

**FABRICATION OF AN ELECTRONIC SOIL MOISTURE SENSOR FOR
EFFICIENT WATER MANAGEMENT IN CROP PRODUCTION**

BY

KAJUBI PAUL

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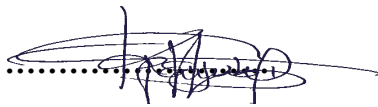
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**A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF PHYSICS AT THE
FACULTY OF SCIENCE AND EDUCATION IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE AWARD OF A BACHELOR'S DEGREE IN
SCIENCE AND EDUCATION AT BUSITEMA UNIVERSITY**

MARCH 2026

DECLARATION

I **Kajubi Paul** hereby declare that that this project is my original work. I strongly affirm that this project has never been submitted to any other institution of higher learning for any academic award.

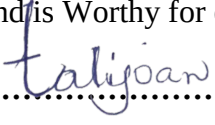
Signature

Date..19.August 2026.....

KAJUBI PAUL

APPROVAL

This project report on fabrication of an electronic soil moisture sensor for efficient water management in crop production by Kajubi Paul has been produced under my supervision and approval and is Worthy for examination.

Signature

date.....*17th August 2026*.....

DR. JOAN TALIBAWO

DEDICATION

I dedicate this book to my beloved father Dr. Augustine Mugabo for the great work he has done for me. It is my pleasure to thank him for the so much efforts and support he has given me to see my success. May the almighty God shower him with his bounties abundantly.

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ABSTRACT

This research presents the development and evaluation of an electronic soil moisture sensor designed to measure soil moisture content in a practical and accurate manner. The sensor utilizes a resistive sensing mechanism, where changes in soil moisture affect the electrical resistance between two probes, resulting in a corresponding voltage output. To ensure accuracy, the sensor was calibrated using a gravimetric method, where soil samples were weighed before and after oven drying to determine the moisture content percentage.

The sensor demonstrated a linear relationship between soil moisture content and voltage output, with a high degree of accuracy and repeatability. The sensor employs a resistive sensing mechanism, where changes in soil moisture alter the electrical resistance between two embedded probes resulting in a corresponding voltage output.

The sensor was constructed using two galvanized nails as the sensing probes, a 10k ohm resistor and a 5v power supply. Testing was conducted using soil samples prepared at five moisture levels that's 0,25,50,75 and 100% moisture content by weight. Results showed that the sensor could clearly distinguish between dry soil and moist soil.

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LIST OF ACRONYMS AND ABBREVIATIONS

BC547	Base-collector
LM7805	Linear monolithic
W1	Initial Weight
W2	Final Weight
LED	Light emitting Diodes
DC	Direct current

CHAPTER ONE: INTRODUCTION

1.0 Introduction.

This research was intended to fabricate an electronic soil moisture sensor. The section here describes the background, problem statement, aim, objectives and the scope and the significance of the study.

1.1 Background.

Agriculture is one of the main sources of economy and food in most countries worldwide. Observing and monitoring the plant's health and maintaining an optimum soil moisture level are required for better agricultural production. Agriculture accounts for over 60% of the world's water consumption, however with typical farming irrigation efficiencies of 40%, over 60% of agricultural water is wasted, contributing to rising poverty and famine levels impacting (Ullah & Zubair, 2024).

Agriculture is one of the main sources of economy and food in most countries worldwide. Observing and monitoring the plant's health and maintaining an optimum soil moisture level are required for better agricultural production. According to a United Nations Food and Agriculture Organization study, food production will increase globally. The production of irrigated food will be increased by 50% by 2050, which shows a further increase in the water demand for agriculture. Water demand is also affected by the greenhouse effect, which shows a climatic change that decreases and disturbs the quantity and equilibrium of water.

The existence of moisture in the soil has a great influence on agricultural land and plants, for better production and normal plant growth, soil moisture is crucial for understanding and controlling soil's physical and biochemical properties, which helps in the plant's normal growth. The accurate monitoring of soil moisture is needed for plant health. Soil moisture sensors are a big deal in farming. They help farmers water their crops using right amounts which saves water and boosts crop yields. These sensors measure how much water is in the soil, which is super useful for making smart decisions about irrigation and water management. Soil moisture also referred to as soil water content, is a crucial geophysical state variable in various fields, including agriculture, hydrology, meteorology, and remote sensing validation. Therefore, accurate measurements of in situ soil moisture are essential to

ensure the improved modelling of geophysical processes, perform and apply them in decision-making for societal benefits (Mane et al., 2024).

1.2 Problem statement.

Plants need a good quality soil to grow healthily, but many farmers in Uganda face challenges related to soil moisture. Some farmers water their crops too much, wasting precious water resources. Others do not water enough, leading to poor harvests. The main problem is that most farmers have no simple, affordable way to know how much water is actually in their soil.

Without moisture sensor, farmers must rely on guesswork methods such as feeling the soil with their hands. These methods are very accurate and can vary from person to person. There is a clear need for a low-cost device that can give farmers reliable information about moisture levels.

1.3 Aim of the study.

To fabricate an electronic soil moisture sensor for precision agriculture applications in Uganda, enabling improved irrigation management and water use efficiency.

1.4 Purpose of the project.

To fabricate and test a low-cost electronic soil moisture sensor suitable for agricultural use by small scale farmers and for educational demonstration.

1.5 Objective of the study.

- (i) To fabricate a low-cost resistive soil moisture using locally available electronic components.
- (ii) To construct a sensor on the bread board and verify its electrical functionality.
- (iii) To measure the output voltage of the sensor across five controlled soil moisture levels.

1.6 Significance of the project.

Smallholder farmers; Provides an affordable tool for irrigation decision-making, potentially reducing water costs and improving crop yields.

Undergraduate education students; Offers a hands-on, low-cost project that integrates electronics, environmental science and agriculture, supporting constructivist learning.

1.7 Scope of the study.

This research project fabricated a soil moisture sensor using transitioned sensing technology for measuring moisture. The study was carried out in the laboratory using standard reference materials and soil samples from Nagongera.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction.

This chapter covers the discussion about soil moisture sensors and types of sensors, structure and principles of working and the usefulness of soil sensors.

2.1 Soil moisture.

Soil moisture is the amount of water held in space between soil particles. This water is essential for plant growth because it carries nutrients from the soil into plant roots. It's a vital factor in farming and environmental monitoring because it helps in plant growth, nutrient movement and ground water recharge.

Soil moisture can be measured directly by drying and weighing soil and can also be measured indirectly by using sensors that detect electrical , thermal and dielectric properties of the soil. Soil moisture sensors measure the volumetric water content indirectly by using some property of the soil, such as electrical resistance, dielectric constant or interaction with neutrons as a proxy for the moisture content (Gumiere, 2021).

The relation between the measured property and soil moisture must be calibrated and may vary depending on environmental factors such as soil type, temperature and electric conductivity. Reflected microwave radiation is affected by the soil moisture and is used for remote sensing in hydrology and agriculture. Portable probe instruments can be used by farmers or gardeners.

Soil moisture is a crucial parameter in agricultural and environmental Systems. Accurate and real time measurement of soil moisture is essential for optimizing irrigation, managing water sources and understanding of climate change impacts. Soil moisture sensors have evolved significantly over the past few decades with a wide range of technologies and these include capacitive, time domain reflectometry resistance and microwave-based sensors.

For practical farming, farmers need faster methods that do not destroy the soil. This is where electronic sensors become useful instead of measuring water directly, these sensors measure some of other property of soil that changes when water is present such as electrical resistance.

2.2 Types of moisture sensors.

There are many types of electronic soil moisture sensors, each working on a different principle. Resistance sensor are the simplest and cheapest type. They work by measuring how easily electricity flows between two metal probes inserted into the soil. Dry soil resists the flow of electricity, so very little current passes between the probes. When water is added, the soil becomes more conductive because water contains dissolved minerals that help electricity move. As moisture increases, resistance decreases, and more current flows. This project used this type of sensor because of its simplicity and low cost.

Capacitive sensors work on a different principle. They measure how well the soil can store an electrical charge, which is called its dielectric constant. Water has a much higher dielectric constant than dry soil or air, so when more water is present, the sensor detects a change. Capacitive sensors are generally more accurate than resistive ones and do not suffer as much from probe corrosion, but they are also more expensive and complex to build.

Frequency domain sensors are even more advanced. They send electromagnetic waves into the soil and measure how the waves change as they travel. The more water present, the slower the waves travel. These sensors are very accurate but are also the most expensive and are usually used for scientific research rather than routine farming.

2.3 Working of a resistive soil moisture sensor.

The resistive sensor built in this project uses a very simple electrical setup called a voltage divider, here is the basic idea. Two metal probes are inserted into the soil. One probe is connected to a 5V power supply. The other probe is connected to one end of a fixed resistor, and the other end of that resistor is connected to ground 0V. A voltmeter measures the voltage at the point between the second probe and the resistor. When the soil is completely dry, it acts like an insulator and does not allow electricity to flow between the probes. In this case, no current flows through the circuit and the voltmeter reads 0V.

When the soil is wet, water allows electricity to flow between the probes. The wet soil acts like a resistor of relatively low value. Current now flows from the 5V supply, through the soil, through the fixed resistor, and to ground. The voltmeter reads some voltage between 0V and 5V, depending on how wet the soil is.

The relationship is straightforward, wetter soil means lower resistance, which means higher voltage at the measurement point. By measuring this voltage, you can tell whether the soil is dry or wet.

2.4 Measurement for soil moisture.

Monitoring of volumetric soil moisture content in the field calls for the fast and accurate method, which allows repeated measurements through time. There are currently two approaches for measuring the spatial distribution and temporal variation of soil moisture content include point measurements and remote sensing.

Point measurement of soil moisture profiles, it has long been recognised that reliable, robust and automated methods for the measurement of soil moisture content can be extremely useful, if not essential, in hydrologic, environmental and agricultural applications. Over the last 70 years, this recognition has fostered the investment of a considerable amount of ingenuity in developing such methods. (Vereecken et al., 2008)

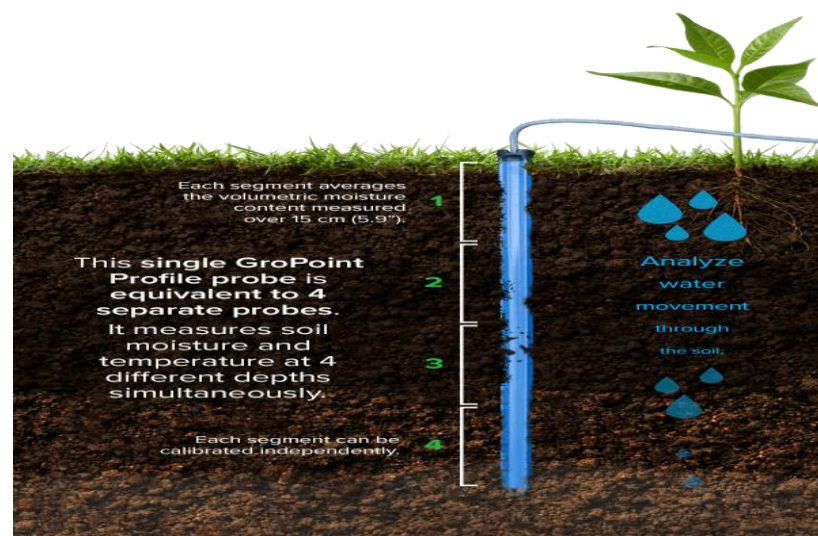


Figure 1: Illustration of measurement soil moisture profile (Pennock, 2004).

Limitations of point profile measurement.

It only measure moisture at a specific point, it cannot measure the overall moisture content of the sample. Point measurement profile is very sensitive to environmental conditions such as temperature, pressure and humidity.

Thermogravimetric method.

The standard method of measuring the volumetric moisture content of a soil sample is the thermogravimetric method which consists of oven drying at 105°C and relating the change in mass to the volume of the sample.

$$\theta = \frac{W_W}{w_d} \frac{P_B}{P_W} \dots\dots\dots \text{Equation 1}$$

where θ is the volumetric soil moisture content fraction, W_W is the weight of water contained in the voids of the moist soil, w_d is the weight of dry soil, P_B is the soil bulk density and P_W is the density of water.

The advantages of this method are that it is inexpensive and soil moisture is easily calculated. However, it is time consuming, difficult to obtain representative samples and destructive. Hence, this method cannot be used for repetitive measurements at exactly the same location.



Figure 2: Illustration of Thermogravimetric method of measuring moisture(P.I.Kalandrov et al., 2021)

Limitations of Thermogravimetric method.

It can't distinguish water from other volatiles. It's not very effective for very low moisture percentage usually limited below 0.1% moisture level.

Neutron scattering Method.

The neutron scattering method is an indirect way of determining soil moisture content in this method, neutrons with high energy are emitted by a radioactive source into the soil and are slowed down by elastic collisions with nuclei of atoms. The energy loss is much greater for neutrons colliding with atoms of low atomic weight than for collisions with heavier atoms. As a result, hydrogen can slow fast neutrons much more effectively than any other element present in the soil, thus giving a relationship with soil moisture. The number of slow neutrons returning to the detector per unit time are counted, and the soil moisture content estimated from a previously determined calibration curve of counts versus volumetric moisture content (Visvalingam & Tandy, 1972).

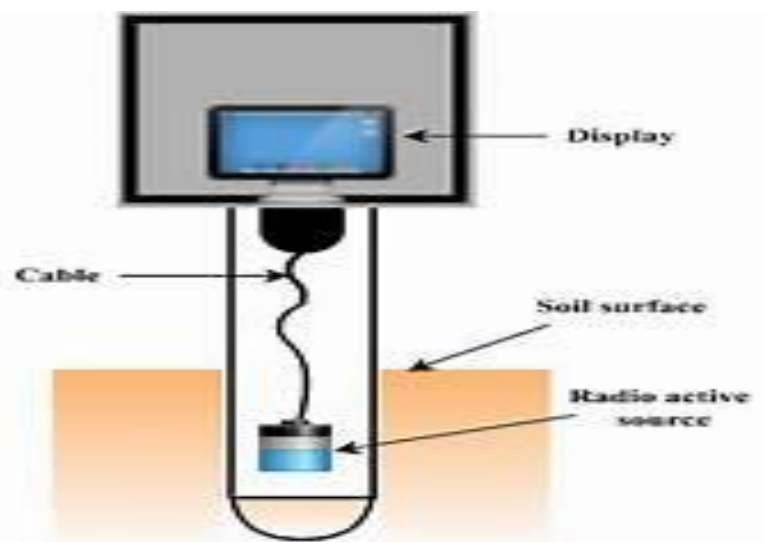


Figure 3: Illustration of Neutron scattering method (Mane et al., 2024).

Limitations of Neutron scattering method.

Long time count is needed to beat statistical noise at low moisture Neutron count rate depends on how tightly soil particles are packed.

Soil electrical conductivity is a function of the volumetric soil moisture content, electrical conductivity and the bulk conductivity. Many techniques for measuring soil electrical conductivity have been proposed. However, all electrical conductance measurements, whether direct or indirect, suffer from similar difficulties, being that it is not water that conducts electricity but rather the ions dissolved in the water.

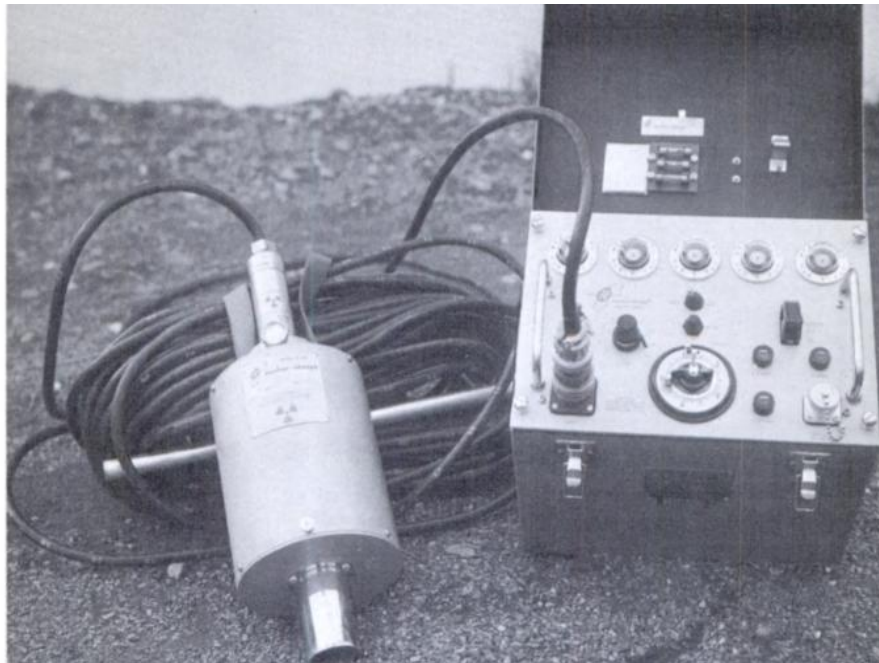


Figure 4: Illustration soil electrical conductivity measurement (Mane et al., 2024).

Electrical conductivity probes consist of both two and four electrode probe types. A four-electrode probe is used to measure soil electrical conductivity in preference to a two-electrode probe, as this eliminates the problem of contact resistance, by measuring current and voltage between different pairs of electrodes. The principal advantages of the electrical conductivity probe for measuring soil moisture content are its ease of use, simplicity, low cost of equipment and the relatively large volume of soil sampled.

Soil dielectric method, the dielectric constant is a measure of how polarisable a material is when subjected to an electric field. This material property is usually measured relative to that of free space and is referred to as the relative dielectric constant. Soil consists of air, soil particles and water. Therefore, the relative dielectric constant of soil is a composite of its components. Soil moisture content can be determined from measurements of the soil

dielectric constant as a result of the large difference between the relative dielectric properties of liquid water and dry soil. Since the dielectric constant is a volume property, the volumetric fraction of each component is involved. Thus, as the soil moisture content increases, the relative dielectric constant can increase (wessel-Bothe,wechemuller 2022).

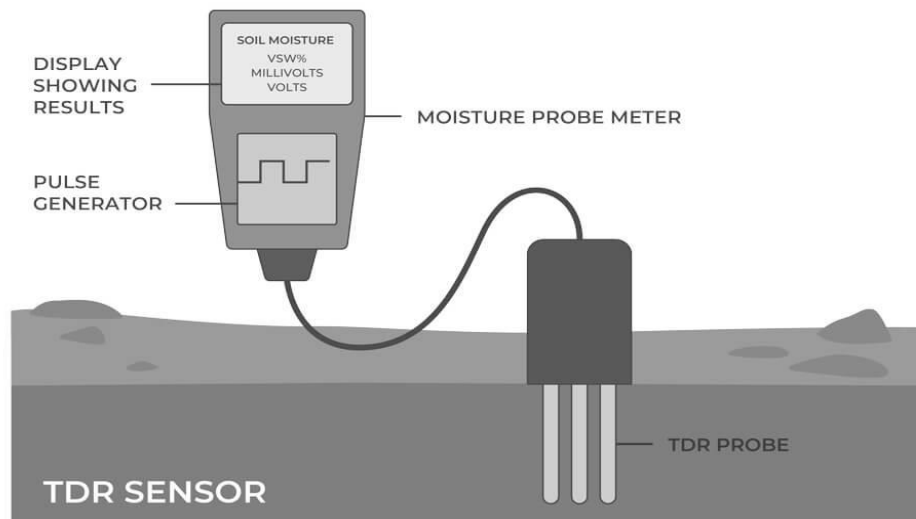


Figure 5: An illustration of dielectric moisture sensor (Mane et al., 2024).

2.5 Previous studies on soil moisture sensors.

(Brennan, 2023) Compared DIY resistive sensors with commercial capacitive sensors in maize fields. They found that DIY sensors had a correlation of $R^2 = 0.89$ with commercial sensors sufficient for relative moisture monitoring. However, they noted probe corrosion after three months of continuous use.

(Pennock, 2004) Investigated corrosion mitigation strategies, including using stainless steel probes and alternating current excitation instead of direct current. They found that stainless steel probes lasted up to six months without significant signal drift.

2.6 Gap in Literature.

While many studies have focused on sensor accuracy, few have provided step-by-step fabrication guides suitable for undergraduate education students with limited electronics background. This study fills that gap by documenting a replicable, low-cost fabrication process. The integration of sensor fabrication into agricultural education curricula remains under explored.

3.0 Introduction.

This study involves the fabrication of an electronic soil moisture sensor using basic electronic components. The sensor measures the moisture content of the soil by detecting changes in the electrical resistance caused by presence of water.

3.1 Research Design.

This study used an experimental approach .A prototype soil moisture sensor was built and tested under controlled laboratory conditions . Soil samples were prepared at different moisture levels 0,25,50,75 and 100% moisture by weight .Each moisture level was tested two times and the average output voltage was recorded.

3.2 Materials.

The sensor was fabricated using several electronic components including a BC547 transistor ,resistors, LEDs, capacitors, a buzzer, sensing probes and a 5V power supply. The BC457 transistor was used to amplify electrical signals from the sensing probes, while resistors controlled the current within the circuit. Galvanized nails were used as sensing probes. Soil samples collected from Nagongera were used during testing the sensor performance.

3.3 Sensor Fabrication.

Two galvanized nails were cleaned and dried thoroughly from any dirt, oil or rust was removed to ensure good electrical contact with the soil. The circuit was assembled on a breadboard as follows. One nail on Probe A was connected to the positive terminal of the 5V power supply.

The second nail Probe B was connected to one end of the 10 k Ω resistor. The other end of the 10 k Ω resistor was connected to the ground terminal. The multimeter's positive lead was connected to the junction between Probe B and the resistor. The multimeter's negative lead was connected to the ground. Test the circuit operation, before inserting the probes into soil, the circuit was tested with no connection between the probes, the multimeter read approximately 0V. When the two probes were touched together, the multimeter read 5V. This confirmed that the circuit was working correctly. The circuit was connected as in

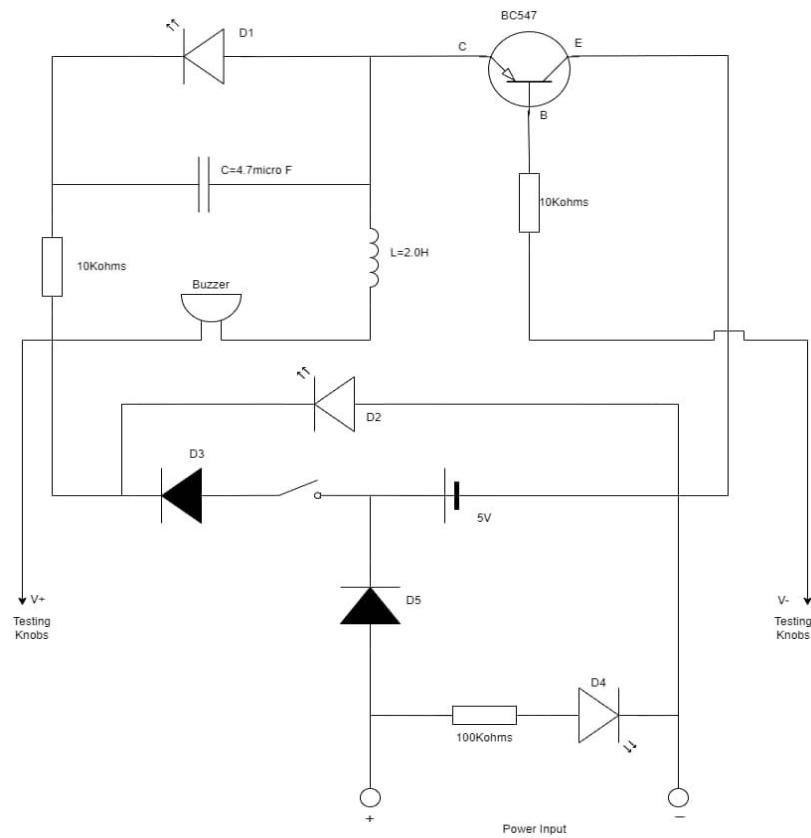


Figure 6: circuit diagram of the fabricated sensor



Figure7: Illustration of sensor components on the bread board.



Figure 8; weighing and drying the soil sample.

3.4 Soil sample preparation.

Obtain and dry the soil, 500g of soil was collected from Nagongera campus area. The soil was placed in an Aluminum foil and dried in an oven at 100 degrees Celsius for 20hrs to remove all the moisture. This created the 0% moisture baseline sample.

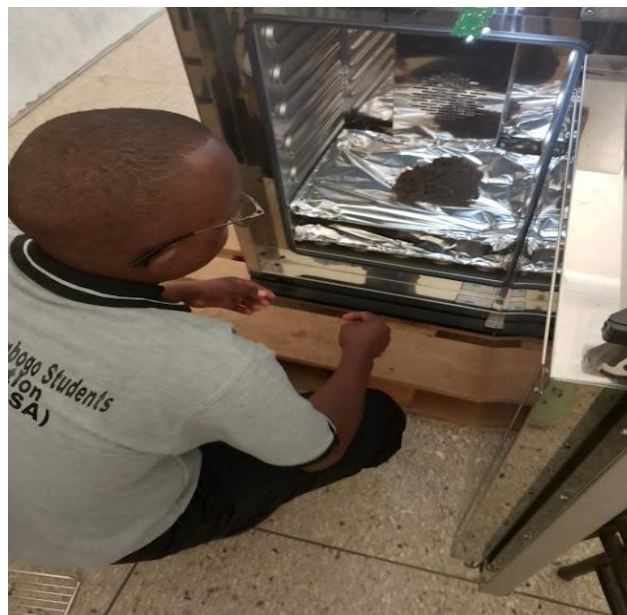


Figure 9: Soil sample placed in an aluminum foil.

Cool the dry sample. After removal from the oven, the dry soil was allowed to cool. Prepare different moisture levels. 100g portions of dry soil were measured out of each moisture level. Distilled water was added according to the following amounts.

Table 1: Shows moisture content and water needed per 100g of dry soil sample

Moisture level (%)	Water needed per 100g dry soil(mL)
0	0
25	25
50	50
75	75
100	100

The water was added slowly and mixed thoroughly to ensure even distribution throughout the soil .

3.5 Data collection and procedure.

The prepared soil sample was placed in a clean and dry container. The two probe nails were inserted into the soil spaced approximately 5cm apart and pushed to a depth of about 6cm. The power supply was turned on. After 10 seconds for the reading to stabilize, the output voltage was recorded from the multimeter. The probes were removed, cleaned and dried.

The entire procedure was repeated three times for each moisture level. The average voltage for each moisture level was calculated.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0 Introduction.

This chapter explores the process through which the measurements were conducted and the analysis of results obtained.

4.1 Experimental Results.

Table 2 shows the average output voltage for each moisture level. As the moisture level increases V_{out} increases indicating a decrease in resistance.

Table 2: Output voltage at different moisture levels

Moisture (%)	V1(V)	V2(V)	$V_{out} = (v1+v2)/2(V)$
0	0.00	0.00	0.00
25	3.38	3.38	3.38
50	3.45	3.45	3.45
75	3.46	3.46	3.46
100	3.46	3.46	3.46

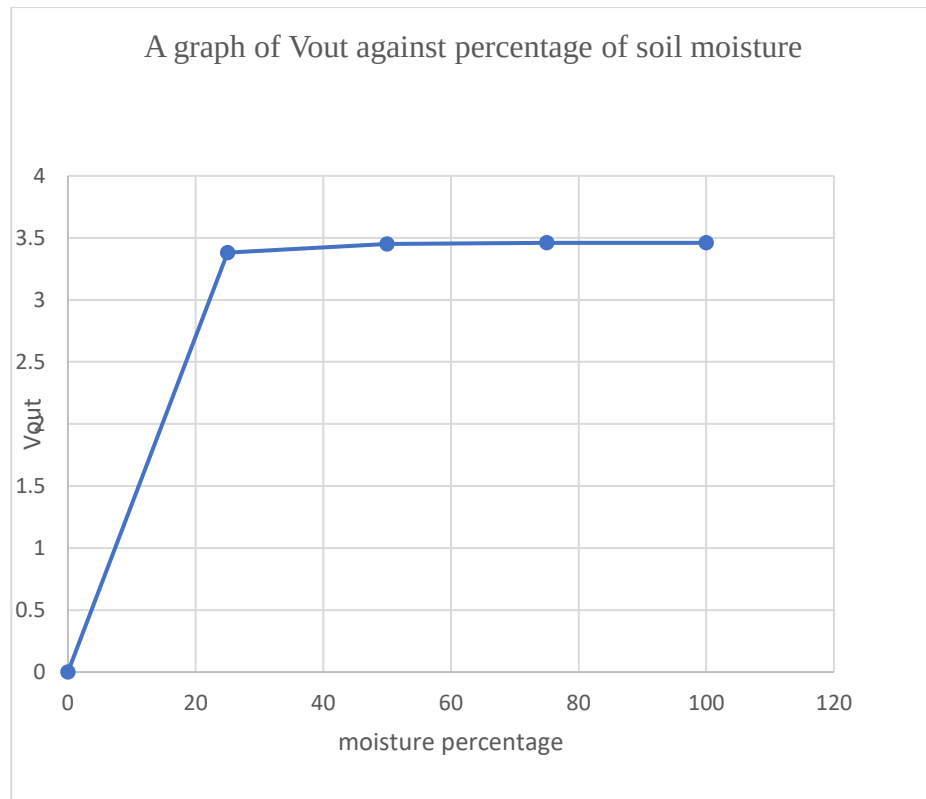


Figure 10; graph of output voltage versus soil moisture content.

This study set out to fabricate a low-cost electronic soil moisture sensor using basic components and to evaluate its performance across five soil moisture levels 0%, 25%, 50%, 75%, and 100%. The sensor was successfully constructed. The experimental results showed that the sensor could clearly distinguish between dry soil and any moist soil above 25% moisture, with output voltage jumping from 0 V to 3.38 V. However, beyond 25% moisture, the voltage increased only marginally, reaching a maximum of 3.46 V at 100% moisture. This means the sensor acted as a reliable moisture presence detector rather than a precise moisture level meter.

When compared with the expected linear relationship reported in some previous studies (Brennan, 2023), my results differed significantly. The most likely explanations are circuit saturation due to my soil type, combined with possible soil salinity. Despite this deviation from theoretical expectations, the sensor remains useful for practical agricultural applications where farmers only need to know whether soil is dry or wet for example, to trigger irrigation when voltage drops below a threshold value. Probe corrosion; Galvanized

nails will corrode within weeks (Sulaiman 2009). For long-term use, stainless steel probes are recommended.

However, the sensor was tested for only a few hours therefore, the study did not investigate how probe corrosion might affect the readings over weeks or months .

Furthermore, only one soil sample from Nagongera was used as a result, the sensor might behave differently in sandy, clay soils or soils obtained from other regions. The tests were conducted in a controlled laboratory environment, whereas field conditions involve temperature fluctuations, varying probe insertion depths, and unevenly mixed soil. Lastly, the electrical conductivity of the soil changes with temperature however, this factor was not measured during the study.

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CHAPTER FIVE: CONCLUSION, RECOMMENDATION, AND FUTURE WORK

5.0 Introduction.

This chapter presents the of the, conclusions, recommendations, and future work basing on the performance fabricated soil moisture sensor.

5.1 Conclusions.

A functional resistive soil moisture sensor was built using two nails, one resistor and a 5V power supply. The sensor worked based on basic electrical principles.

The sensor showed a threshold response rather than a linear response. It was excellent for detecting the transition from dry to moist but poor for measuring moisture levels above 25%.

The sensor was suitable for practical irrigation management if used with a simple threshold voltage when the output voltage falls below a set value.

The fabrication process was simple enough to be used as a teaching activity for secondary school or university students learning about electronics and agriculture.

5.3 Recommendations.

Setting a simple threshold voltage to trigger irrigation decisions, this approach eliminates the need for complex data logging or user interfaces. When the sensor output voltage exceeds the threshold, the soil is sufficiently dry to require irrigation when below the threshold, moisture levels are adequate. Such a binary decision framework is easily implemented with low cost comparator circuits making the sensor accessible to farmers with limited technical resources.

The use of stainless-steel probes as the electrode material instead of galvanized nails are prone to rapid corrosion when exposed to moist soil, leading to increased contact resistance, signal drift and eventual sensor failure within a single cropping season. Stainless steel probes offer superior corrosion resistance, longer operational lifespan, and

more stable voltage readings over time, thereby improving the reliability of the sensor for extended field use.

REFERENCES.

- Brennan, P. V. (2023). An Antenna Solution for Glacial Environmental Sensor Networks. 11(May), 61813–61828.
- Gumiere, S. J. (2021). Efficient Irrigation of Maize Through Soil Moisture Monitoring and Modeling.
- Mane, S., Das, N., Singh, G., Cosh, M., & Dong, Y. (2024). Advancements in dielectric soilmoisture sensor Calibration : A comprehensive review of methods and techniques. 218(March), 1–9.
- Pennock, D. J. (2004). Designing field studies in soil science. 8(May 2003), 1–10.
- S, Sulaiman. (2009). Design , Fabrication and Testing of Fringing Electric Field Soil Moisture Sensor for Wireless Precision Agriculture Applications I ntroduction T heory D evice design. 1–7. <https://doi.org/10.1109/ICIMT.2009.54>
- Ullah, A., & Zubair, M. (2024). Sensors and Actuators A : Physical Highly sensitive screen-printed soil moisture sensor array as green solutions for sustainable precision agriculture. 371(June), 1–10.
- P.I. Kalandrov, P. I., Mukhina, I. M., & Sokolov, A. V. (2021). Thermogravimetric method for soil moisture determination. *Soil Science Annual*, 72(2), 1-8.
- Vereecken, H., Huisman, J. A., Bogaen, H., Vanderborght, J., Vrugt, J. A., & Hopmans, J. W. (2008). On the value of soil moisture measurements in vadose zone hydrology : A review. 44, 1–21.
- Wessel-Bothe, S., & Weihermüller, L. (2020). *Field measurement methods in soil science*. Bontrager Science Publishers.
- Rhoades, J. D., Chanduvi, F., & Lesch, S. (1999). *Soil salinity assessment: Methods and interpretation of electrical conductivity measurements*. FAO Irrigation and Drainage Paper 57. Food and Agriculture Organization of the United Nations
- Visvalingam, M., & Tandy, J. D. (1972). The neutron scattering method for measuring soil moisture. *Journal of Hydrology*, 16(2), 4-10