PERFORMANCE EVALUATION OF GYPSUM BLOCK, TENSIOMETER AND MOISTURE SENSOR FOR SOIL MOISTURE CONTENT DETERMINATION

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ABSTRACT
Measurement of soil moisture has become very critical in irrigation water management studies especially in Africa. This research investigated the response of Tensiometer, Gypsum blocks and Sensor to changes in soil moisture and their appropriateness for irrigation scheduling on farms. Gypsum block was fabricated using a mould containing 15 cubicles of size (5x 4 x 2.5) cm in a wooden box frame, tensiometer irrometer – model SR was used to measure soil moisture tension. Arduino 1.8.7 board connected to two probes was used to build the soil moisture sensor. The three soil measuring devices were installed, calibrated and validated using the gravimetric method as the standard. The response of each moisture testing device was carried out using a t-test at a 5% significance level. The results revealed that the value of bulk density, field capacity, PH and electrical conductivity of the soil obtained were 1.463g/cm3, 20%, 5.50 and 0.034dS/m, respectively. The soil was sandy loam with percentage contents with sand, silt and clay in the soil were 69.8%, 19.4% and 10.8%, respectively.The mean difference between the Gravimetric method, compared to gypsum, Tensiometer and Sensor, was 6.30, 3.95 and 3.02, respectively. It could be concluded that the Sensor used with the Adruino board measures moisture content more accurately than Gypsum and Tensiometer.

KEYWORDS: Adruino board, Calibration, Gravimetric, Gypsum, Sensor, Soil moisture, Tensiometer

1. INTRODUCTION
Water scarcity seems to affect every continent of the world, up to 1.2 billion people dwell in areas of the physical scarcity of water (Guarino, 2017). According to Oyedepo (2012), the future of this very important resource may recede soon. The world at present is facing a shortage of water which is hampering the development of agriculture; judicious use of water is therefore of paramount importance. Good agricultural practices include both the knowledge of water used by crops and techniques that permit efficient irrigation management; judicious application of irrigation water involves the application of the required amount of water to crop water requirement and improving crop water use efficiency, for improved soil water management (Khan *et al.,* 2013). Soil moisture measurement is one of the best and simplest ways to get feedback to help make improved water management decisions (Ajayi *et al*., 2019).

Soil water monitoring is a tool that can help to make the best use of irrigation water. Measuring soil moisture at regular intervals enables evaluation of irrigation depth, crop water use efficiency and fine-tuning of irrigation scheduling. This not only leads to efficient water use, but it also improves the health of the crop being irrigated, land managers making decisions concerning livestock grazing patterns, crop planting, soil stability for agricultural machinery operations, others are: optimizing plant health, maximizing productivity, minimize input costs, reduces leaching and drainage among others (Bittelli, 2010; Ajayi *et al*., 2019).

Several methods and devices have evolved over the years to estimate soil moisture content; broadly classified by Bharathi *et al.* (2018) into two: those that measure and indicate how much water is present in the soil (quantitative), and those that measure and express how tight the water is held with the soil pores (qualitative). Some of the quantitative methods and devices include the gravimetric method, neutron scatters method using the Neutron probe, Theta probe, Time Domain Reflectometer (TDR) or Frequency Domain Reflectometer (FDR) and sensors. The qualitative methods and devices include the use of tensiometers and electrical resistance blocks commonly referred to as a Gypsum Block among others (Lien *et al.,* 2009).

Several tests would be conducted during the development and the calibration of a sensor to make it functional, during the development of each sensor or some laboratory calibration is done by end-users, due to the differences in design and functionality, each sensor may perform differently when used in real measurement operations in a specific region. The reliability of those tests is consequently limited by specific laboratory configurations and soil types (Micheal and Lascano, 2003). Given the wide range of sensors and soil types covered in the above-mentioned inter-comparisons, it is safe to conclude that soil moisture sensors performed differently with soil types, different soil depths and different parts of a field. Climate and soil physical conditions may be additional factors that directly or indirectly influence the sensitivity of sensors. For example, the soil temperature is closely related to the conductivity and movement of soil water which could significantly influence soil water measurements (Hanson and Peters, 2000; Keyhani, 2001).

Numerous methods and devices for measuring soil moisture are available. However, very little is known about their performance in the study area. The design and functionality of most moisture devices perform differently when used in real measurement operations, their performance varies under different soil and cropping systems, these discrepancies are only slowly being tested; only a few studies described comparisons of some of these methods. Thus, the most suitable methods to monitor soil moisture for accurate irrigation scheduling are yet to be determined (Huang *et al.,* 2004; Zambrano *et al.,* 2019).

There is the tendency to over or under-irrigate due to the absence of information about the soil moisture status down the soil profile. The result of over-irrigation is poor utilization water production problems associated with excessively wet soil such as waterlogging, leading to recharge of underlying aquifers, leaching of nutrients, and increased incidence of plant disease and reduced daily water use (Thomson *et al.,* 2005).

A soil-specific calibration of each moisture device under prevailing climatic conditions is a necessary prerequisite for a device to achieve its highest degree of absolute accuracy in soil water content measurements. However, the calibration conditions may not always be available, so an inter-comparison of different responses of soil moisture testing devices with calibration would be very useful for the successful applications of sensors (Thomson *et al.,* 2005).

The ability to accurately measure soil water content is an integral mechanism in the process of developing an irrigation scheduling program that allows a better understanding of plant and soil water relations, it grants farmers a better working knowledge of what depth of water to apply to crops, its relation to plant water use and soil moisture status. A soil-specific calibration of each moisture device is a necessary prerequisite for a moisture device to achieve absolute accuracy in soil water content measurements in a specific location, where it is intended to be used. However, since it is not always available, users are encouraged to calibrate and possibly validate moisture devices before they should be used. This study will help researchers to uncover better methods for in situ testing of moisture content measurement among options considered in this research; hence, the objective of this study were to develop and carry out the performance evaluation gypsum block, soil moisture sensor and irrometer.

2. MATERIALS AND METHODS

2.1 Study Area

The field experiment was conducted during the 2018/2019 academic session at the Federal College of Forestry Jos, Plateau State- Nigeria. It's in a region of the middle belt of Nigeria and falls between latitude 7^{o}-11^{o}North and longitude 7^{o} – 25^{o} East with an altitude of 1,200 mm above sea level. The topography of the area lies south of the guinea savannah of Nigeria, with a mean annual rainfall of 1460 mm and a temperature between 10°C – 32°C. Jos has an area of about 291 km^2 and a population of about 492,300 (Oiganji *et al.*, 2016).

2.2 Soil Sampling and Analysis

Soil samples were collected using a soil core at varying depths of between 2 and 30 cm at ten different locations and placed in airtight Aluminum containers and conveyed to the Federal College of Forestry soil and chemistry laboratory to ascertain soil textural class. The soil electrical conductivity determined based on the procedure proposed by Radi *et al.* (2018) and Shangning *et al.,* (2009), while the field capacity was ascertained with respect to the procedures outlined by Vories and Sudduth (2021).

2.3 Fabrications and Specification of Soil Moisture Sensors.

Fabrication of gypsum block was done using a mould containing 15 cubicles of size (5x 4 x 2.5) cm in a wooden box type frame; it was constructed using a plyboard of 10 mm thickness. Stainless screen electrode of 10 x 5x 2 mm size was connected to 0.1 cm diameter thick single care with PVC coated wire. The electrodes were spaced 1cm apart and embedded in the block. Two parts of $CaSO_4$ powder were properly mixed with one part of water forming a slurry or paste and was carefully poured into the moulds, while this is done, it was ensured that the positions of the electrodes did not shift. The blocks were then allowed to dry under the sun for 48 hours, after which the moulds were removed as reported by Ajayi *et al.* (2016).

The blocks were left in water for 24 hours and then allowed to air dry at room temperature. While they were drying at room temperature, the changes in resistance were monitored twice a day for three days. This was done to test if the blocks were working, particularly to ascertain that the electrical cables were not disconnected from the electrode while casting the blocks.

The measurement of soil moisture was based on the electrical resistivity of the gypsum block which decreases as the water content increases and vice versa. The amount of electricity that was passing through the porous block depended partly on the material and partly on the water content as described by Nagy *et al.* (2013). A digital multimeter (DMM) of the model fluke of 87V, which has a numeric display interface, was connected to the electrical cables of the gypsum blocks to measure the value of soil moisture in resistance (ohms). Also, the tensiometer (irrometer –model SR) was used to measure soil moisture tension throughout the research.

2.4 Assembly the embedded system

Arduino 1.8.7 board, which is a programmable circuit's board with an open-source platform, used for building electronics was connected to soil moisture sensors to measure soil moisture content. The Arduino program was uploaded with integrated development environment software (IDE) version 1.8.7, that runs on the computer, which was used to write and upload computer code to the Arduino physical board. The soil moisture sensor consists of two components i.e. a two-legged lead that goes into the soil vertically and had two header input pins that is connected to an amplifier/ A-D circuit of four out pins for Analog, Digital, which supplied voltage of 3.3-5V signals, which in turn connects to the Arduino which was used to get soil moisture values to the laptop.

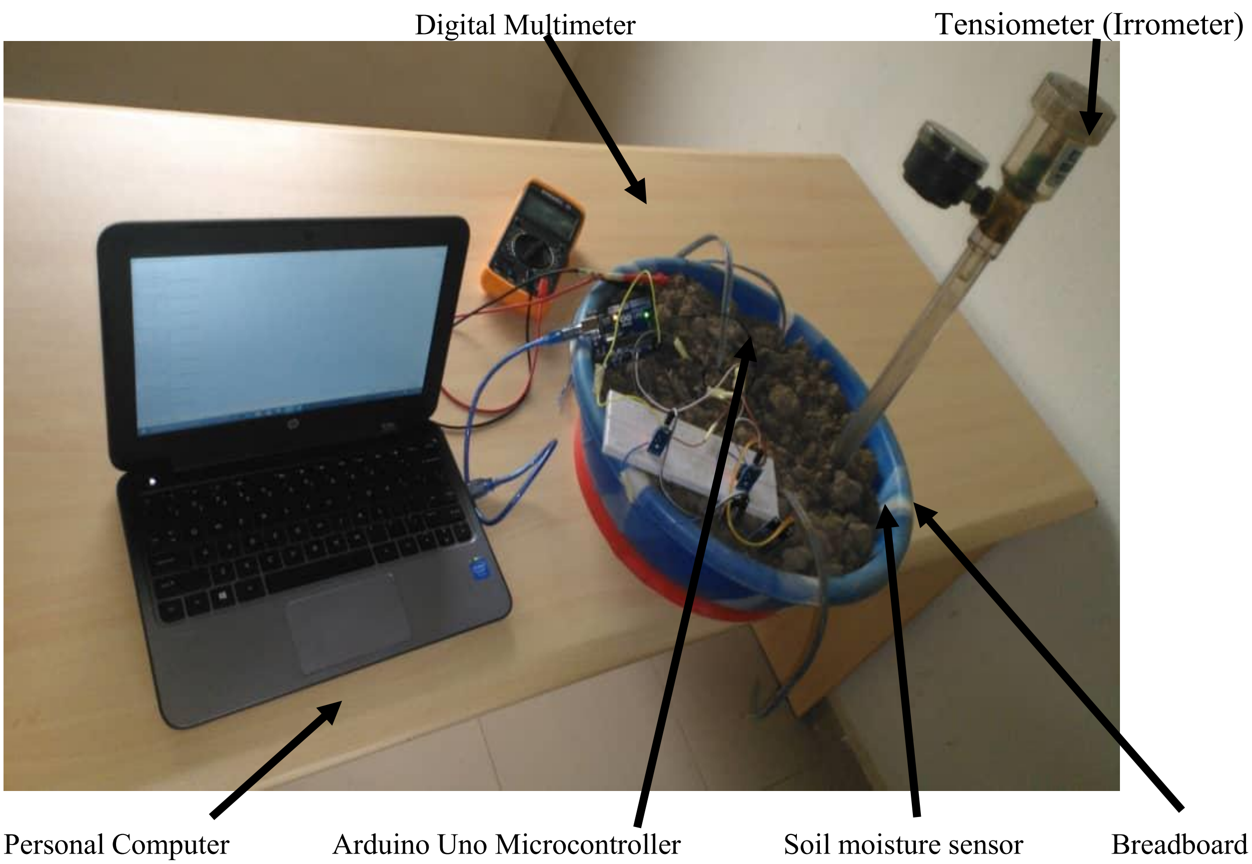

Figure 1: Automated soil moisture sensor/ Laboratory set-up of soil moisture measuring equipment.

2.5 Calibration of Soil Moisture Devices

The calibration for the soil moisture sensor was based on the procedure proposed by Radi *et al.* (2018) and Shangning *et al.,* (2009). After each sensor reading, soil samples were collected and determined using gravimetric method, the calibration of the gypsum block and tensiometer was done by measuring soil moisture with each device independently; soil samples were taken from the experimental area to the laboratory and were oven-dried at 105°C for 24 hours to determine the calibration curve for each device used (Ajayi *et al*., 2019). The calibration curve for each device was used to ascertain their response to moisture content using the gravimetric method as a reference method.

2.6 Validation of Soil Moisture Devices

The validation the calibrated instruments were carried out based on the procedures outlined by Justice *et al.* (2000). Soil samples were collected randomly from the field to measure soil moisture content. The calibrated instruments were used to determine the moisture content of the soil samples and the samples were oven-dried to determine the percentage moisture content of these samples(Ajayi *et al*., 2019)..

2.7 Statistical Analysis

The data obtained were analyzed using Statistical Package for Social Science (SPSS) software version 10, to ascertain the response of each moisture testing device by employing student independent paired t-test at a 5% significance level.

3. RESULTS AND DISCUSSION

3.1 Soil Analysis

Soil sample was analyzed at the Federal College of Forestry Soil and Chemistry laboratory to ascertain soil textural class. The value of bulk density, field capacity, pH and electrical conductivity of the soil obtained were 1.463 g/cm^3, 20 %, 5.50 and 0.034 dS/m respectively. The sandy, silt and clay values were 69.8, 19.4 and 10.8%, respectively, indicating that the soil was sandy loam.

3.2 Calibration of soil moisture device

The reading of the soil moisture devices and oven-dry moisture contents of soil samples were calibrated, the mean and standard error of the pooled data were presented in Fig 2. The oven-dry moisture content was plotted against the readings obtained using the soil moisture devices, a regression coefficient (R^2) of 0.67, 0.63 and 0.73 were obtained for Sensors, Gypsum and Tensiometer, respectively. The regression coefficient (R^2) was used to evaluate the relationship between the oven-dry moisture content and the other instruments soil moisture content, which was an acceptable range as outlined by Evett *et al.* (2006).

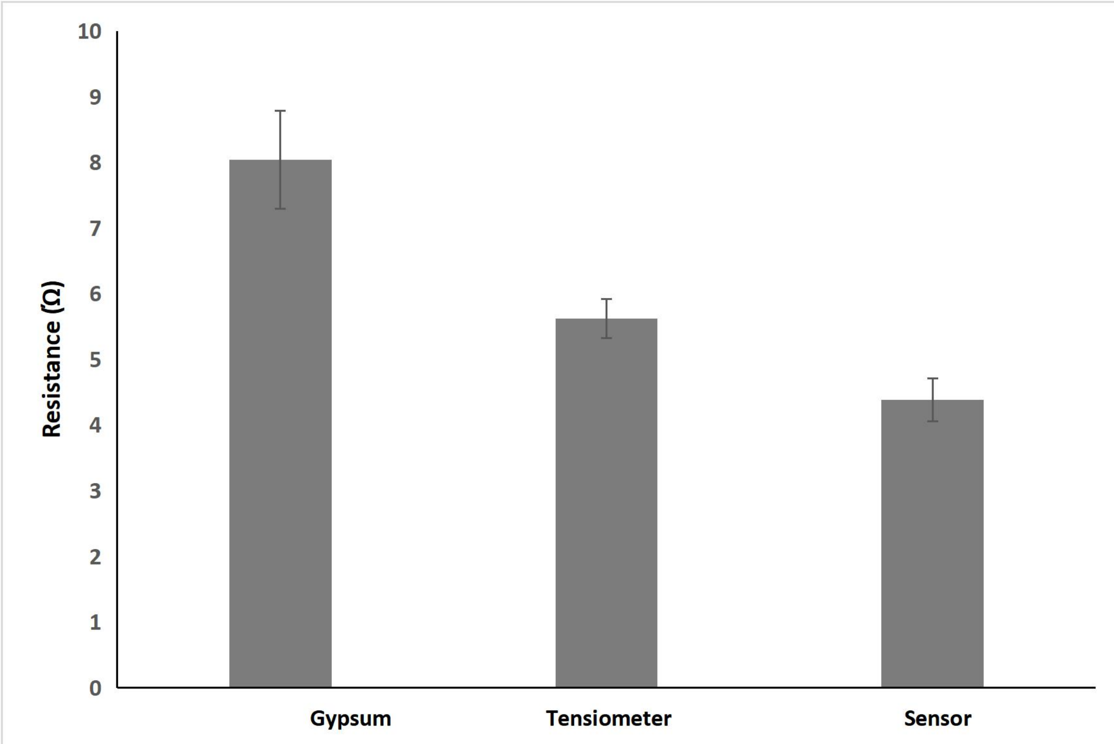

Figure 2: Mean and standard error of the Pooled data for the three moisture testing devices

3.3 The calibration curve of gypsum block

The calibration equation for the gypsum block was $5.268GB^{-079}$. The Correlation coefficient between gypsum block reading and soil moisture content was positive because gypsum block reading increased with decreasing soil moisture content. The soil moisture potential curve for the gypsum block device showed that the maximum water productivity can be maintained by providing soil moisture up to field capacity level; at this point, tension becomes zero. This is at par with what Intrigliol *et al*., (2002) reported, that gypsum block can be operated in a drier range domain on the field, however, Ajayi *et al*. (2016) recorded R^2 0.93 as against 0.63 reported herein using different block sizes.

3.4 The calibration curve of the sensor

The calibration equation for the sensor was at $205.03MC^{0.3989}$. The device demonstrated that measurement of soil moisture based on the electrical resistivity of the block decreases as the water content increases and vice versa. The sensors provided up to 67% accuracy in estimating the value of the soil moisture content as against 96% accuracy on the developed sensor reported by Ogbu *et al.* (2016). Similarly, Groves and Rose (2004) obtained an R^2 value of 0.93 for laboratory calibration of the sensors in clay soil. The R^2 values obtained by these researchers were higher than the values obtained in this study. This may be due to the controlled environment the laboratory provided in their study compared with field calibration.

3.5 The calibration Curve for Tensiometer

The calibration equation for the tensiometer was $32.469T^{1.382}$, Correlation coefficients of tensiometer and moisture contents were positive because tensiometer reading increased as soil moisture content decreased. This implies that the relationship between the variables of the tensiometer and the calibrator are inversely related.

The tensiometer has a higher R^2 value than the gypsum block, several reasons could be responsible for the underperformance of both tensiometer and gypsum in the test, one of them is that resistance type had a calibration drift issue which is related to the configuration of the device. According to Lieb *et al.* (2003) the sensors were more temperature-sensitive and also were easily influenced by other factors beyond water content changes such as fertilizer scheme even with gypsum buffering. Furthermore, the soil contact and the level of soil salinity could affect the performance of the device.

3.6 Validation of soil moisture measuring instrument

The output devices, using their default settings were compared with the volumetric water content from the gravimetric analysis. Table 1 showed the mean difference between each of the devices. The mean difference between the Gravimetric method, compared to gypsum, Tensiometer and Sensor, were 6.30, 3.95 and 3.02 respectively, which indicates that sensor reading is the closest to the gravimetric reading.

Table 1: Validation of Gypsum, Tensiometer and Sensor Reading

Parameters	Mean	SD	SEM
Gypsum	7.70a	4.53	0.70
Gravimetric	1.40b	0.87	0.13
Tensiometer	5.35a	1.90	0.29
Gravimetric	1.40b	0.87	0.13
Sensor	4.42a	1.97	0.30
Gravimetric	1.40b	0.87	0.13

SD = Standard deviation, SEM = Standard mean error, different alphabet shows that is statically significant.

Table 1 shows that sensor is very reliable method for determining soil moisture over the range used in this study as this also support the evidence of Leib *et al.,* (2003) who reported that Sensors was found to perform better than Tensiometer and Gypsum method in previous research and this may be due to poor hydraulic contact between the porous cup and the loamy sand correlation coefficient between Tensiometer. This finding is similar to the research finding by Hanson and Peters (2000) who found that sensors were generally more accurate than other methods in all kinds of soils in their tests. The results achieved showed that the sensor is more reliable, sensitive, precise and easy to use compared to the use of gypsum block and Tensiometer for measuring soil moisture content.

CONCLUSION

The performance of the Gypsum block, Tensiometer, and soil moisture Sensors for their sensitivity to soil moisture were evaluated. It can be concluded that the sensor is more reliable, sensitive, precise and easy to use compared to others employed in this research.

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