

## Internet of Things for Smart Agriculture – State of the Art and Challenges

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### ABSTRACT

Agriculture is the primary source of food production for humankind. The drastic increase in the global population is paving the way to directly increase the food productivity creating enormous pressure on the agriculture sector. The demand for food production is increasing rapidly every day across the globe. According to the UN world population index, the world population is expected to reach 9.7 billion by 2050. Doing traditional conventional farming will not be sufficient for the production and catering to the needs of 9.8 billion people. We are now shifting from conventional traditional farming to new advanced precision farming methods to meet the demand. The introduction of the Internet of things (IoT) into the agriculture sector has changed the dynamics of the sector. The IoT based devices are mainly proving to be efficient in giving a high performance with low energy usage. IoT based devices automatically monitor and maintains agricultural farms reducing the minimal use of human involvement. This article mainly highlights the recent IoT based products and their usage in the agriculture sector. The public and private projects across the globe which provide feasible growth in the agriculture sector are discussed. Further, this article discusses the use of unmanned aerial vehicles (UAV) and their applications in the agriculture sector. After a thorough review of the future of IoT in the agriculture sector, its Applications, challenges, research potential and limitations are briefly discussed.

**Keywords:** Internet of things (IoT), precision farming, unmanned aerial vehicles(UAV), agriculture.

### INTRODUCTION

For generations, agriculture has been the primary food source for the human life existence. Food for humankind is commonly generated from traditional conventional farming. The rapid increase in the growth of the population asks for more demand for food. According to the most recent United Nations (UN) population index, the present world population is 7.9 billion as of November 2021 [Current World Population, 2021]. The population is expected to increase from 7.7 billion people to 9.8 billion people by 2050 and

reach 11 billion people by 2100 [Worldpopulation 2019, 2021]. As the population increases, the demand for food increases globally. Traditional conventional farming may not be sufficient to maintain the demand and supply ratio of food production. So, the inclusion of technology research and development in the agriculture is need of the hour. Generations of agriculture evolved from four distinct revolutions 1) period of conventional agriculture done by humans and animals, 2) period of mechanized agriculture done by machines, 3) period of automated agriculture machines, 4) period of smart agriculture done by the Internet of

things devices [Friha et al. 2018]. Smart precision farming is the most advanced level of farming that has been implemented now lately.

Many limitations like climate change, global warming, degradation of fertile soil, and many more factors lead to less arable land on the earth's surface. At present, 11 per cent, i.e. only 1.5 billion hectares of the earth's surface, is used in crop production [Arable land for crop production, 2021]. Over the last decade, the agricultural land utilized for food production declined due to soil erosion, climatic changes etc. The total arable area for food production in 1991 was 19.5 million square miles (39.47% of the world's land area), which was reduced to approximately 18.6 million square miles (37.73% of the world's land area) in 2013 [Ayaz, 2019].

At present, the demand for food production is increasing rapidly and maintaining the high food production supply. There is enormous stress on the agriculture sector. The conventional methods, traditional farming practices, and changes in the environment due to an increase in global temperatures due to global warming and change in climatic conditions are bringing more challenges to the agriculture sector. Few concerning challenges are 1) Depletion of topsoil due to floods and winds 2) Destruction of tropical forests are, leading to global climate change 3) Monocropping is reducing the essential nutrient levels in the soil and also leading to soil erosion 4) Use of traditional conventional farming techniques hinder the optimization of both cost and time [Kour & Arora, 2020]. The use of modern technology and bringing modern practices into the agriculture sector is necessary to reduce these challenges. The use of IoT in the agriculture sector is bringing a huge difference in modern farming practices.

IoT has brought a significant revolutionary change in the agriculture sector. Using IoT devices, many traditional farming practices are being performed faster with less time and less human activity. IoT devices have also increased crop production and helped maintain the demand and supply of crop production. IoT devices mainly use wireless sensors networks, which collect data about the crop and send it to the main servers. Data collected from the sensors give different information about the environmental conditions, crop conditions, etc. Through the IoT devices, we can monitor the crop productivity, evaluation of the crop, field management, movement of wild

animals and unwanted objects, thefts, geolocation, etc [Farooq et al. 2019].

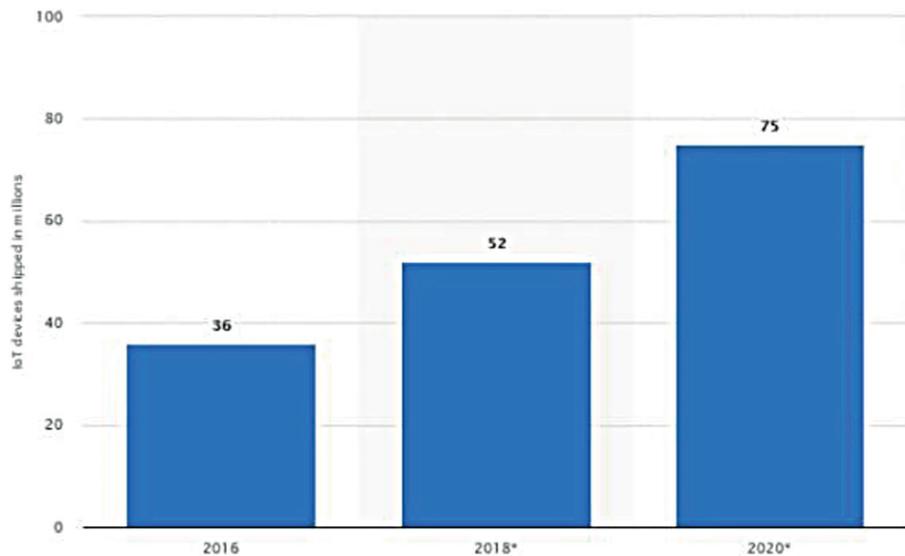
Internet of things (IoT) usage in the agriculture sector is growing progressively. Farmers gradually understand the significance of the implementation of IoT in agriculture. The benefits of using IoT devices in farming are attracting the farmers. In 2020, the usage of IoT devices in the agriculture industry will be 75 million and is estimated to grow 20% annually. The global wise agriculture market size will triple by 2025 [IOT devices globally...].

The market for agriculture IoT is expected to grow from USD 11.2 billion in 2018 to USD 20.9 billion by 2024. It is projected to grow at a compound annual growth rate (CAGR) of 10.4% from 2019 to 2024 [Countries leading in...]. Agriculture Internet of Things device shipment forecast worldwide from 2016 to 2020 in millions (Figure 1). It is estimated that around 52 million agricultural IoT devices shipped globally [Agriculture IoT devices...]. It is estimated that the market for IoT in agriculture is around 1.3 billion US dollars per year, solely contributed by the United States of America, and emerging countries like India, China, Malaysia, Brazil, Argentina, and others have slowly adopted IoT in the agriculture sector. The major countries implementing IoT in the agriculture sector and the country's Gross Domestic Product (GDP) percentage in agriculture are listed in Table 1.

In this article, an extensive review of IoT products commercially available across the globe has been given. The basic implementation and working of these IoT products in agriculture are briefly discussed. The role of unmanned aerial vehicles in agriculture and their purpose in the agricultural sector is being studied. The future challenges and research problems have been discussed in the last section, concluding the article.

## **APPLICATIONS OF IoT IN AGRICULTURE**

Implementation of the Internet of things in agricultural practices enhances and changes the fundamental traditional farming. The introduction of the Internet of Things into agriculture will bring dramatic changes in the traditional farming methods, and the production of agricultural products may increase by taking less time. In agriculture, the Internet of Things is implemented



**Figure 1.** The increase of agricultural IoT products shipped across the years [Statistics of Agriculture IoT...]

**Table 1.** The IoT usage countries vs GDP

S. No.	Countries using IoT in Agriculture	Agriculture percentage in its GDP (%)
1	Malaysia	7.1
2	Israel	2.4
3	Japan	1.14
4	Australia	3
5	Netherlands	1.59
6	United States of America	5.2
7	China	7.7
8	Argentina	6.84
9	Brazil	4.44
10	India	14

across the whole sector. The IoT in agriculture is implemented in Irrigation, in the usage of fertilizers, crop disease and pest management, soil sampling and mapping, yield monitoring forecasting and harvesting and many others, as shown in the Figure 2 which lists the hierarchy of significant applications of Internet of Things IoT in the agriculture sector To enhance the efficiency of every application used in agriculture sector new and advanced technologies are used in every application of agriculture sectors which are discussed below.

### Irrigation monitoring

In Agriculture, Irrigation is one of the most important aspects which needs to be adequately addressed. To achieve sustainability in agriculture, proper irrigation methods should be

followed. The primary use of IoT in an irrigation system is to minimize the wastage of water, irrigate the whole agricultural land, and irrigate the agriculture fields only when required by the crops. To perform these operations through IoT, wireless sensor nodes should be placed across the field to sense various parameters required for irrigation. The soil moisture sensor, temperature sensors, npk sensors and all the required sensors collect the readings and send the data to the cloud. The data which has been sent to the cloud can be accessed by the farmer anytime and from any location. There are mainly three types of irrigation methods implemented in the agriculture sector while considering soil type, soil topography, climatic conditions etc. They are Surface Irrigation, Sprinkle Irrigation and Drip Irrigation.

The quantity and quality of the crops are mainly affected due to irregular irrigation, excess irrigation, or water shortages. Excess irrigation may also lead to a reduction in soil nutrients. Depending upon the type of the soil, crop type and considering many other factors, the irrigation should be done to the agricultural field. Considering soil moistures sensors and integrating IoT technology into the drip irrigation system and sprinkle irrigation system makes use of optimal water and leads to better crop health. The usage of IoT changes the implementation of irrigation methods completely. According to the crop water stress index (CWSI), there will be a significant change in crop efficiency after using IoT based irrigation methods.

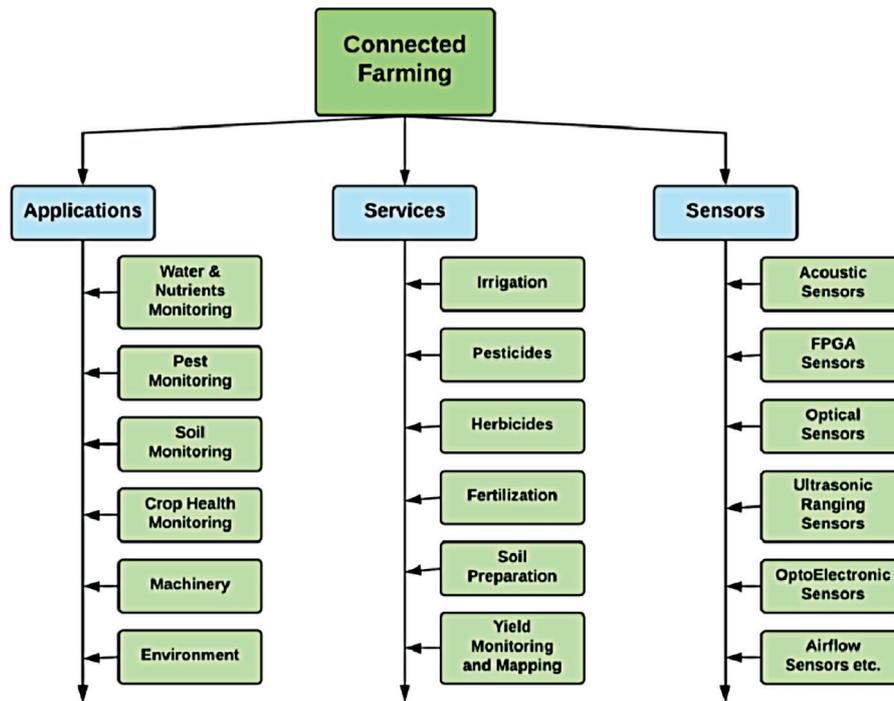


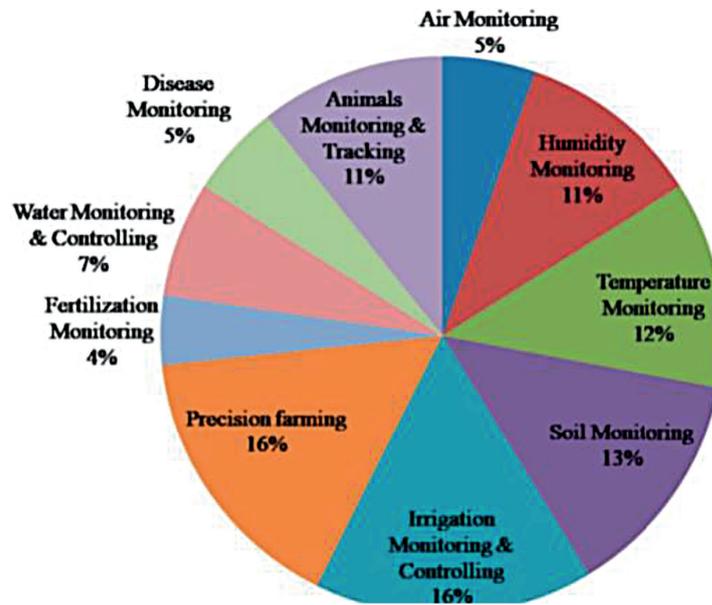
Figure 2. It shows the hierarchy of applications, services for smart agriculture

### Fertilizer monitoring

Fertilizers are widely used in agriculture for providing sufficient nutrients to the crops. Fertilizers are made naturally or with artificial chemicals. Crops require a certain amount of nutrients for their proper growth. Nutrient deficiency in the crops may lead to less production and improper growth of the plants. Likewise, providing excessive nutrients will also cause damage to the plant’s health. The excessive usage of mainly chemical fertilizers causes harmful damage to the soil by decreasing the soil quality and leading to soil erosion. So, smart farming will be beneficial to contain the amount of fertilizer level and precisely estimate the required dose of nutrients for the crops. By using IoT technology, the fertilizers are being used according to the type of soil, crop type, soil absorption rate, etc. New IoT based fertilization approach like NDVI (normalized difference vegetation index) uses aerial/satellite images to monitor the crop nutrient levels. The other benefits of IoT based smart farming are fertigation and chemigation. Fertigation and chemigation are nothing but applying the fertilizers through the irrigation systems. Fertigation is recently considered one of the best practices for supplying proper nutrients to crops. The Figure 3 depicts importance in the form of percentage in agriculture monitoring.

### Soil monitoring

Soil is the base for any agricultural activity. Soil consists of organic matter, nutrients, many microbes, minerals, etc, which help grow crops, plants, and trees. So, monitoring soil health is essential for crop growth health and production. The main objective of soil analysis is to determine the number of nutrients in the soil so that measures can be taken accordingly regarding nutrient deficiency in the soil. To analyse the soil nutrient level, the required factors are topography, cropping history, soil type, irrigation level, fertilizer applications, etc. These factors give proper knowledge regarding the soil’s biological, chemical, and physical status. The integration of IoT sensors will help monitor the soil’s nutrient level regularly and will also be helpful in soil mapping. Soil mapping is used for sowing different crop varieties in the field, and it helps give information like which seed suits which type of soil, when the seed should be sowed, and at what depth the seed should be sowed. These are the essential benefits of integrating IoT-based sensors into the soil. The IoT-based sensors monitor the main soil properties, water holding capacity of the soil, texture of the soil, and absorption rate of the soil, which help minimize soil erosion, desertification, acidification, salinization, and pollution. By monitoring all this data, the soil nutrient level is maintained, giving good crop production.



**Figure 3.** Depicts percentage of importance of monitoring all agriculture applications

### Crop disease and pest monitoring

Crop disease and pest infection are the major concerns for a farmer. According to the UN FAO estimates, farmers lose an average of 30% in their crop production every year due to disease and pest infection. To control the crop's disease and pest infection and avoid vast production losses, farmers use pesticides and agrochemicals. Heavy usage of pesticides is harmful to human and animal health and decreases soil fertility, creating a severe, irreversible impact on the environment. So, to control the usage of pesticides, IoT-based devices such as unmanned aerial vehicles, wireless sensor-based devices, robots, etc are effectively used by using the pesticides in the required area only. The IoT-based devices provide real-time monitoring of the crop and disease forecasting regularly by keeping the crop safe and reducing the wastage of the crop by disease and pest infection. The central aspect of IoT devices is to sense the area of the disease, evaluate the whole area based on image processing, and lastly, treat the area which has been infected with disease or pest. This process is done via UAVs, field sensors, or remote sensing satellites. Once the area is sensed via image processing, the data is sent to the cloud for evaluation, and after evaluating the data, the area where the disease or pest is identified is sprayed with pesticides using UAVs. This IoT-based pesticide management reduces the overall expenditures

and does the work precisely by creating less impact on soil and the environment.

### Yield monitoring

Yield monitoring is used for analysing the agriculture yield and harvested grain quantity, and it is also being used to assess the moisture level in the soil to estimate the performance of the crop. We are using the IoT technology the crop forecasting, which predicts the yield and production even before the harvesting of the crop. The harvest forecasting will help the farmer with his future crop yields. Using IoT, we can also predict the right time for harvesting the crop, which benefits in maximizing the crop quality, production, and less wastage.

### Weather monitoring

Weather plays a crucial role in the agriculture sector. Significant changes in climatic conditions directly impact the agriculture fields. The climatic factors which majorly affect the agriculture fields are droughts, storms, floods, hail, cyclones, etc. So, an IoT-based weather prediction system is highly needed to regularly monitor the weather parameters like rain, wind speed, the direction of the wind, light intensity, temperature, humidity, barometric pressure, etc. Using this weather monitoring system, the farmer can adequately plan for irrigation, plowing, fertilization, sowing of seeds, etc., depending on the weather conditions like

cloudy, rainy, etc. In this way, the IoT devices will help predict the weather prior to the harvesting, helping farmers acquire the crop on time.

## **ADVANCED INTERNET OF THINGS PRACTICES IN AGRICULTURE**

Many advanced technological practices are implemented in agriculture for crop production, and new IoT-based sophisticated technologies around controlled environments are developed. The importance of these newly generated agriculture cultivation ideas is increasing as we slowly progress towards intelligent urban farming methods. These advanced agriculture practices are mainly developed with IoT-based technology and sensor-based technologies. These new technologies are aeroponics, aquaponics, greenhouse farming, vertical farming, hydroponics, and phenotyping. These all are discussed in detail below.

### **Greenhouse farming**

Greenhouse farming is a unique and advanced practice of growing crops in a controlled and monitored environment within sheltered structures covered by transparent material. The main benefit of greenhouse farming is to provide good favourable conditions to grow crops and to protect crops from unfavourable weather conditions and various pests. The farmer can grow the required crops anytime and anywhere, complying with certain environmental factors. Greenhouse farming is entirely different from regular traditional farming. External natural climatic conditions ultimately impact traditional farming. In greenhouse farming, the inside environment conditions are controlled using IoT technology. A high precision rate is required in greenhouse farming while cultivating the crops. In greenhouse farming, crops are significantly less affected by the external environment. So, the crops suitable to grow only under certain conditions in certain parts of the world are now being grown anywhere and anytime. Precisely monitoring the indoor environment parameters is an essential thing in greenhouse farming.

### **Vertical farming**

In Vertical Farming, the food crops are grown in vertically stacked layers in a controlled environment. The crops are grown in vertically

stacked layers saving more space and using less water for crop production. Many parameters are essential, while vertical farming and CO<sub>2</sub> measurements are critical. Using vertical farming, crop production can be increased multiple times with less usage of the ground surface. This vertical farming is highly efficient. We can cultivate many varieties of crops at once due to less consumption of area and water. The irrigation requirement of vertical farming is also less compared to regular traditional farming.

### **Hydroponics**

In addition to greenhouse farming and vertical farming, agriculture scientists have come up with the idea of hydroponics. In hydroponics, the plants and crops are cultivated without the soil. Hydroponics generally uses the concept of an irrigation system. The nutrients are dissolved in water, and the dissolved nutrient solution is fed to the roots of the plants through a channel that uses the phenomena of an irrigation system, and the roots are supported with a medium like gravel. The main advantage of hydroponics is to increase yield production with less water usage. It also reduces soil-related cultivation problems like pests and diseases. When both the vertical farming technology and hydroponics are used simultaneously, the farmer can produce more crop production than traditional farming practice, and it also uses significantly less water.

### **Aquaponics**

Aquaponics is generally an extension of the hydroponic system. In aquaponics, the fish water waste is fed into the crop farms using the same irrigation method as hydroponics, which provides essential nutrients to the plants and the crops. In aquaponics, all the required parameters are constantly measured for the crops' proper production using the integrated IoT systems. The main parameters constantly being monitored are the pH level of the nutrient water, water level, and quantity, temperature levels, humidity, etc.

### **Aeroponics**

Aeroponics is the practice of growing plants either in a moist environment or in the air without using any substrate, mixed medium, or soil. The method used in aeroponics is that the roots

of the plants are suspended in the air, and a nutrient solution or aerosol of nutrient solution is sprayed periodically. Hydroponics uses a liquid nutrient solution as a growing medium, aquaponics uses water and fish waste, but aeroponics does not use any growing medium. The fundamental concept of the aeroponics method is to grow plants effect in a closed or semi-closed atmosphere nearby, sprinkle the hanging roots and lower stem of the plant with an atomized or sprinkled, nutrient-rich solution of water. The main advantage of this system is that the roots are exposed to the air completely, which means there will be an immense amount of oxygen supply to the roots, which helps for the faster growth of the plants. These aeroponics systems are also highly water-efficient, and they can grow large quantities of food in small spaces.

### Phenotyping

The previously discussed advanced agriculture practices (Figure 4) are already being implemented across the globe and are beneficial for future agriculture, as they are already being used for producing different crops in precise environments. Many other prominent methods are being developed to increase crop production, one of which is phenotyping, which is based on plant genomics. Research Scientists declare that plant phenotyping is highly beneficial to investigating quantitative characteristics like the plant’s growth, yield quality and quantity, and plant stress. The image-based phenotyping and sensing technologies are also beneficial in screening numerous bio stimulants.

### IOT DEVICES EMPLOYED IN THE AGRICULTURE FARM FIELDS

Farmers across the globe started to understand the significance of the implementation of the Internet of things (IoT) in agriculture. They started to use these IoT-based agriculture devices slowly in their agriculture farmlands. Some of the widely used agriculture-based IoT devices are discussed below.

1. Yuktix Green Sense is an off-grid remote monitoring analytics solution for smart agriculture. It connects with an external control panel, which effectively monitors irrigation management, pest control, and crop disease. It is a next-generation solar-powered long-range wireless device. It detects water data, micro weather, and soil data from multiple locations. It is also used for disease prediction of the crops using normalized difference vegetation index (NDVI) and enhanced vegetation index (EVI). Satellite images of the crop. It is a remote monitoring device for greenhouses, fruit orchards, farm crops, and plantations. It has humidity, lux, leaf wetness, temperature, soil moisture, and rain sensors. Yuktix’s ankiDB cloud stores the data from the sensors and also runs reports, providing disease analysis and weather forecasts [Yuktix Green Sense...]. The devices are planted across the crop fields to monitor the crops and weather throughout the day. The network of devices planted across the field is connected to the primary device. The sensors collect the weather, humidity, leaf wetness, rain, soil moisture, temperature, and crop

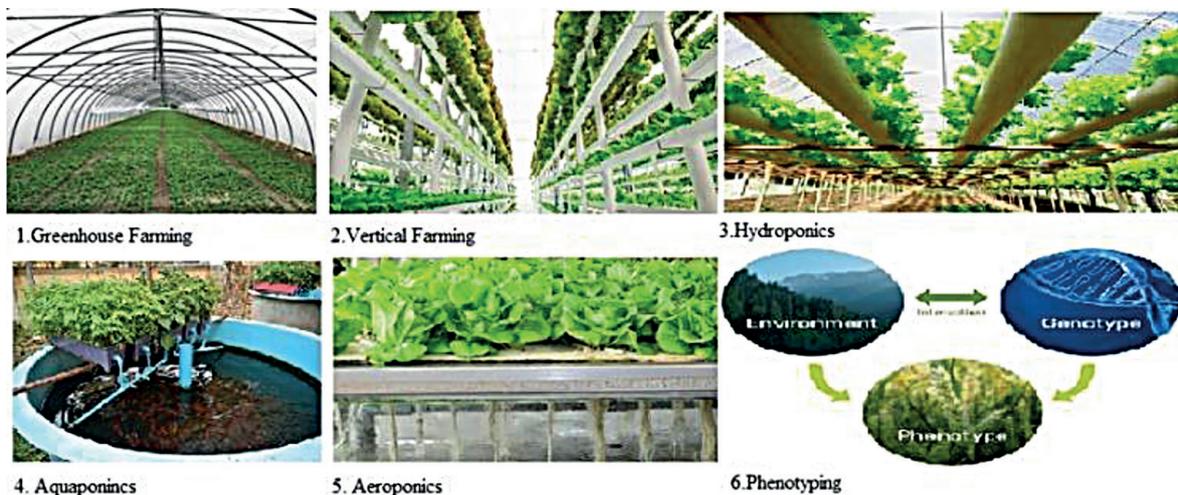


Figure 4. Advanced IoT practices in agriculture

health detection data and send the data to the primary device. The primary device collects the data from all the secondary devices planted across the fields and sends it to the Yuktik ankiDB cloud, which stores the data, provides disease analysis, weather forecast, and many other applications, which are finally displayed on the dashboard of the user. The analysed data in a report is user-friendly and can be easily presented to the end-user. Message alerts are also notified to the end-user.

2. Agrela Ecosystems PheNode is a modular and customizable phenotyping device. Phenotype is defined as the set of observable characteristics of an individual resulting from the interaction of its genotype. It is integrated with environmental, soil, and many other wireless sensors. The remote imaging monitors the plant pheno-phases, crop damage, and many other applications. It is integrated with wind speed/wind direction sensors that measure the wind's accuracy and with temperature, humidity, air pressure, lux (light quantity), and PAR (light quality) rainfall sensors. It also consists of soil sensors which are used to measure volumetric water content (VWC), matric potential (water pressure), electrical conductivity (EC), and soil temperature permittivity. It consists of an RGB imaging module for crop disease detection. The communications used are LoRaWAN, Wifi, and cellular communication for connecting with the cloud services. It is entirely a solar-powered battery-operated device [AgrelaPheNodeApplications...]. Depending upon the crop, the height of the PheNode has to be adjusted with the pipe sections. The pipe sections are added for taller crops like maize, and the different pipe sections are removed for shorter crops like soybeans. The sensors and cameras attached to the PheNode measure all the required parameters like temperature, rainfall, wind speed, humidity, etc. The data collected from these sensors is transmitted to the servers via LoRaWAN or Wifi communication. The users can access the data collected from the PheNode at the base station.
3. Agrila is a modular IoT building block for smart agriculture and smart irrigation. It is a modular smart sensor station built for agricultural purposes. Its sensor station is based on cutting-edge Internet of Things and Cloud Technologies. The sensor station is integrated with multiple sensors: humidity, soil moisture, gust,

leaf wetness, wind/speed/direction temperature, air temperature, and solar irradiation sensors. The raindrop sensor detects the exact start of the rain, and the solar irradiation sensor is used for shadow casting inside the greenhouse. Its mechanical construction and connectors allow rapid customization of the sensors onto the modular sensor station. The sensor station is also designed to integrate with greenhouse controllers. It uses cellular communications for connecting the device with the cloud, and its battery is solar powered [Agrila IoT device...]. Additional Agrila Modular IOT sensor station features are tilt detection, Anti-Theft GPS localization Remote SW Update. The data collected from the sensors stations is transmitted to the base station, where the reports regarding the irrigation, disease and fertilization models are being prepared. The generated reports have been sent to the end-user via LoRaWAN or Wifi Communication. The end-user, the farmer, will get the information regarding the weather forecast, yield optimization, and water and fertilizer reduction notifications.

4. Fasal is a data-driven smart farming device using the internet of things. It collects the agricultural land data to predict the ideal growing conditions. It is used for irrigation systems, spraying, fertigation, and other preventive measures. This system continuously monitors the soil's water level and moisture level to ensure the irrigation requirement for the crop. It also monitors micro and macro climatic conditions, soil parameters, crop stage, crop growth characteristics, etc. [The arable mark...]. It provides a farm-specific microclimate forecast. The disease prediction and assessment systems in the device installed on farmland forewarn the possibility of a crop disease or pest outbreak. Fasal device is integrated with temperature, pest detection, and irrigation management sensors. It helps farmers increase the quality and yield of the crop and reduce the cost of cultivation through an AI-powered platform for horticulture.
5. Arable Mark 2 is an infield sensing and data capture IoT device. It measures more than 40 climate and plant metrics and is integrated with the multiband spectrometer, infrared thermometer, and acoustic disdrometer. It is used to measure the temperature, precipitation pressure, humidity, wind vapour pressure deficit (VPD), dew point temperature, solar radiation

and other spectral measurements [Exabit RobotiX device...]. It also measures the plant NDVI, chlorophyll index, evapotranspiration, leaf wetness, growing degree days, and crop water deficit. It is also used as an irrigation system in the crop field.

6. Exabit RobotiX is an internet of things device (Figure 5) which records the soil condition, micro-climate data and real time controls to make it productive for a better crop growth. The exabit systems give service for crop management and advisory, precision/smart farming, farm automations and Agri-analytics. It is a device which is installed in the crop fields to sense soil conditions, environmental conditions and uploads the data into the exabits cloud server. It is integrated with temperature sensors, soil moisture sensor, wind sensor, and many other sensors. It is powered with solar battery and is made for both open field and hi-tech farming solutions [Fasal IoT device...].

## UNMANNED AERIAL VEHICLES IN AGRICULTURE

An unmanned aerial vehicle (UAV) is used to enhance agriculture operations, monitor crop growth, and increase crop yield. The information provided by the agriculture drone will help assess

the time for fertilisation and irrigation, crop disease management, and improving crop production. The aerial view from the drone reveals many issues like fertility of the soil, pest and fungal infestations of the crop and irrigation issues. The drones' digital imaging capabilities and built-in sensors give farmers a richer picture of their farm fields. The sensors and the advanced digital cameras implanted on the UAVs show the farmers the difference between healthy plants and unhealthy plants [Praveen et al. 2021]. Using these UAVs, the agricultural farmland can be monitored and surveyed. The agriculture drones are used for UAV crop spraying and precision agriculture. These agricultural drones are easy to carry and can be used for different purposes. These unmanned aerial vehicles can analyse the field with high-resolution cameras to see where there is a need for water or fertiliser. These drones also have other accessories like a spectrometer that allows checking the level of humidity, temperature etc [Kim et al. 2019].

Unmanned Aerial Vehicles used in the agriculture sector are for soil and field analysis, crop monitoring, planting and sowing seeds, crop irrigation, spraying the pesticides/herbicides, plant counting and recognition of new plant species etc. The major areas in which the UAVs are already helping the farmers are crop monitoring, sowing seeds, irrigation, soil analysis, detection of new species, and spraying pesticides.



Figure 5. IoT devices used in agriculture fields

## **Crop monitoring**

Unmanned aerial vehicles(drones) are extensively used for crop monitoring purposes. The drones have entirely monitored the large area of the field. Drones will real-time monitor the far fields accurately and cost-effectively compared to satellite imaging. The digital image sensing modules attached to the unmanned aerial vehicles will show the aerial images that observe the soil's moisture levels, nutrient levels in the soil, and all other required parameters. Unmanned aerial vehicles (agriculture drones) are being utilized to understand the growth of the trees. These drones are mainly used to study crop conditions.

## **Irrigation**

In the agriculture sector, unmanned aerial vehicles(drones) are also used in irrigation applications. The UAVs are installed with multiple image sensing digital cameras and a sprinkling system that helps in the sprinkling of pesticides, fertilizers, and irrigation. The integrated sensors onto the UAVs detect the water stress level in the soil and sprinkle the water wherever necessary. Due to this application of detecting the water stress and sprinkling precisely over the water stress area, these UAVs gratefully helped reduce the water wastage. The sprinkling of water and pesticides via drones would save both time and wastage for the farmer. These drones help detect the physiological and structural changes in the crops.

## **Soil analysis**

The sensors implanted into the UAVs detect the condition of the soil, the type of the soil and many other characteristics of the soil. Before sowing seeds into the soil, the sensors on UAVs detect the type of the soil and help decide which type of crop should be grown in the soil, which gives more crop production. It also helps the farmer by giving precise information about the soil regarding the fertility levels of the soil and many other characteristics of the soil. These drones are also helpful in detecting soil erosion levels. The applications of UAVs are not only limited to that. These drones are used for soil mapping techniques like recognizing the best time to sow the seed, detecting the type of soil suited for the seed, telling the seed's depth, and many other practical applications.

## **DISEASE AND PEST ASSESSMENT**

Unmanned aerial vehicles are highly beneficial in detecting the crops infected with pests or diseases. The UAVs are highly accurate in detecting the bacteria or fungus-infected the crops and plants. These drones are implanted with visible and Infrared (IR) light sensors capable of identifying the infected plants and crops. The early detection of these infections helps prevent the disease from being spread to other parts of the plant and crop areas.

## **DETECTION OF NEW PLANT SPECIES**

The UAVs are very helpful for agricultural scientists. The UAVs have been able to go to places where it is less possible for a human being to enter, and there these UAVs are being very helpful in detecting new plant species. Many plant species are being recognized and are being considered extinct. These drones go into remote locations almost inaccessible to human beings and detect new plant species, which are very helpful for further research. We can also detect the forest biomass and fuel using advanced cameras on this drone system.

## **UAV'S USED IN THE AGRICULTURE APPLICATIONS**

AgEagle RX60 is one of the most durable professional drones capable of capturing NDVI aerial maps. This drone is used for agricultural crop monitoring. It is paired with the aluminium launcher. This drone is easy and safe to use, making every flight successful and straightforward to operate. Aerial maps are automatically created and georeferenced. Its unique design makes it easy to fly at higher speeds winding up to 30 mph. The Normalized difference vegetation index (NDVI) images provide the results of crop health. The farmer can configure the images according to the required file size. Another sensor in the drone monitors the battery life, and the sensors get activated when the battery is getting low and lands the aircraft safely before the battery gets drained [AgEagle drone...]. The flight plan is entirely loaded into autopilot mode before the drone's launch. The device is GPS installed as the device is continuously monitored from the user end in case of sudden battery failure or any unplanned landing.

AgBot is an aerial robotic craft which is compact and industrial graded, designed for precision agriculture applications. It is fully autonomous and durable with several sensors. This unmanned aerial vehicle carries an NDVI sensor package, FLIR, or a small HD camera with 30 minutes of fly time. It has autonomous return to home and landing capabilities. It can cover an area of about 70 acres in one flight. The Phoenix 6 AG Agriculture hexacopter drone is a fully customizable platform suitable for a wide range of applications. This drone can handle harsh climatic conditions and still perform tasks with unprecedented flexibility and ease of operation. DJI Agras MG 1 crop-spraying drone can efficiently spray a field of 5000 square feet in very little time. It will be used in large farms in multiple cycles and will also be used in smaller farms. It requires minimal assembly and training. It flies 8 meters per second and sprays the field proportionately. It can spray 10 acres of land in an hour with precision. It has a few automatic systems that help adjust the fertilizer flow automatically based on the climatic conditions. Table 2 presents differentiation of unmanned aerial vehicles in agriculture. Table 3 presents additional Internet

of Things (IOT) products in agriculture. Figure 6 presents types of UAV’s used in agriculture fields

### CHALLENGES AND FUTURE WORK

As discussed previously, the implementation of IoT is moving in a rapid phase across the globe, but still, there are many challenges to be addressed. The IoT devices may face hardware issues due to technical malfunctions. The challenges are not only in hardware implementations but also at the network level. The farmlands, located in remote areas, are inaccessible to internet connectivity due to inadequate communication infrastructure [Misra et al. 2020]. The IoT devices are expensive in terms of hardware and software to implement in the agricultural farm crops, and farmers may not show interest in installing the IoT devices in their farmlands. Here are the security risks and privacy challenges in IoT devices. An enormous amount of data is collected by IoT agricultural systems, which may be challenging to secure. In developing countries, most farmers are from rural areas where education is least preferred and maximum numbers of farmers are uneducated [Ferrag, 2020].

**Table 2.** Differentiation of unmanned aerial vehicles in agriculture

Platform	Products	Sensors	Communication	Usage	Advantages	Limitations	Reference
Fixed Wing Unmanned aerial vehicle	Lancaster 5 Sentera PHX eBee SQ Honey Comb AgEaGLE RX-60	GPS receiver Photo detector Multispectral Camera Hyper spectral Camera RGB camera Thermal Camera	Wireless radio	Used for mapping crop monitoring irrigation diagnosis of insect pests	The Average flight time is 2 hours and can go up to 16 hours. They fly at very high altitude and also have the ability to carry more weight	Are expensive. Hard to land. Cannot hover in air. Can only move forward. Training is required to fly them	<a href="https://ieeexplore.ieee.org/document/8782102">https://ieeexplore.ieee.org/document/8782102</a>
Helicopter Unmanned aerial vehicle	AgBot	Inertial Measurement unit (IMU)RGB Camera Multi-Spectral Camera Wind speed sensor	Wireless Local Area Network, Bluetooth	Used for mapping spraying artificial pollination	Long endurance. Heavy payload capacity. Strong and durable and can hover vertical in air	Expensive Harder to fly than multirotor. Can be dangerous due to heavy spinning blades	<a href="https://ieeexplore.ieee.org/document/8782102">https://ieeexplore.ieee.org/document/8782102</a>
Quadcopter Unmanned aerial vehicle	Sentera NDVI	GPS Receiver Photo Detector Multispectral Camera Hyper spectral Camera RGB camera Thermal Camera	Wifi Wireless Radio Xbee	Used for mapping spraying crop monitoring irrigation artificial pollination	They are very easy to control and manoeuvre. Ability to hover. Take off and land vertically. And are very stable.	Shorter flight times Small payload capacity	<a href="https://ieeexplore.ieee.org/abstract/document/9316211">https://ieeexplore.ieee.org/abstract/document/9316211</a>
Hexacopter Unmanned aerial vehicle	Dji Matrice 210	RGB Camera light detection and ranging (LiDAR) Inertial Measurement Unit IMU Hyper-Spectral Camera	Wireless radio	Used for crop monitoring Diagnosis of insects pests artificial pollination	They are very easy to control and manoeuvre. Ability to hover. Take off and land vertically. And are very stable.	Shorter flight times Small payload capacity	<a href="https://ieeexplore.ieee.org/abstract/document/9316211">https://ieeexplore.ieee.org/abstract/document/9316211</a>

**Table 3.** Additional Internet of Things (IOT) products in agriculture

Product	Sensors	Communication	Usage	References
Smart agriculture PRO	Soil temperature leaf wetness soil moisture solar radiation atmospheric pressure etc	Wifi and wireless communication	Used for vineyards monitoring selective irrigation and for control in greenhouses	<a href="https://www.libelium.com/iot-products/">https://www.libelium.com/iot-products/</a>
Smart Agriculture Xtreme	Soil oxygen level leaf and flower bud temperature humidity and pressure soil water potential etc	Wifi and wireless communication	Used for atmospheric soil monitoring and plants health	<a href="https://www.libelium.com/iot-products">https://www.libelium.com/iot-products</a>
Smart Environment Pro	Carbon monoxide carbon dioxide molecular oxygen methane particle matter temperature humidity etc	Wifi and wireless communication	Used to enable air quality index AQI and to measure high end particle matter in air.	<a href="https://www.libelium.com/iot-products/">https://www.libelium.com/iot-products/</a>
Smart water Xtreme	pH optical dissolved oxygen and temperature sensor salinity luminosity etc	Wifi and wireless communication	Used for potable water monitoring fish farm management chemical leakage detection etc	<a href="https://www.libelium.com/iot-products/">https://www.libelium.com/iot-products/</a>
Ecorobotix	Weed detection sensor	Wifi	Used for fertilizer spraying and weeds removal	<a href="https://www.ecorobotix.com/en/avo-autonomous-robot-weede/">https://www.ecorobotix.com/en/avo-autonomous-robot-weede/</a>
Terrasentia	RGB cameras GPS long range radio connectors LiDar	Wireless communications	Used to collect data on plant health and crop physiology	<a href="https://www.earthsense.co/">https://www.earthsense.co/</a>
Nibia Devices	Soil NPK (nitrogen phosphorus and potassium) sensor, soil temperature and moisture sensor	Wifi wireless communications	Used to measure the soil temperature and moisture. It is also used to measure the soil nutrients like nitrogen potassium and phosphorous	<a href="https://www.nibiaadevices.com/smartagri.html">https://www.nibiaadevices.com/smartagri.html</a>
iNELS Air	Soil moisture sensor weather sensor temperature sensor	Sigfox Lora or NB-IOT (LPWA) protocols	It provides information about temperature air and soil humidity precipitation and strength and wind direction	<a href="https://www.inels.com/smart-field-farm-meadow-and-poultry-farm">https://www.inels.com/smart-field-farm-meadow-and-poultry-farm</a>
Milesight SMTC	Soil moisture sensor, electrical conductivity sensor and temperature sensor	LORAWAN	It is used to measure accurate and instantaneous information on soil moisture content temperature and electrical conductivity	<a href="https://www.milesight-iot.com/lorawan/sensor/em500-smtc/">https://www.milesight-iot.com/lorawan/sensor/em500-smtc/</a>
Pragmatix device	Irrigation pH sensor temperature sensor EC sensor LDR sensor	Cellular connectivity	It is used to measure the temperature humidity soil moisture LDR pH EC and can be connected to the motor for irrigation purpose.	<a href="https://pragmatix.org/">https://pragmatix.org/</a>
WISE web inside smart engine	Weather temperature and humidity sensors	Wireless communication	It is used for monitoring weather temperature	<a href="http://www.icpdas.com/wise/products/WISE-5800-MTCP.html">http://www.icpdas.com/wise/products/WISE-5800-MTCP.html</a>
IFFCO Kisan	Soil moisture sensor automated wireless weather station	Cellular connectivity and wireless communication	It is used for drip irrigation system. It is also used for soil moisture and temperature	<a href="https://www.iffcokisan.com/">https://www.iffcokisan.com/</a>

The inability to utilise IoT devices by the farmers is also one of the significant challenges due to which the IoT in agriculture is not moving ahead. There is an interoperability challenge where the IoT devices installed in the farmlands which are using unlicensed spectrum may create hindrance with the other devices [Elijah et al. 2018].

### FUTURE SCOPE

The development of new applications and research in the internet of things in the agriculture sector is envisioned. The internet of things technological devices entirely dominates the future of the agriculture sector. Designing platforms



**Figure 6.** Types of UAV's used in Agriculture fields

using artificial intelligence AI in a user-friendly manner, that is, ease of use to a farmer [Showkat, 2021]. As the environment is harsh and the climatic conditions keep on changing, it is advised to develop robust, sustainable devices that can withstand harsh environmental conditions and perform well in any climatic conditions. Farmers come from different ethnic and linguistic backgrounds [Ruan, 2019]. So, it is essential to develop applications in the native language of the farmer so that there will not be an issue on the farmer's side while interacting with the IoT tool. It is suitable for further research into integrating the internet of things into greenhouse, vertical, hypophonic, and phenotyping farming.

## CONCLUSION

This article presents the various devices used in agriculture crop fields using internet of things technology. It is understood from the contents presented in the paper that the usage of internet of things devices in agriculture has an enormous contribution to the elevation of production in the crop. The quality and quantity of the crop have been increased due to the use of IoT devices in agriculture. The use of unmanned aerial vehicles (UAVs) in the agriculture sector proves to be very efficient and helps in increasing crop production. The unmanned aerial vehicles perform efficient crop monitoring, spraying, and other activities.

This paper also explores various agriculture sensors implemented in crop fields. This paper also discusses the development of new devices based on internet of things technology for improving crop yield and production. This paper considered all the roles of various agricultural IoT devices to make agriculture more innovative and more efficient. A summary of the agriculture sector's current challenges and future expectations in the IoT industry has been listed. Based on this review, we can conclude that IoT-based devices in the agriculture farm fields are vital, and sustainable IoT-based devices in agriculture are necessary.

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