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APPLICATION OF MOISTURE CONTENT SENSORS FOR IRRIGATION SYSTEM PURPOSES: A REVIEW

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Abstract: The need for quick advancements in food production technologies is driven by the ever–rising demand for food. We are unable to fully utilize agricultural resources in a country like Nigeria where the economy is built primarily on agriculture and the climate is isotropic. This is as a result of unplanned water consumption, manual irrigation, etc. which results in enormous water waste. In manual based irrigation system, intense man power is required for irrigation and water management is not utilized properly. In addition, manual–based irrigation system leads to improper water allocation since labour is not automated at the right time. All these factors impact the growth rate, seed quality and productivity of crops negatively. In order to negate such problems, there is a need to develop an automated irrigation system by using the knowledge acquired in soil–water plant relationship. This study proposes to review earlier works on automated irrigation system enhanced with soil moisture content sensor, which resulted in efficient and effective irrigation and irrigation scheduling of farmlands. The most significant advantage of this automated irrigation system is that the right amount of water is supplied and stopped automatically at the right time, to the right depth in the soil for crops when the right crop water requirement (CWR) is achieved, and when the soil moisture content has reached its required volume.
Keywords: sensor, IoT, precision agriculture, soil moisture, irrigation

1. INTRODUCTION

Plant irrigation is typically a labour–intensive task that takes a lot of manpower to complete in a fair amount of time. Traditionally, humans carried out each stage of the irrigation. Nowadays, some systems make use of technology to cut down on labour costs or plant–watering times (Frederick *et al*., 2023). Such systems have very little control, and a lot of resources; fuel, water, nutrients etc. are being squandered. One of these squandered or overused resources is water. One technique for the plant watering is mass irrigation. Given that the plants receive more water than they require, this strategy results in enormous losses (Frederick *et al*., 2023).

According to FAO (2013), Nigeria's irrigation capacity ranges from 1.5 to 3.2 million hectares, there are also approximately 2.3 million hectares in total, with over 1 million hectares in the north. Only about 40% of the 142–106 hectares irrigated by public schemes are actually accurately irrigated; 32% for irrigated areas managed or controlled by the River Basin Development Authorities (RBDAs) and 55% for those managed or controlled by states. This low rate can be attributed to the need for rehabilitation in most schemes, which accounts for 80% of the equipped area; high operation upkeep, and maintenance costs; fuel shortages; or technical weakening of infrastructure and pumps. On the other hand, some known irrigation methods have the disadvantages of high labour costs, the cost of setting up an irrigation project and system, poor water management and control, erosion, water runoff and percolation losses, evaporation losses, and water–logging, which can lead to mosquito breeding and other parasites.

The importance of a smart irrigation system as well as the issue dealing with water efficiency in agriculture productivity comes into focus here because of the pressing need to consistently increase agricultural productivity levels while utilizing water effectively and economically (Blasi *et al*., 2020). In addition, the traditional irrigation system also cannot provide an efficient irrigation scheduling (duration and frequency) which leads to unnecessary irrigation process and water wastage to occur. Therefore, smart irrigation system with the application of soil moisture sensor is developed to overcome all these problems.

2. OVERVIEW OF SOIL MOISTURE AND IRRIGATION

Soil Moisture & Moisture Content

Soil moisture is said to be related to the temperature sensitivity of ecological systems plant growth and production, community composition, soil microbial community, soil carbon, nitrogen and phosphorus flux and storage. Surface measurement is undoubtedly the most accurate and easiest method of obtaining soil moisture; however, this method still has its own insurmountable shortcomings (e.g., the temporal and spatial scale at which it operates are relatively small). Plants need air and water in the soil. During a rain shower or irrigation application, the soil pores will be filled with water. If all soil pores are filled with water the soil is said to be saturated. At saturation, no air is present and the plant will suffer. Many crops cannot withstand saturated soil conditions for a period of more than 2–5 days. Rice is one of the exceptions to this rule. The period of saturation of the topsoil usually does not last long. After the rain or the irrigation has stopped, part of the water present in the larger pores will move downward. This process is called drainage or percolation (FAO 2017).

The water drained from the pores is replaced by air. In coarse textured (sandy) soils, drainage is completed within a period of a few hours. In fine textured (clayey) soils, drainage may take some (2–3) days. After the drainage has stopped, the large soil pores are filled with both air and water while the smaller pores are still full of water. At this stage, the soil is said to be at field capacity. At field capacity, the water and air contents of the soil are considered to be ideal for crop growth. Little by little, the water stored in the soil is taken up by the plant roots or evaporated from the topsoil into the atmosphere. If no additional water is supplied to the soil, it gradually dries out. The dryer the soil becomes, the more tightly the remaining water is retained and the more difficult it is for the plant roots to extract it. At a certain stage, the uptake of water is not sufficient to meet the plant's needs. The plant loses freshness and wilts; the leaves change colour from green to yellow. Finally, the plant dies. The soil water content at the stage where the plant dies is called permanent wilting point. The soil still contains some water (hydroscopic water), but it is too difficult for the roots to suck it from the soil (FAO 2017).

The soil moisture content indicates the amount of water present in the soil. It is commonly expressed as the amount of water (in mm of water depth) present in a depth of one meter of soil. Crop water requirements (CWR) are defined as the depth of water, usually measured in mm, needed to meet the water consumed through crop evapotranspiration by a disease–free crop, growing in large fields under non–restricting soil conditions including soil water and fertility, and achieving full production potential under the given growing environment. It always refers to a crop grown under optimal conditions, i.e. a uniform crop, actively growing, completely shading the ground, free of diseases, and favorable soil conditions (including fertility and water). The crop thus reaches its full production potential under the given environment. The crop water needed mainly depends on; climate, crop type, and growth stage of the crop (FAO, 2017).

Irrigation

Irrigation is the artificial supply of water to the root of plant. Irrigation has been used to assist in the growing of agricultural crops, maintenance of landscapes, and re–vegetation of disturbed soils in dry areas and during periods of inadequate rainfall. In crop production, irrigation helps in protecting plants against frost, suppressing weed growth in grain fields and preventing soil consolidation. Irrigation systems are also used for dust suppression, disposal of sewage, and in mining. Water is artificially applied to the soil or land during irrigation. It is used to support the development of crops, the upkeep of landscapes, and the re–vegetation of disturbed soils in arid regions and during dry spells (Frederick *et al.*, 2023). The water is forced via the lateral lines and eventually arrives at the irrigation emitter (drip) or sprinkler heads when a zone is activated. A fitting and the pipe can be attached to many sprinklers; this is as a result of the pipe thread inlets on the bottom of the device. The top of the sprinklers' heads is often set flush with the ground. The head will emerge from the earth and water the chosen area once the water is pressured until the valve closes and turns off that zone. The sprinkler head will retract back into the earth once there is no longer any water pressure in the lateral line. To minimize evaporation losses, emitters are often placed on the soil's surface or buried a few inches. An automatic irrigation system does the operation of a system without requiring the manual involvement of persons. Every irrigation system such as drip, sprinkler and surface gets automated with the help of electronic appliances and detectors such as computers, timers, sensors and other mechanical devices (Frederick *et al*., 2023).

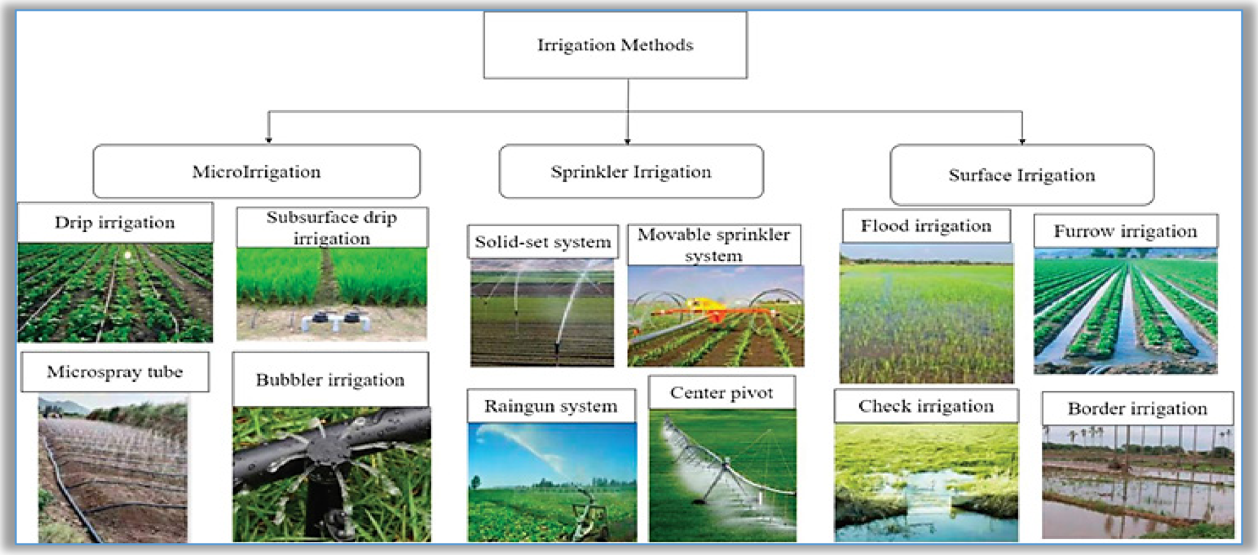

Figure 1: Irrigation methods graphically represented.
Source: The researchers (2023)

The three foremost techniques of irrigation are, namely, drip/micro (subsurface), surface, and sprinkler irrigation (Surai *et al*., 2018). Water flows over the soil (land) for surface irrigation. Sprinkler irrigation supplies water to crops by sprinkling or spraying water from moving or fixed systems. Micro–irrigation supplies water with frequent, small applications, usually wetting a portion of the field. Another minor irrigation technique is the sub–irrigation method. Here, the water level is raised to or held near the crop root zone employing ditches or subsurface drains to supply the water. The types of irrigation methods are discussed further below;

— Sprinkler irrigation

Sprinkler irrigation is a system where water is uniformly applied over the crop canopy or soil surface identical to rainfall. With a sprinkler irrigation system, water is pumped and conveyed through high–density polyethylene pipes eliminating water losses through seepage and evaporation as in the case of surface canals under surface irrigation. Compared to conventional flood irrigation, sprinkler irrigation is more efficient, with irrigation efficiency of up to 80–90%. The performance of a sprinkler irrigation system solely depends on the design and selection of sprinklers. In irrigation design, it is recommended to select a sprinkler whose application rate is lower than the soil infiltration rate to prevent surface ponding and runoff. The implementation of intelligent sprinkler irrigation systems involves high control precision, high intelligence, good dependability, simple operation, wired or wireless sensor network technology, and crop water demand data collection devices (Bwambale *et al*., 2022).

— Drip Irrigation

Drip irrigation or trickle irrigation is a type of micro–irrigation system that has the potential to save water and nutrients by allowing water to drip slowly to the roots of plants, either from above the soil surface or buried below the surface. The goal is to place water directly into the root zone and minimize evaporation. Drip irrigation systems distribute water through a network of valves, pipes, tubing, and emitters (Wikipedia, 2023). Drip irrigation transports water and fertilizer to crops directly, provides a suitable soil environment for crops, and is regarded as one of the most efficient irrigation technologies in terms of water, energy, and fertilizer use.

Water is delivered at low pressure through emitters by a distribution system located on the soil surface, beneath the surface, or suspended above the ground in drip irrigation systems. Irrigation water droplets are directed to the plant root zone via emitters, sprayers, or porous pipes, where it then infiltrates by gravity or capillary rise. The applicator's design reduces the water pressure within the delivery lines, resulting in a low discharge.

Drip irrigation has received a lot of attention from agriculturalists, especially for high–value crops like vegetables, fruits, and nut trees (Bwambale *et al*., 2022).

— Surface irrigation

Surface irrigation is the oldest irrigation application method in the world. It involves the application of water over the surface of the land to supply moisture to the plant. Surface Irrigation includes furrow, border, basin and, check irrigation. Surface irrigation requires less pressure than sprinkler or micro–irrigation systems. Under surface irrigation, irrigation water is applied at the inlet end, and the water subsequently flows to the downstream end. A part of the water infiltrates as it progresses over the field. Water is frequently applied by gated pipelines, siphons, or gates. The soil infiltration rate is very crucial in the proper functioning of surface irrigation systems. If the soil's infiltration rate is excessively high, the depth of water that infiltrates at the entrance will be significantly bigger than the downstream end. The land slope and its regularity also considerably effect surface irrigation (Brian and Darell, 2014).

Irrigation Scheduling

Irrigation scheduling is the process of determining the frequency, duration and quantity of irrigation water to apply to meet the crop water requirements. In conventional irrigation systems, irrigation scheduling is determined through experience, observation, and heuristic methods. Irrigation aims to maintain the root zone soil moisture between field capacity and the wilting point. When the soil moisture goes above the field capacity, the soil becomes saturated, and below the wilting point, the plant experiences water stress and eventually die. Management allowable depletion of 50% is adopted for most irrigation designs to ensure that the available moisture does not get depleted before irrigation occurs. This available moisture in the root zone depends on the plant's effective root zone (Delgoda *et al*., 2016).

Irrigation scheduling is a systematic process of determining when and how much to irrigate. This depends on various factors, including daily crop water requirement, the effective root zone, and the available soil moisture. Irrigation scheduling can be done using one or all of the following approaches: 1. Plant–based, 2. soil–based, and 3. weather–based irrigation scheduling approaches (Bwambale *et al*., 2022).

— Plant–based irrigation scheduling

Plant–based irrigation scheduling is based on the physiological and phonological status of the plant. The physiological condition depicts the water stress level, which is estimated from canopy temperature depression relative to air temperature measured by infrared thermometry. Phenological stages can also be used to determine when to irrigate. For example, in wheat cultivation, crown root initiation (CRI), tilling, jointing, flowering, and the grain filling stage are critical stages of growth that need irrigation. Failure to supply irrigation water at these critical stages of growth leads to low yields as water stress becomes severe. The cumulative effect of water stress is determined with this method, making it effective as a water stress indicator. This helps to capture the moisture reduction in the soil through evapotranspiration.

Direct and indirect measurement techniques are used to determine plant water status. Direct plant water stress detection methods include using sap flow sensors, xylem sensors, leaf sensors, and others. On the other hand, indirect methods involve thermal sensing, near–infrared spectroscopy, and aerial imagery. Several authors have used plant–based approaches for irrigation scheduling. For example, King *et al*. (2020) used data–driven models for canopy temperature–based irrigation scheduling of sugar beet and wine grape. The data driven models developed by the authors estimated reference temperatures enabling automatic calculation of the crop water stress index for crop water stress assessment. Similarly, Meeks *et al*. (2020) used leaf water potential monitoring system for irrigation scheduling of winter rye cover crop. The authors reported significant water savings and an improvement in crop yields.

— Soil moisture–based irrigation scheduling

Soil moisture–based irrigation scheduling involves determining the soil moisture status within the root zone, and knowing the permanent wilting point (Pramanik *et al*., 2022). Soil moisture measurements are compared to moisture thresholds to trigger irrigation. Soil moisture monitoring is done by time–domain transmission sensors, neutron probes, capacitance sensors, or granular matrix sensors. Soil moisture based irrigation scheduling allows variable rate irrigation scheduling due to its ability to measure spatio–temporal variability in the field (Bwambale *et al*., 2022). For example, Pramanik *et al*., (2022) developed an automated basin irrigation system based on soil moisture sensors for irrigation scheduling. The authors highlighted that the ideal position of sensors for shutting the system would be at 37.5cm depth put at 25% length from the intake in larger soil moisture deficit situations and at 7.5cm depth set at 75% length in low moisture deficit conditions.

— Weather–based irrigation scheduling

Weather–based irrigation scheduling involves the use of weather sensors to monitor and measure the parameters that affect evapotranspiration. Automatic weather stations with temperature, humidity, wind speed, rainfall, and air pressure sensors are installed in the field to collect field data around the plant. The data from the weather sensors are then used to estimate water demand using evapotranspiration models. The Penman–Monteith evapotranspiration model is used to determine the daily water demand. Irrigation is scheduled after a pre–determined amount of evapotranspiration has occurred and this threshold varies with soil type, crop type, and stage of growth (Allen *et al*., 1998).

Precision Agriculture

Precision Agriculture is one of the potential avenues for smart technologies in agricultural development that promotes employing the appropriate inputs in the right amounts at the right time and place using appropriate technologies or procedures. It has evolved just in time to manage the complications as it specifically caters to the diversity of agriculture, including farm size, types of farming, techniques, and output management, which can vary substantially even between farms. A wide range of Precision Agriculture technological enablers exist, including Global Navigation Satellite Systems, wireless sensor networks, unmanned ground and aerial vehicles, as well as autonomous navigation systems for object identification, geo–referencing, and measurement of specific parameters. Machine learning (ML) and artificial intelligence (AI) algorithms are fundamentals of data driven strategy and analytics and act as enablers of digital technologies (Ayoub *et al*., 2022).

Precision Agriculture is also an umbrella terminology used for ICT–based farming where IoT, robotics, drones, and AI are employed to manage the farm in terms of soil and crop health. An interconnected network supported by a combination of AI, robotics, and IoT–enabled devices serves as the technical underpinning of this possibility and as the enabler of real–time data analysis (Zhang *et al*., 2017).

Precision irrigation systems aim at spatio–temporal irrigation scheduling depending on weather, soil, and plant physiological characteristics. Precision farming helps the farmers to improve, automate and optimize all feasible directions in order to enhance the agricultural productivity and make cropping system smart. The controlled monitoring of agricultural systems has enhanced the sapience of the changing dynamics of the water, plant and soil environment throughout the cropping season. With advances in big data analytics, more agricultural systems are becoming data driven for decision–making purposes rather than relying on heuristic physics based models (Pylianidis *et al*., 2021).

Soil Moisture Sensors

Soil moisture sensors are very productive instruments in measuring soil moisture to assess crop growth. It also measures the water content at the root zone and is useful in irrigation scheduling, precision agriculture and hydrology. Generally, there are two methods of measuring soil moisture, which are Direct inspection; feel and appearance method, Hand–push probe, and Gravimetric method, and Meters and Sensors; soil moisture blocks, time domain reflectometry (TDRs), frequency domain reflectometry (FDRs), etc. Some soil moisture devices are listed below:

— Tensiometers

Tensiometers are simple soil moisture tension measuring devices used frequently in irrigation scheduling. Figure 2 shows a typical tensiometer which consists of a porous ceramic tip connected to vacuum gauge through a poly vinyl chloride (PVC) tube. The tube consists of water, which should be free from air. The porous ceramic cup is installed into the soil in such a way that soil water pressure is transmitted to the tensiometer, which is read by pressure sensing devices mounted on the tensiometer. This instrument does not measure soil moisture content directly, instead it measures soil water tension. Generally, the response time of a tensiometer is 2 to 3 hours (Zazueta and Xin, 1994).

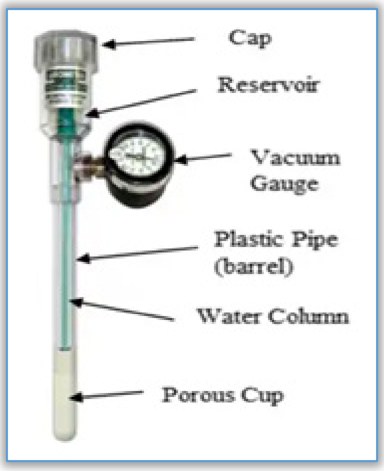

Figure 2: Soil water tensiometer
Source: Rasheed *et al.* (2022)

— Time Domain Reflectrometry (TDR)

In time domain reflectrometry, a pulse of radio frequency energy is injected into a transmission line and its velocity is measured by detecting the reflected pulse from the end of the line. This velocity depends upon the dielectric constant. It measures the moisture content by measuring how long it takes the reflected pulse to come back (Cepuder *et al*., 2008).

— Granular Matrix Sensor (GMS)

The granular matrix sensor is made of a porous ceramic external shell with an internal matrix structure containing two electrodes as shown in Figure 3. The electrodes inside the GMS are imbedded in the granular fill material above the gypsum wafer. The water conditions in the granular matrix change with variation in corresponding water conditions in the soil and these changes are continuously indicated by difference in electrical resistance between two electrodes in the sensor (Irmak *et al*., 2006).

Figure 3: Granular matrix sensor
Source: Jacob *et. al.* (2021).

— VH400 Soil Moisture Sensor

VH400 soil moisture sensor is resistive based soil moisture, which measures dielectric constant of soil. It helps in precise low cost monitoring of soil water content. It has rapid response time, can take reading in under one second and is much sensitive at higher volumetric water content (Ravi *et al*., 2011). The soil moisture probe is inserted into the ground, preferably in horizontal position at the root level. This sensor is small in size, rugged, waterproof, and consumes less power. It is also insensitive to salinity of water, does not corrode over time, and is sensitive to even small changes in water content.

Several soil moisture monitoring systems that use commercially available and inexpensive soil moisture sensors and development boards have already been developed and tested, both globally and locally. However, there are fewer research studies on monitoring systems that use ESP8266 development boards. Khan (2017) proposed automatic drip irrigation through soil moisture sensors. The water level was maintained at the same level, and water was delivered to the roots one drop at a time. In intelligent drip irrigation system, for controlling the drip irrigation system, a command sends to computer from an android mobile. This process of irrigation is highly efficient system having less requirement of water to save plants.

Vikas *et al*. (2019) proposed integration of soil moisture sensor based automatic drip irrigation system for Okra crop. The soil moisture sensor was used to perform the electrical resistivity process. When the farmers are occupied with other tasks in the field, the machine makes it very quick and convenient for them to turn on and off the water pump when the water is applied. The controller and the soil moisture sensor were connected using American wire gauges (AWG) wires.

Automated Irrigation Systems

Irrigation systems in agriculture can be automated or semi–automated to utilize water efficiently. The sensor based automatic irrigation can be made i.e. soil sensor can be deployed and measure the varying values and compare with the default values and turn motor on and off. In an automatic irrigation system water level indicators are placed in water reservoirs. Sensors placed in root zone of the plant and sensors information are sent to a gateway unit which transfers to a microcontroller and turn gateway accordingly (Babanna *et al*., 2016).

Automating farm irrigation allows you to apply an appropriate amount of water regardless of the availability of labor to your own valves on or off and to know the plant growth status. Nowadays, automation has been implemented in all fields like industries, home automation, agriculture etc. Touati *et al*. (2013) offered a workable approach based on an intelligent and efficient system for a field of extreme aridity. The system comprises a Zigbee–GPRS remote monitoring and database platform and a feedback fuzzy logic controller (FLC) that logs important field metrics using certain sensors. Without undergoing any physical modifications, the system was installed in already–existing drip irrigation systems. These sensors data are collected by fuzzy logic controller (FLC), which then applies fuzzy rules to determine the ideal timing and duration of irrigation. Dong *et al*. (2013) created an autonomous precision irrigation system where a center–pivot irrigation system and wireless subterranean sensor networks were combined together. By using wireless underground sensors to monitor the soil conditions in real time, the centre pivot system with wireless underground sensor assistance will be able to handle irrigation on its own.

— Machine Learning Based Automated Irrigation System

Coates *et al*. (2013) utilizing valve control hardware and software pushed commercial wireless sensing and control networks. A unique node firmware, actuator hardware and firmware, an internet gateway with control, communication software, and a web interface were all developed for the valve actuation system. The system uses a single–hop radio range using a mesh network with 34 valve actuators for controlling the valves and water meters. Dursun and Özden (2014) proposed an efficient water usage system by pump power reduction using a solar–powered drip irrigation system in an orchard. Artificial Neural Networks (ANN) evaluates soil moisture content to deliver an equitable distribution of water for the desired location. By doing this, water consumption will be reduced and wasteful irrigation will be avoided.

Chang *et al*. (2019) offered a machine learning–based accurate and intelligent irrigation system with LoRa P2P networks that could automatically and smoothly pick up irrigation knowledge from experienced farmers. The suggested system first determines how much water is needed for each

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

irrigation based on the trained irrigation model combined with environmental data, such as air temperature/humidity, soil temperature/humidity, light intensity, etc., and then uses the long–distance and low–power LoRa P2P network to automatically irrigate the crops. The proposed intelligent and accurate irrigation system was shown to be a great fit for contemporary greenhouse–based agriculture, according to experimental results.

Data driven machine learning models for irrigation have gained attention over physical and mechanistic models to predict soil moisture content because data–driven models require less data for calibration as compared to mechanistic model calibration. In addition, machine learning models process spatial and temporal data easily in less time and show good predictive performance over physical models. The machine learn model based irrigation systems have a closed–loop controller that learns from calibration, in which the system itself employs feedback from the comparison between pre–processed data and measured real time data (Abioye *et al*., 2023).

— Internet of Things (IoT) Based Automated Irrigation System

Internet of Things (IoT) can be defined as a globally linked network of uniquely addressable 'things' based on standardized communication protocols over the internet. Sensor–based systems for monitoring crops, soil, farms, animals, storage facilities, and other electronic devices are just a few of the building blocks that make up the IoTs (Verdouw *et al*., 2016).

Pylianidis *et al*. (2021) defined IoT as a cosmos of interrelated computing devices, sensors, appliances, and machines connected with the internet, each having unique identities and capabilities for performing remote sensing and monitoring.

Efforts made on wireless sensors networks have enabled farmers to collect data from sensing devices and send it to the main servers. Data collected through sensors gives information about different environmental condition to monitor the whole system properly. 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. With the advancement of technology, it has been expected that by using IoT, agriculturalists and technologists are finding out the solution to the problems which farmer are facing such as shortages of water, cost management and productivity issues (Kamienski *et al*., 2019).

Babanna *et al*. (2016) proposed that irrigation should be done based on soil fertility and moisture level. Different techniques in irrigation would produce higher outgrowth. In this, depending upon the water level indicator and soil moisture sensors, motor and solenoid valves are controlled which helps to supply water to field. The entire system is monitored and controlled by MQTT server through an internet.

Shweta *et al*. (2014) designed a system with an Arduino–Uno as an embedded Linux board which helps to communicate with the soil sensor and ultrasonic sensor. The node MCU monitors the physical conditions such as temperature, humidity with the help of DHT11 sensors. Using these values, signal is sent to the motors. A timer is set for water flow according to the temperature and soil sensors water flows manually. IoT based smart farming consist of four major components. These four major components are physical structure, data acquisition, data processing, and data analytics. The physical structure is the most important factor for precision agriculture to avoid any unwanted happening. Whole system is designed in such a way which controls the sensors, actuators, and devices. A sensor performs multiple tasks like soil sensing, temperature sensing, weather sensing, light sensing, and moisture sensing. Similarly, devices perform many control functions like, node discovery, device identification and naming services etc. All these functions are performed by any device or sensor which is controlled through a microcontroller. This controlling operation is performed by any remote device or a computer which is connected through the Internet (Farooq *et al*., 2019).

The reference architecture of IoT with six layers namely; perception layer (hardware devices), network layer (communication), middleware layer (device management and interoperability), service layer (cloud computing), application layer (data integration and analytics), and end–user layer (user–interface). In the agricultural domain, IoT devices in the physical layer gather data related to environmental and crop parameters such as temperature, humidity, pH value, water level, leaf color, fresh leaf weight, etc. The transmission of this data takes place in the network layer, the design of which depends on the selection of suitable communication technologies relevant to the field size, farm location, and type of farming method. For instance, ZigBee, LoRa, and Sigfox are widely used and employed in outdoor fields because they are cheaper and have low energy consumption and a good transmission range (Shaikh *et al*., 2010).

— Sensor Based Automated Irrigation System

To measure 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 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. Mehamed *et al*. (2015) proposed a sensor based automatic irrigation management system. This system was used to increase the efficiency of water distribution and to automate the process of management in the irrigation field. The system was more reliable and the cost of the system also cheaper.

The development of sensor technology has provided technical support for accurate measurements. Xie *et al*. (2022) used wireless sensor network (WSN) technology to collect data for accounting and analysis to enhance the intelligence of irrigation systems with the help of machine learning algorithms. Soulis *et al*. (2015) determined the effect of soil moisture sensor positioning and the accuracy of soil moisture–based drip irrigation scheduling systems under different conditions. It emphasized the selection of suitable soil moisture sensors for specific crop needs.

Ndunagu *et al*. (2022) proposed an innovative irrigation system using drip irrigation methods, which was designed and implemented using wireless sensor networks and Thingspeak.com to manage water resources effectively.

An Arduino–based irrigation control system was proposed by conducting extensive experimental trials to automatically adjust soil water content within a specific depth range (Zhu *et al*., 2022). Ling and Zhang (2014) designed a ZigBee based automated irrigation system to achieve real time monitoring, remote monitoring, and alarm functions, providing an intuitive on–site management platform for irrigation users.

3. CONCLUSION

The use of soil moisture sensors helps farmers with irrigation scheduling by providing information about when to water the crops. The development of wireless sensor applications in agriculture makes it possible to increase efficiency, productivity and profitability of farming operations as well as the maximum crop yield with minimum use of irrigation water.

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ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665