

SMART FARMING WITH SOIL MOISTURE SENSORS: SIMPLIFYING PRECISION AGRICULTURE

K. K. Chauhan* and M. M. Lunagaria

Department of Agricultural Meteorology, B.A.C.A. College of Agriculture, Anand Agricultural
University, Anand

Corresponding author: kalyansinhc@gmail.com

ABSTRACT

Precision agriculture uses soil moisture sensors to optimize watering practices and crop yield. While various types of soil moisture monitoring sensors are available, modern satellite sensors are particularly valuable because they can remotely track ground moisture levels without needing installation. This type of sensor provides data that can inform decisions in many areas of precision agriculture and related industries. With the information provided by satellite sensors, farmers can make informed decisions about when to irrigate, how much water to use, and where to focus their efforts to improve crop yield. Overall, using satellite sensors for soil moisture monitoring is an important tool for enhancing the efficiency and productivity of modern agriculture.



INTRODUCTION

A soil moisture sensor is a device that measures the amount of moisture in the soil. Integrating this tool in the irrigation system allows for more precise watering scheduling than is possible with historical data or weather forecasts. Conventional approaches to irrigation have limitations that farmers must consider. Relying on historical data alone can be risky as it doesn't account for unexpected weather changes. On the other hand, planning irrigation based on projected crop evapotranspiration requires complex calculations unique to each field's conditions.

Modern soil moisture measurement sensors provide more precise and timely data. These sensors can display results in near real-time, allowing farmers to adjust their watering schedule effortlessly for optimal crop development. Farmers can avoid over or under-watering by monitoring soil moisture levels, which can significantly impact crop yields. Overwatering can lead to water wastage and lower crop yields, while under-watering can harm crops, resulting in reduced yields or even crop failure. Farmers can optimize their irrigation practices and promote sustainable agriculture by using soil moisture sensors. Soil moisture sensor is an essential tool for modern agriculture, allowing for more precise and efficient watering

scheduling. These sensors provide farmers with real-time data, enabling them to make informed decisions about their irrigation practices and optimize crop yields.

Types of Soil Moisture Sensors

Soil moisture sensors are an essential component of smart farming, and they continue to evolve to become more user-friendly. Today's smart soil moisture sensors can transmit data wirelessly, be deployed at varying depths, and upload readings directly to a GIS database, eliminating the need for manual data collection. Portable soil moisture sensors are also available, which can collect data from any area and depth compared to stationary sensors. Soil moisture sensors have undergone significant advancements, and their different types allow for greater flexibility and precision in measuring soil moisture levels. The integration of these sensors into smart farming practices can help farmers optimize irrigation practices, reduce water waste, and promote sustainable agriculture.

There are two types of soil moisture sensors based on underlying technology:

- **Ground sensors** are installed below the ground to monitor the root zone conditions.
- **Satellite sensors** estimate the situation from space, do not interfere with field activities, save costs, and do not require labour-consuming installations.

GROUND SENSORS

VOLUMETRIC SOIL MOISTURE SENSOR

A volumetric soil moisture sensor is a device that measures the amount of water in the soil, expressed as a percentage of the soil's volume. These sensors are designed to provide accurate and reliable data on the moisture content of the soil, which is a critical factor in plant growth and health.

Volumetric soil moisture sensors work by using time-domain reflectometry (TDR) or capacitance technology. TDR sensors send a high-frequency pulse through the soil, and the time it takes for the pulse to bounce back is used to determine the moisture content. Capacitance sensors use two electrodes to measure the electrical conductivity of the soil, which is proportional to the moisture content. One of the main advantages of volumetric soil moisture sensors is their ability to measure moisture content at different depths within the soil. This information is critical for farmers and agriculturalists to make informed decisions about irrigation, fertilization, and other aspects of plant management. Additionally, volumetric soil moisture sensors can provide continuous monitoring, allowing for real-time adjustments to be made in response to changing soil conditions.

NEUTRON PROBE

A neutron probe is a type of soil moisture sensor that measures soil moisture levels by detecting the amount of hydrogen in the soil. The probe works by emitting a beam of neutrons into the soil, and the neutrons interact with the hydrogen atoms in the soil. The number of neutrons that are slowed down by the hydrogen atoms is measured, and this information is used to calculate the soil moisture content.

Neutron probes are considered one of the most accurate methods of measuring soil moisture levels. They can provide precise data about moisture content at different depths within the soil, making them an essential tool for farmers and agriculturalists who need to optimize irrigation practices and ensure the health and productivity of crops.

While neutron probes are highly accurate, they are expensive and require specialized training. In addition, the use of radioactive isotopes in the probe requires strict safety protocols and regulations.

Despite these drawbacks, neutron probes remain valuable in precision agriculture, particularly for research purposes where high accuracy is necessary. By providing precise and detailed information about soil moisture levels, neutron probes can help farmers make informed decisions about irrigation and other crop management practices, leading to increased yields and more sustainable agricultural practices.

ELECTROMAGNETIC SENSORS

Electromagnetic sensors have become an increasingly popular alternative to neutron probes for measuring soil moisture levels since the late 1980s. Various types of electromagnetic sensors are available, but two of the most common types are capacitance or frequency-domain refractometry (FDR) sensors and time-domain reflectometry (TDR) sensors.

Capacitance or FDR sensors work by generating an electromagnetic signal that is sent into the soil. The signal is then reflected back to the sensor, and the frequency shift between the outgoing and reflected waves is analyzed to determine soil moisture content.

TDR sensors, on the other hand, use voltage on parallel rods to create pulses that are reflected back to the device for analysis. The soil moisture content can be calculated by measuring the time it takes for the pulse to return to the device.

Another type of electromagnetic sensor is transmissometry sensors in the time domain (TDT). These sensors operate on the same principle as TDRs but use a closed circuit with the rods connected in a loop. As a result, the speed of the returned pulse will be lower in damp ground than in dry ground, allowing for soil moisture levels to be measured.

Electromagnetic sensors offer several advantages over neutron probes, including lower costs, easier operation, and the ability to measure soil moisture levels at different depths. While they may not be as accurate as neutron probes, they are still valuable in precision agriculture and can help farmers optimize irrigation practices and improve crop yields.

SOIL WATER TENSION SENSORS

Soil water tension sensors, also known as tensiometers, are another type of instrument used to measure soil moisture levels. These sensors measure the tension or suction force required to extract water from the soil and are widely used in precision agriculture to optimize irrigation practices and improve crop yields.

Tensiometers consist of a hollow ceramic tip, which is inserted into the soil, and a vacuum gauge or pressure transducer, which measures the tension or suction force required to extract water from the soil. As the soil dries out, the tension or suction force required to extract water increases, and the tensiometer provides a corresponding reading.

One of the advantages of soil water tension sensors is their ability to measure the available water content of the soil, which is the amount of water that can be extracted from the soil at a certain tension level. This information can be used to optimize irrigation practices and ensure that crops are not over or under-watered. Another advantage of tensiometers is their low cost and ease of use. They require minimal maintenance and can be left in the soil for extended periods without the need for recalibration.

However, one potential disadvantage of soil water tension sensors is that they may not be suitable for all soil types. For example, soils with high clay content or high levels of organic matter may cause the sensor to become clogged, affecting its accuracy. Soil water tension sensors are a valuable tool in precision agriculture and can help farmers make more informed decisions about irrigation practices to improve crop yields while minimizing water usage.

SATELLITE SOIL MOISTURE SENSORS

Satellite-based soil moisture sensors have become an indispensable tool for farmers and researchers who need to monitor and manage soil moisture levels promptly and accurately. These sensors can analyze infrared (IR) emissions from the Earth's surface, allowing them to provide highly precise measurements of soil moisture content.

One of the key advantages of satellite remote soil moisture sensors is their ability to operate at a large scale. Unlike traditional soil moisture sensors, which need to be physically installed in the ground, satellite sensors can survey expansive regions of land from above. This makes them ideal for monitoring soil moisture levels in remote areas or regions with difficult terrain where installing sensors would be too time-consuming or difficult.

Satellite remote soil moisture sensors are also highly accurate, providing real-time data on soil moisture levels. This data can be used in conjunction with satellite photography to create detailed field maps showing moisture distribution across different land zones. Farmers can use this information to identify areas of their fields that may be experiencing water stress and respond appropriately to ensure optimal crop growth.

In addition to monitoring soil moisture levels, satellite remote sensors can provide information on other factors affecting crop growth, such as temperature, precipitation, and vegetation health. This information can be used to make informed decisions about irrigation schedules, crop selection, and other important farming practices.

Overall, satellite remote soil moisture sensors are valuable for anyone involved in agriculture, environmental monitoring, or land management. They provide accurate and timely data on soil moisture levels and other important factors that can help optimize crop growth and ensure the sustainable use of natural resources.

MONITORING SOIL MOISTURE FROM ABOVE: PRINCIPLES OF SATELLITE-BASED SENSORS FOR PRECISION AGRICULTURE

The basic principle behind satellite-based soil moisture estimation is that the amount of moisture in the soil affects the dielectric constant of the soil. The dielectric constant is a measure of a material's ability to store electrical energy in an electric field. The higher the moisture content, the higher the dielectric constant.

When a microwave signal is transmitted from a satellite to the Earth's surface, it interacts with the soil and is partially absorbed and partially reflected back to the satellite. The amount of reflection depends on the dielectric constant of the soil, which in turn depends on the soil moisture content.

Microwave radiometers or SAR sensors on board the satellite measure the strength of the reflected signal, which can be used to estimate the soil moisture content. This estimation is based on empirical relationships between the microwave signal and the soil moisture content that have been developed through field measurements and modelling.

To obtain accurate soil moisture estimates, satellite-based soil moisture estimation algorithms also take into account other factors that can affect signal strength, such as vegetation cover, topography, and surface roughness. In addition, these algorithms use machine learning techniques to analyze satellite data and separate the signal from noise and other factors.

Satellite-based soil moisture estimation tool monitor and manage soil moisture levels over large areas, which can help farmers make more informed decisions about irrigation, crop selection, and water resource management. The concept is based on the relationship between the dielectric constant of the soil and the strength of the microwave signal reflected from the soil, which can be used to estimate soil moisture content.

PRECISION IRRIGATION AND OTHER APPLICATIONS OF SOIL MOISTURE SENSORS IN PRECISION FARMING

Throughout the growing season, the conditions of the land undergo various changes that can significantly affect crop growth and yield. In the past, farmers would have to scout their fields and collect soil samples to analyze the soil's water and ground conditions. This process could take several weeks as samples must be sent to laboratories for analysis. However, with modern soil moisture sensors, farmers can now quickly respond to changes in field conditions.

Soil moisture sensors allow farmers to monitor specific areas of the field and adapt their irrigation scheduling strategies based on evapotranspiration loss and plant response to water stress. This approach has been shown to be the most straightforward and effective method for optimizing irrigation practices. By incorporating soil moisture sensor data, weather information, and crop history, growers and landowners can obtain valuable insights to enhance their precision agriculture practices.

One of the most crucial applications of soil moisture sensors in agriculture is tracking moisture levels near plant roots to reduce wasteful water use. This leads to increased crop yields, reduced water consumption, protection of local waters from depletion, and lower energy and fertilizer costs. All these benefits result in higher farmer profits.

Soil moisture sensors also play a crucial role in other areas of precision agriculture, such as greenhouse monitoring and control, fertigation management, analyses of water balance, classification of watersheds, predicting crop disease spread, plant (phyto) ecology, soil solarization, and assessing soil health, among others. Soil moisture sensors are a valuable tool for modern agriculture, enabling farmers to obtain accurate and real-time information on soil moisture levels. This information can be used to optimize irrigation practices, reduce water wastage, and improve

crop yields while minimizing environmental impact. Farmers can achieve more precise and efficient farming practices by utilizing soil moisture sensors, leading to greater profitability and sustainability.

REMOTE SENSING-BASED CROP MONITORING ENHANCES PRECISE SOIL MOISTURE ESTIMATION

Remote sensing-based crop monitoring can be a useful tool for precise soil moisture estimation as it allows for the collection of data on crop growth and development, as well as environmental conditions, over large areas and with high temporal resolution.

Through remote sensing techniques, such as satellite imagery, it is possible to obtain information on the vegetation index (VI) of crops, which is a measure of the vegetation's health and growth. The VI can then be used to estimate the crop's water use and its water stress, which can be linked to soil moisture levels.

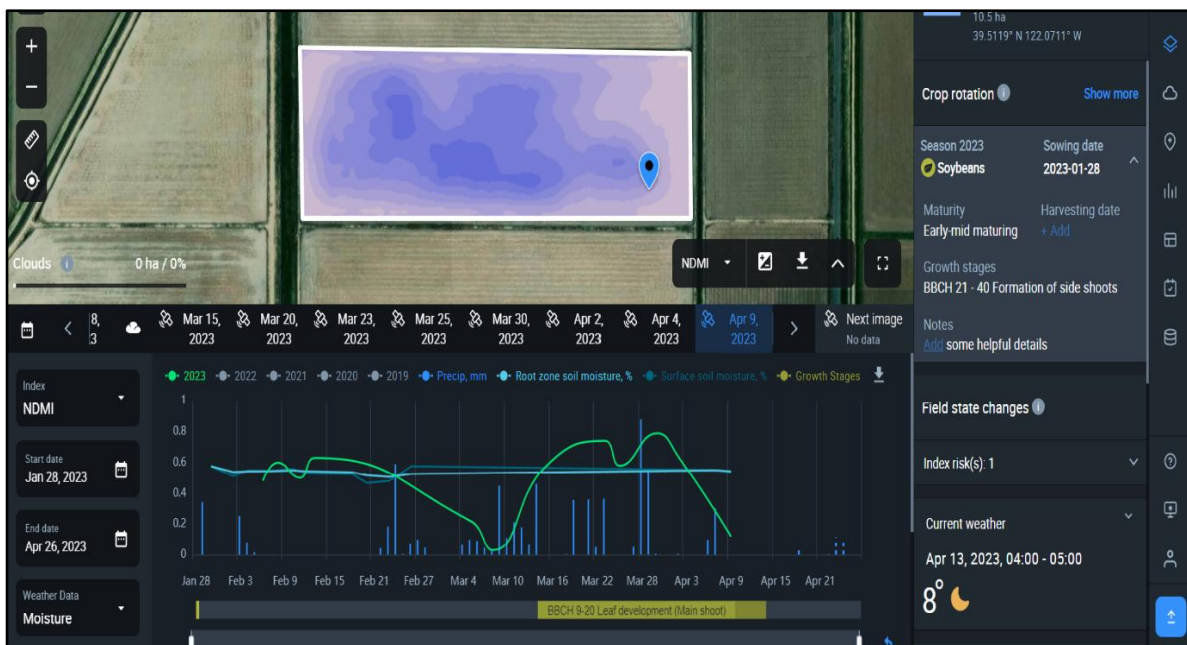


Figure 1. Graphs of seasonal surface and root zone soil moisture in remote sensing-based crop monitoring.

Remote sensing can also provide data on weather and climate conditions that can influence soil moisture levels. This data can include rainfall, temperature, and humidity, which can be used to estimate soil moisture through various models and algorithms. By combining data on crop growth and development with environmental conditions, remote sensing-based crop monitoring can provide precise soil moisture estimation, allowing for more accurate management decisions regarding irrigation, fertilizer application, and other agricultural practices.

Remote sensing-based crop monitoring platforms, such as **CropX**, **FieldView**, **EOS Crop Monitoring**, **AgriTask**, **TerrAvion** can estimate soil moisture levels at two different depths, which are both crucial for decision-making in agriculture. These depths are the soil surface (0-5 cm or 0-2 inches) and the root zone/rhizome (up to 70 cm or 27.5 inches).

One of the platform's main advantages is its ability to mine satellite data for patterns and trends, providing valuable insights into crop yields, precipitation totals, and vegetation indices. Furthermore, this information is compiled into a single graph, giving users a comprehensive view of the data in one place.

Crop Monitoring displays the data in the following sequence: vegetation, root zone moisture, and soil surface moisture, allowing users to easily analyze and understand the relationship between vegetation growth and soil moisture levels (**Figure 1**).

CONCLUSION

In conclusion, integrating soil moisture sensors with satellite imagery has revolutionized precision agriculture. The ability to obtain real-time data on soil moisture levels through sensors and the availability of high-resolution satellite imagery has informed farmers' decision-making. In addition, the use of satellites such as soil moisture and ocean salinity (SMOS), soil moisture active passive (SMAP), and geostationary operational environmental satellite (GOES) has provided a global perspective on soil moisture levels, which has greatly enhanced the management of agricultural practices. The combination of ground-based and satellite-based data has allowed for a comprehensive picture of crop health and growth, enabling farmers to make optimal management decisions for irrigation, fertilization, and other practices. As technology continues to advance, more sophisticated sensors and satellite missions are expected to emerge, further improving the capability to monitor and manage soil moisture levels for increased crop yields.

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