukhopadhyay S, Burkitt L. A temperature compensated smart nitrate-sensor for agricultural industry, IEEE Trans. Ind. Electron. 2017;64(9):7333–7341.

75. Balaji S, Nathani K, Santhakumar R. IoT technology, applications and challenges: A contemporary survey,'' Wireless Pers. Commun. 2019;108(1):363–388.

76. Yang Y, Wu L, Yin G, Li L, Zhao H. A survey on security and privacy issues in Internet-of-Things," IEEE Internet Things J. 2017;4(5):1250-1258.

*Peer-review history:*
*The peer review history for this paper can be accessed here:*
*https://www.sdiarticle4.com/review-history/74436*