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1. Artificial Intelligence in Agriculture and Allied Sciences

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Abstract:

The world population is rapidly increasing causing an escalation of food demand. This has put pressure on the present arable land. To create a world free of hunger or achieve sustainable development goal of "zero hunger", the agriculture industry needs to be smart and modernized. Traditional farming practices needs to be transformed using new technologies such as artificial intelligence and Internet of Things. Artificial Intelligence (AI) is an interdisciplinary field of study which aims to replicate human intelligence in robots that resemble human cognition and behaviours, which includes reasoning, learning, problem solving and perception. Internet of Things (IoT) is an embedded system or a computer that connects everything together into a network and to the internet. The various connections allow collection and exchange of data which can be remotely controlled by setting up certain chains of actions. The various application of AI and IoT in agriculture includes soil and field analysis, planting or sowing, crop spraying, crop monitoring, irrigation, crop and soil health assessment, autonomous tractors, remote sensing, precision nutrient management, agricultural drones, agricultural robots and abiotic stress management. Though AI is a step forward towards smart farming but there are various challenges in its way. Despite the limitations, AI technologies are providing precise solutions to major agricultural issues and there is a considerable development and a promising prospect in the future of this field.

Keywords:

Artificial intelligence, agriculture, allied sciences

1.1 Introduction:

Agriculture is one of the oldest sector and backbone of the country. It is crucial for economic growth of the nation. Development in the agriculture sector is a huge concern for Indian government and is required to end poverty, provide employment to increasing population and to feed a projected 9.7 billion people by 2050. The impact of climate change has further cut the crop yield and caused food security concerns for the rising population. Traditional methods used by farmers are not sufficient to meet the requirement of people and farmers are forced to seek new solutions to these problems. Industrialization tends to overexpose and overutilize the present arable land. To meet the yield expectations, we are moving towards overuse of fertilizers and pesticides causing a threat to the soil and environmental

health. Therefore, scientists must come up with techniques to enhance crop yield without hampering the environmental health in a sustainable way. In India, modern technology in agriculture which includes Artificial Intelligence, Internet of Things (IoT) and big data and analytics represents some hope. Research is going on to improve the quality of agricultural products by use of smart farming tools and techniques.

Artificial Intelligence (AI) is an interdisciplinary field of study which aims to replicate human intelligence in robots that resemble human cognition and behaviours, which includes reasoning, learning, problem solving and perception. The term "Artificial Intelligence" was first introduced by the American scientist John McCarthy in 1955 Dartmouth Conference. He defined it as the science and engineering of making intelligent machines. He proposed a study to be carried out grounded on the hypothesis that "every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it" [1].

AI is a branch of computer science which involves machines and deep learning algorithms to interpolate data and mimic human intelligence. These predictions and networks can help create solutions to various complicated situations. In our daily life various AI powered technologies are prevalent ranging from tracking codes in postal companies to mobile face recognition apps to modern printers, smart doorbells, smart thermometers to self-driving automobiles. According to Agriculture secretary Sanjay Aggarwal "AI and big data are going to be a game-changer in the agriculture sector and the government is aiming to collate about 80% of such data by 2020."

1.2 Internet of Things (IoT) and AI:

The Internet of things is an idea from computer science of connecting ordinary things like lights and doors to a computer network to make them "intelligent". It is embedded system or a computer that connects everything together into a network and to the internet.

The various connections allow collection and exchange of data which can be remotely controlled by setting up certain chain of actions. IoT has improved the ease of life for humans. IoT system integrates various sensors and servo motors and then this integrated circuit is fit into the device which is to be made smart. These smart devices then generate structured or unstructured data. The experiential analysis of the data is done by AI. IoT system generates data while AI has the potential to derive insights from it. Hence both these systems together make an intelligent and smart system. Thus, *Artificial Intelligence and the Internet of Things is like a match made in Tech Heaven!!* The importance of AI in IoT has been summarized in **Figure 1.1.**

In agriculture, IoT helps in data collection, data analysis, data storage and building a smart farming platform. The quality and quantity of agricultural produce can be optimised by connecting multiple farms with the help of a single platform and make them smart by sharing, storing and analysis data. The various applications of IoT in agriculture includes accurate data analysis, enhanced food production and farm efficiency, smart farming, real time crop planning and harvesting, agriculture automation, drought monitoring and livestock tracking among others.

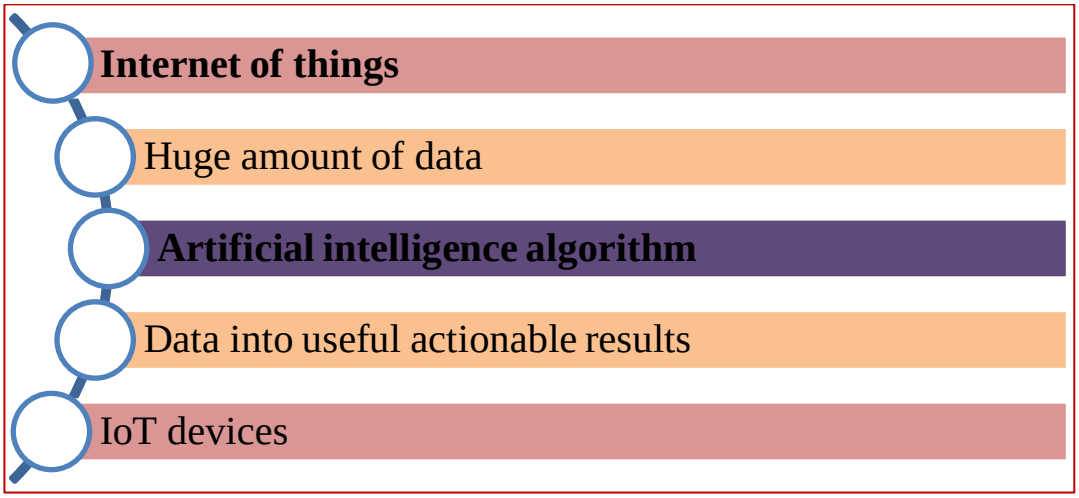


Figure 1.1: Importance of AI in IoT

1.3 Need of AI in agriculture: Moving Towards Smart Farming:

McKinion and Lemmon in 1985 were the first to apply AI in agriculture field to create GOSSYM, a cotton crop simulation model using expert system to optimize cotton production under the influence of fertilization, irrigation, weed control, climatic and other factors [2].

Use of AI technology in agriculture has a huge potential to improve the world. It can perform a variety of tasks ranging from simple to complex. The basic aim of artificially intelligent machines is to learn, reason and perceive [3].

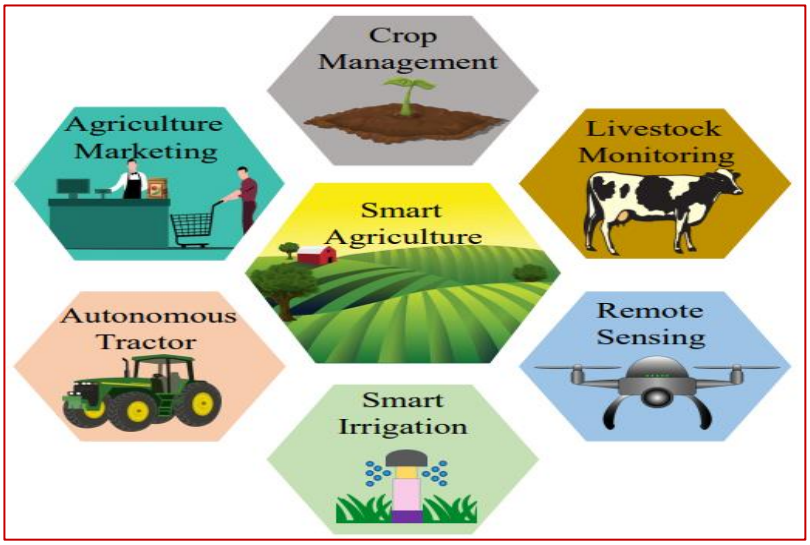
Traditional agriculture with manual labour requirement and low productivity needs to be transformed into intelligent, ecofriendly, sustainable agriculture with the use of technologies such as Artificial Intelligence, machine learning, big data, IoT, Unmanned Aerial Vehicle, robotics and nanotechnology.

This will transform the old-world agriculture to "smart farming" or "digital farming" (**Figure 1.2**). In smart agriculture, the focus is to optimize a complex system towards enhancing the quality and quantity of the produce along with reducing human labour [4].

Advantages of smart farming over traditional methods are:

- Optimization of use of fertilizers, pesticides and herbicides.
- Enhanced crop production efficiency and reduced production cost.
- Water conservation.
- Reduced soil erosion
- Lower emission of greenhouse gases.
- Real time nutrient management

The process of AI adoption in agriculture has been illustrated in **Figure 1.3**.



Source: Mitra *et al.* 2022 [4]

Figure 1.2: Components of smart agriculture

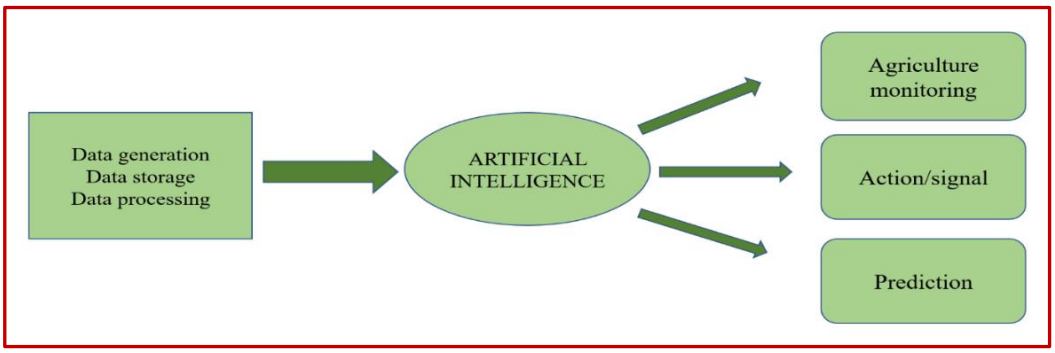


Figure 1.3: Process of artificial intelligence adoption in agriculture

1.4 Applications of AI in Agriculture:

1.4.1 Drones/ UAV's:

An agricultural drone is an unmanned aerial vehicle (UAV) used to help optimize agricultural operations, increase crop production and monitor crop growth (**Figure 1.4**). Sensors and digital imaging capabilities can give farmers a richer picture of their field. It can either be autonomous or controlled by pilot from the ground. The benefits of use of drone technology in agriculture field includes enhanced production, better farming techniques, greater safety of farmers, lesser wastage of resources, faster data for quick decision making and 99 % accuracy rate.

Figure 1.4: Fixed wing and multi rotor type of drones.

Applications of agricultural drones in agriculture

A. Maping/Surveying:

NDVI (Normalized Difference Vegetation Index): It quantifies vegetation by measuring the difference between Near Infra-red (which vegetation strongly reflects) and red light (which vegetation absorbs). The value of NDVI ranges from -1 to +1. Healthy vegetation i.e., chlorophyll reflects more NIR and absorbs more red light. Higher NDVI value indicates healthy vegetation and low NDVI value indicates less or no vegetation.

$$NDVI = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$$

NIR = Reflection in NIR spectrum

RED = Reflection in red range of spectrum

Chlorophyll strongly absorbs visible light of the electromagnetic spectrum and strongly reflects NIR light. When the plant becomes dehydrated, sick or diseased the spongy layer of the chlorophyll deteriorates, and plant absorbs more of the NIR rather than reflecting it.

Drones which are equipped with camera sensors allows it to see the spectrum of light that plant uses to absorb light for photosynthesis. From this information, plant health can be mapped.

B. Crop spraying or dusting: Drones are also used for fertilizer and pesticide application. Drones used for crop spraying can carry large liquid storage reservoirs which can be safely operated.

C. Irrigation management: Drones equipped with cameras provides insight into the areas in the field which require irrigation by highlighting areas having water logging or water pooling and those which have insufficient soil moisture.

D. Livestock monitoring:

Livestock management is an important part of agriculture. Drones with cameras helps to monitor the livestock by tracking grazing animals, checking the herd for any injury, missing or birthing animals or optimizing breeding practices for them. Health of the cattle can be monitored by using a wearable collar or a tag on animals and measuring the body vitals which includes heart rate, respiratory rate or blood pressure. GPS tracking may also be used.

E. Field and soil assessment:

Before the start of cropping season and after crop planting, data is collected by drones regarding soil fertility and soil physical properties which helps in management of irrigation, fertilization or nutrient application, crop species to be sown and pattern of planting.

F. Planting:

Drones also have inverted drone planting systems that allows it to plant seeds and nutrients into the soil. Various startups have created drone planting systems that achieve an uptake rate of 75% and decrease planting cost by 85%.

The various sensors used in drones are:

a) Visual sensor (mapping and images)
b) Multispectral sensors (plant health and water quality)
c) Thermal spectral (heat detection)
d) Lidar sensor (plant height measurement and flood mapping)
e) Hyperspectral sensor (plant height and water quality)

1.4.2 AI and Precision Agriculture:

Precision Agriculture is a holistic and environmentally friendly approach in which farmers can vary input use and cultivation methods, including application of seeds, fertilizers, pesticides, water, tillage and harvesting to match varying soil and crop conditions across the field, considering spatial and temporal variability of the field. It is the science of enhancing crop productivity and decreasing production cost using technology, sensors and different analytical tools. It ensures effective management of various resources and at the same time enhances quality and quantity of crops. Precision agriculture is an advanced innovative and optimized field level management strategy that aims to improve the productivity of resources on agricultural field [5-6]. Different components of precision farming have been summarized in **Figure 1.5**.

A. Five Rs of Precision Agriculture:

- Right time
- Right dose
- Right place
- Right source
- Right manner

B. Principles of Precision Farming:

- Understanding the temporal and spatial variability in agricultural field
- Timely analysis of variability on soil, crop and environment.
- The recommended nutrients in a current season may not be required during next season.
- Managing the variability with site specific nutrient management.

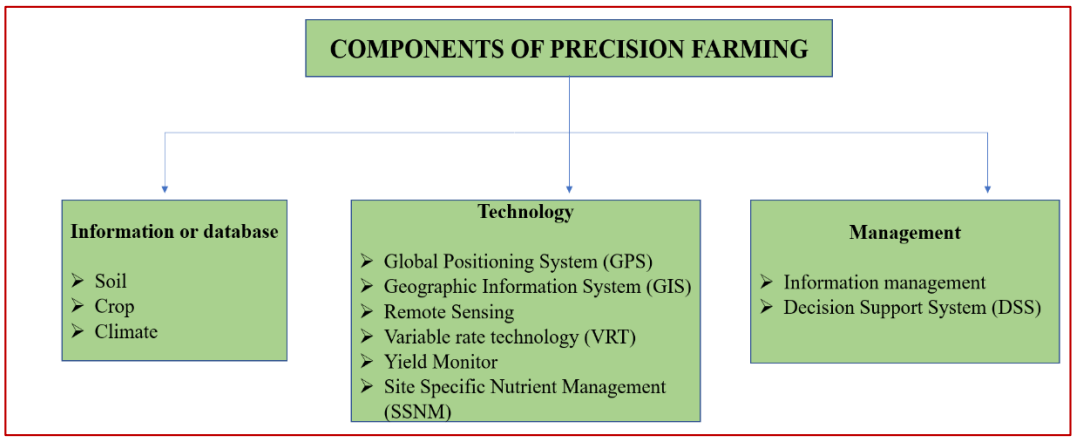


Figure 1.5: Different components of precision farming.

C. Use of AI in Precision Farming

The various technologies used in precision farming uses artificial intelligence.

a. GIS (Geographic Information System): It is a computerized mapping system to acquire, store, analyse and display information which is specially references to the earth. It consists of a software which imports, exports and processes spatial and temporal data. It comprises of hardware, software and procedures that are designed to support storage, retrieval and analysis of location data to produce maps. These maps are helpful for irrigation management, crop management, land and soil mapping.

b. GPS (Global Positioning System): GPS is a navigation system which utilize a network of satellites in outer space that helps to record information about latitude, longitude and altitude of a position. In agriculture, GPS is used for precise mapping of the field and informs the farmer regarding status of his crop and resource (water, fertilizers or pesticides) allocation.

c. Remote Sensing: Remote sensing is defined as the art and science of obtaining information about an object or an area without being in direct contact with the object or from a distance. The sensors which are used are not in direct contact with the object. Therefore, there must be an intervening medium through which the information will travel from the objects to the sensors. In remote sensing, the information carrier is electromagnetic radiations, and the output is observed in the form of an image from which the useful information can be extracted by further analysis and interpretation.

The various applications of remote sensing in agriculture includes:

- Yield assessment and crop area estimation with the help of indices such as NDVI (Normalized Deviation Vegetative Index), leaf area index (LAI), Chlorophyll Index and Temperature Crop Index (TCI).
- Nutrient stress information, soil moisture condition, crop growth parameters, weather conditions or rainfall patterns, weather forecasting, drought patterns of an area which helps in proper resources management.
- AI is an advanced technology that helps farmers to remain updated with data related to weather forecasting. The predicted data then helps farmers enhance their crop yield and increase profit. The data analysis then helps the farmers to take precautions and thus make smart decisions on time. AI is helpful in precision farming and predictive analytics (**Figure 1.6**).
- Remote sensing is also helpful for soil and land use mapping and plant breeding research.

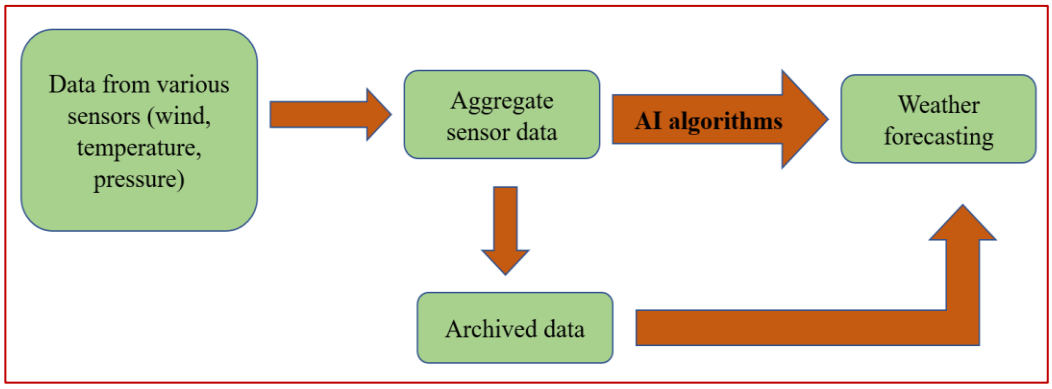


Figure 1.6: Abiotic stress management by Artificial intelligence

d. Variable Rate Technology (VRT): VRT allows use of various resources such as fertilizers, pesticides, irrigation water, gypsum, lime and various farm inputs at different or variable rates across the field. Variable Rate Application (VRA) is done keeping in mind crop yield potential, spatial variability and makes the system more efficient by minimizing environmental impact. There are two types of VRT, one is map based control. In this a map of application rate is produced before application of various nutrient or water sources and another is real time control where decisions regarding rate of application is done using information gathered during the operation. This process requires use of sensors to detect variability in the field. VRA has three components which includes control computer, locator and actuator.

e. Yield monitor: It is an essential component of site-specific nutrient management strategies. It is used on combine equipped with differentially corrected global positioning system (DGPS) receiver. It simultaneously records yield, grain moisture content and position data, which are required to produce yield maps which will help in observing the magnitude and location of yield variability.

f. SSNM (Site Specific Nutrient Management): Site Specific Nutrient Management is an approach of supplying crops with nutrients at the right time, right amount, right place and in the right manner. It aims at optimal use of nutrients by the crop from indigenous sources i.e., soil, crop residue, manure and irrigation water and timely application of fertilizers at optimum doses. Feeding of crops with nutrients is done as and when needed by the crop. The goal of SSNM is to match nutrient supply from various sources with the crop requirement and at the same time minimize nutrient losses from fields. This is done using optical sensors, GIS and GPS technology. Precision farming is broad field which includes use of GIS, GPS and VRT. Sensors are mounted on the farm machinery and there is computer system which provides input recommendation maps and controls the application of various inputs based on information received from GPS receivers. This ultimately helps in soil maps generation, assessment of soil degradation status and soil survey.

1.4.3 Identification of Pests' Outbreak, Disease and Crop Management:

Using artificial intelligence, farmers are equipped with sensors and other latest technologies which are placed on site and monitor the plant growth. The sensors notify or aware the farmers regarding presence of any unwanted pests or insects that affect plant growth. AI can forecast plant illness or disease and recommend efficient pest control measures. AI can also suggest the agronomic products to be used, when to apply nutrients and the irrigation scheduling. It also assists in choosing the best stage for harvesting for crops. High quality images from drones can help in real time predictions. With image recognition approach, AI can identify possible defects and nutrient deficiencies in the soil. It can provide farmers with valuable information regarding the soil type, soil condition, pests or insects infestation and weather conditions. Deep learning applications are developed with the help of AI which are used for analysis of floral patterns in agriculture. It helps in understanding any soil defects, plant insects, pests or diseases.

1.4.4 Agricultural Robots and their Applications:

A robot is a mechanical or an artificial agent which because of software programming makes complicated tasks easy to perform. Agricultural robots use automation in the field of agriculture, forestry and fisheries. Robots replace the conventional techniques to perform the same tasks efficiently. Robots usually have five parts:

- Sensors which send information in the form of electronic signals back to the controller.
- Comptroller which acts as the brain of the robot
- Drive which is the engine of the robot that produces motion.
- Arm which acts like a human arm with a shoulder, elbow, wrist and fingers.
- End receptors which are the last end of robot. Tools are attached at the end point and this part of the robot interacts with the environment.

The various techniques involving agricultural robots are:

- Seed bed preparation/ ploughing
- Seed mapping by recoding geospatial position of each seed.

- Reseeding where seed was not placed.
- Seed placement in a particular seeding pattern using robots.
- Weed control based on weed identification by colour photography.
- Demeter robots used for harvesting.
- Fruit picking robots
- Forester robots used for cutting up of wood or trees.

1.4.5 Autonomous Tractors:

These are vehicles used in farms that are operated automatically with an intelligent system which guides it for proper functioning. These are programmed to independently observe the position, speed, avoid obstacles in the field while performing their tasks.

These tractors use GPS and other wireless technologies without the need of a driver. They operate by the supervision of a person monitoring the progress at a control station and have different sensors that fetch information of the field on real time basis.

1.4.6 Assessment of Soil Quality:

Soil is one of the most important resources which is required for crop production. It is the major source of various nutrients, organic matter, water and provides a suitable medium for crop growth and development. Assessment of soil quality is required to help farmers know the nutrient status of their soil and apply various resources effectively. Soil quality is enhanced using composts and manures which improves soil aggregation, soil porosity and water holding capacity. AI based apps helps in soil quality assessment by

A. Soil testing and Monitoring:

Mobile agriculture applications may help farmers manage their farms more effectively. Sending soil and water samples to soil testing laboratories for chemical analysis is often expensive and time taking tasks. Now a days AI powered apps can help farmers assess soil quality on the field itself. Farmers can a put drops of water or soil on the test strip which changes colour based on level of pH, EC and nutrients present in the sample. These apps also give fertilizer recommendation for enhancing crop productivity. AI based systems analyse a vast amount of data and produces forecast for specific areas of farm.

B. Soil moisture and Temperature Detection:

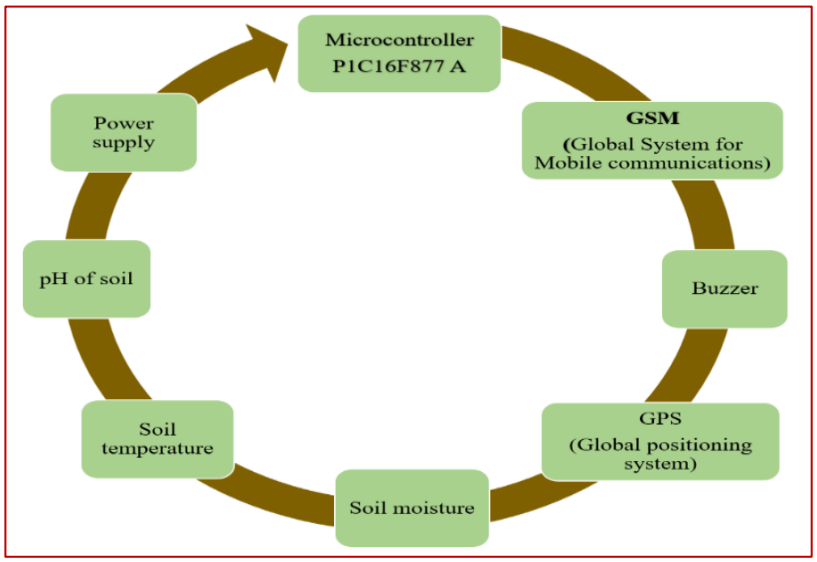
Soil moisture plays an important role in plant growth and acts as a medium for nutrients availability to plants. Soil temperature is also an essential factor for belowground plant activity and influences root growth, root respiration, decomposition and mineralisation of nutrients. IoT based systems uses soil moisture and temperature sensors and notify the user when soil is too wet or too dry by burying probe with electrodes into the soil. The device with sensors can then share the data with IoT cloud server platform from where the data can be controlled (**Figure 1.7**). This will allow farmers to monitor and improve the productivity of crops.

C. Monitoring of Soil/Land cover/Land management:

It is done using multispectral and thermal imagery from UAV. The drones are fixed with professional cameras with sensors which are capable of capturing information in certain regions of the electromagnetic spectrum. Index maps and thermal maps are computed based on thermal imagery [7]**.** Thus, it can have a great potential in agriculture.

D. Remote monitoring of soil characteristics using IoT based system:

Basic parameters of the soil such as pH, soil temperature, soil humidity is sensed are transferred via a bluetooth connection to a device. The data is then made available to farmers to help them decide the choice of crops and fertilizers.



(Source: Sowmiya and Sivaranjani 2017) [8]

Figure 1.7: Smart System Monitoring of Soil Using Internet of Things

1.5 AI Startups in Agriculture

Some of the popular AI related startups in agriculture field are:

1.5.1 IBM Technology: Agropad, 2018:

In this AI app, farmers can put a drop of soil or water on the test strip. The five indicators can change their colour based on the level of pH, nitrogen dioxide, aluminium, magnesium and chlorine that are present in the sample. Also, it can make fertilizer recommendations which can help to optimize crop growth. The data is also uploaded into the cloud along with other chemical reads from the area, which helps to track trends of soil and water in the geographical area.

1.5.2 Mumbai Startup: AutoNxt, 2016:

AutoNxt's autonomous tractor is ideal for various farm operations such as tilling, ploughing, control of pests and sowing. This startup envisions to build a tractor sharing platform for a wider and affordable reach. It is currently working with bigger farmers working with grapes.

1.5.3 Prospera, 2014:

This AI powered device can be used in green houses or in fields. It is powered by a variety of climatic sensors, technologies and in field cameras. The input from these sensors provides real time analysis of the field activities which allows farmers to manage pests, diseases, irrigation, nutrient deficiencies and other agro-technical activities.

1.5.4 Blue River technology, 2011:

The focus of this startup is towards reducing the use of harmful chemicals, saving costs of farmers and improving crop yield with minimum impact on the environment. With the help of machine learning and robotics, they intend to create intelligent machinery on a world-wide scale.

1.5.5 FarmBot, 2011:

It helps the owner to do end to end farming all by himself. Everything is taken care of by this physical bot ranging from seed plantation to detection of weeds, soil testing, irrigation to plants using an open-source software system.

Figure 1.8: Different AI related startups in agricultural field.

1.6 Challenges in the use of AI in agriculture:

- Power issues and power consumption: Smart farming requires high amount of power to operate and large machine automation. Thus, resulting in high power requirements.
- Connectivity Issues: In rural areas across the globe, internet connection is poor, which prevents the adoption of smart agriculture practices.

- Lack of familiarity and technical knowledge among farmers: Although there are many benefits of artificial intelligence in agriculture but, farmers are still not familiar with the AI tools and technologies and lack the technical knowledge and are unaware of the existence of such technologies. The adoption of AI in agriculture is a challenging task because of lack of experience with the latest technologies.
- Privacy and security issues: Privacy and security issues are a major challenge in smart farming. There are no policies or rules and regulations for using AI in agriculture field. So, there are security issues such as data leaks which can create a major problem for farmers.
- Lack of investment and venture capital funds.
- Complexity, scalability and affordability of the technologies.

1.7 Conclusion:

AI is regarded as one of the feasible solutions for less manual labour and gap between world population and food grain production. There are many applications of AI in the field of agriculture. AI has the potential to increase crop yield and decrease input cost, helps in monitoring soil health status and achieving the goal of sustainability. Remote sensing technology helps in land/soil mapping, computation of vegetation indices and predicting crop yield. Drones helps in irrigation, crop spraying, soil and crop management. Autonomous tractors can perform various cultural operations without human intervention. Although there many limitations and challenges associated with the adoption of AI technologies in agriculture, but it is a changing tool as the modern agriculture is concerned and has a promising prospect in this field.

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