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Calibration of Five-pin soil Sensor for Soil Monitoring of Greenhouses in Rwanda

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Abstract. As the population of the world increases, more food must be produced. The proper management of soil properties is essential for increasing agricultural productivity. This study makes use of the Internet of Things by analyzing soil with a low-cost 5-pin soil sensor rather than in a laboratory. However, they come without calibration. The aim of this research is to calibrate a 5-pin soil sensor to measure seven soil properties. The calibration allowed for exact measurement to be accomplished because the correlation revealed only very small changes. The electrical conductivity correlation from the sensor and laboratory for the districts of Musanze and Kicukiro was 4.3 and 5.41, respectively. The sensor's accuracy was tested using laboratory-based data on soil analysis and validated by adding NPK 17:17:17-10g of fertilizer to a 200-ml soil sample. The sensor responded in accordance with the amount of NPK applied and the expected increase. As a result, if you follow the procedure, you can make an NPK decision based on what the sensor detects.

Keywords: Sensor, Soil, Real time monitoring, agriculture Internet of Things.

1. Introduction

The Internet of Things (IoT) is widely used in agriculture to assess soil quality and make decisions regarding land management [1]. The United Nations ‘Food and Agriculture Organization estimate that food production must increase by 60% by 2050 [2]. As a result, it can be done by fusing IoT with a variety of other technologies. Martin P. Mascianica et al. and Piotr Mazur et al. [3] [4] showed that Soil EC can be used to estimate NO3-N in soil, with correlation between EC and P and K. However, cheap sensors are not calibrated and nobody is certain if they function as intended. To enable the sensor to deliver useful data, a technique for testing and calibrating the sensor is being developed. This study used the five pin soil sensor to measure the volume percentage of soil moisture that meets the standard, temperature, electrical conductivity and pH value testing.

2. Review of Literature

This section outlines the existing approaches developed for performing soil monitoring. Calculating the volumetric water content requires multiplying the gravimetric water content by the bulk density of the soil. The soil moisture sensors have frequently been calibrated in real-world settings [5]. Bellosta-diest et al [6] analysed the performance of three commercial sensor Nutrients, RIKA, and JXCT were tested at 35% volumetric soil moisture. The performance was examined in relation to electrical conductivity (EC) (0-50 mS/cm) and nitrate content in aqueous solution and in sand - 0-180 ppm NO3. They concluded that although the manufacturer had previously calibrated these sensors, they may be recalibrated to produce a reliable NO3 measurement. In [7],Jahangir Arshad et al used The intelligent sensors module contains a temperature and humidity sensor, NPK sensor, soil moisture sensor, soil conductivity sensor, and pH sensor to transmit the statistics to the cloud over the internet via Long Range (LoRa) using Serial Peripheral Interface (SPI) communication protocol.

In [8] a soil-specific calibration was performed to integrate a sensor with an automated soil moisture monitoring system to measure soil moisture measurements by Ekanayaka Achchillage Ayesha et al. Authors

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in [9], designed and calibrated moisture sensor based on inductive coils and electromagnetic fields. Hasan Mirzakhaninafchi et al. [10] developed a sensor algorithm for monitoring the amount of soil N content. The findings showed a strong correlation between electrical conductivity and soil moisture content as well as soil nitrogen content. Chen Lipping et al. [11] used a calibration Procedure for commercial soil moisture sensors used to monitor soil moisture content. All the above mentioned studies have considered varied sensors as well as calibration methods to perform soil monitoring and control. In addition to the positive aspects and assertions made in the studies, there is still need for more research and improvement in using commercial sensor for soil monitoring. In this study the sensor was calibrated using soil data analysed in a laboratory as reference.

2.1 Purpose of work/Significance

As the sensor manufacturer do not calibrate the sensors, they must be calibrated. The proposed study's main objective is to address the problem that sensor providers currently don't calibrate their products. The suggested strategy outlines the sensor calibration methodology.

3. Materials and Methods

This section mainly emphasizes methodologies as well as the calibration method toward soil testing using sensors. The development of this study is carried out considering using soil testing from a laboratory as a reference for calibrating sensors. The calibrated sensor is tested to measure seven parameters, some of which are directly monitored and others are derived from the measurements.

3.1 Experimental material

Soil samples were collected from two locations in Rwanda, one at the University of Rwanda's College of Agriculture, Animal Sciences, and Veterinary Medicine in the Busogo sector of the Musanze district and another at Nyanza in Kicukiro District. The soils were classified as andisol or andosol types with pH between 5.7 and 5.8 and with a pH between 6 to 8.1. Irrespectively [12].

The two different geographic sites from which soil samples were collected for laboratory analysis. The laboratory findings from the examination of the soil samples were used to calibrate the sensor. After calibration, sensors were used in two different geographical area, musanze and kicukiro, to analyse the soil in the field to verify that they can generate the same results as those produced in a laboratory. With a five-pin sensor, seven parameters were monitored. Some were monitored directly and others were derived from the measurements**.**

Fig. 1: Five-pin soil sensor

Fig. 1 shows the 5 pin sensor, which monitors seven parameters, including temperature, electrical conductivity, soil moisture content, pH that are monitored directly while nitrogen, phosphorus, and potassium are derived from electrical conductivity.

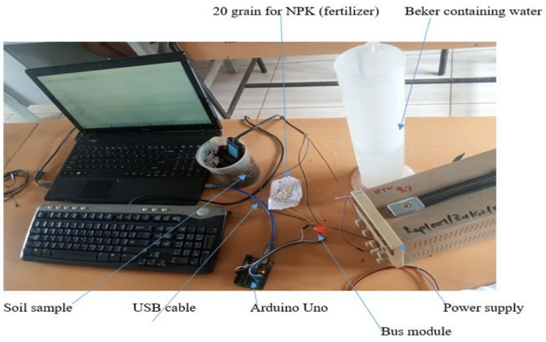
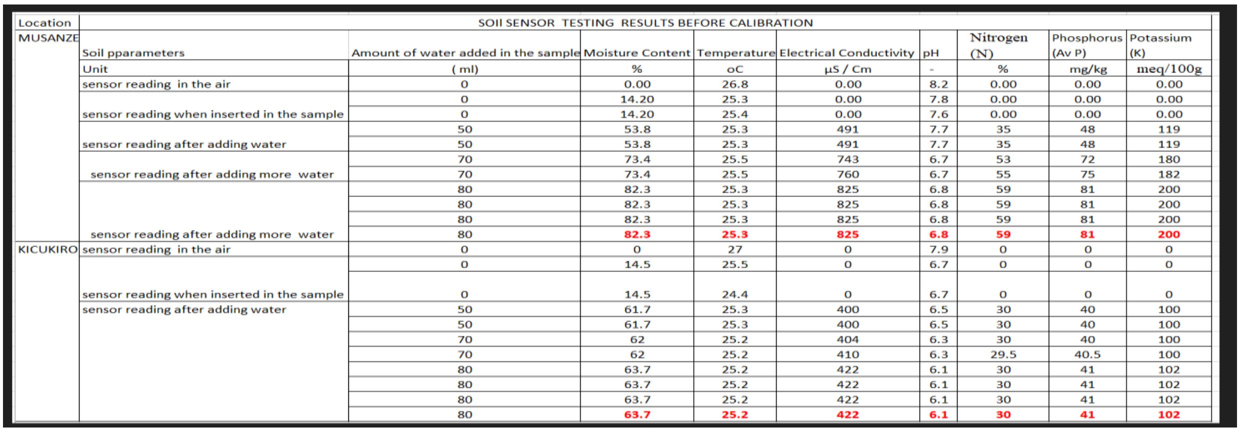


Fig. 2: Hardware design of the proposed system

Fig. 2 shows the sensor configuration, which consists of an Arduino Uno board, a soil sensor, and a bus module. Through the USB cable, the PC supplied power to the Arduino Uno board. The bus module was powered by an Arduino board at 5 V, whereas the soil sensor was supplied by a power source at 12 V. The bus module, which is wired to an Arduino Uno board, is where the soil sensor is connected. Using the Arduino IDE, an Arduino program was created and uploaded to the Arduino microcontroller. The soil sensor node was receiving the temperature, moisture content, electrical conductivity, amounts of Nitrate, potassium, and phosphorus, as well as its pH levels from the router node and were serially displayed on laptop.

3.2 Soil testing with five pin sensor

Two distinct soil samples were taken from two different geographic regions to test the sensor. A 200 ml sample of soil was placed in the beaker. The soil sensor was tested in the air before being inserted into the soil sample, and it was then tested once more inside the soil sample before and after water was added.



Location	SOIl SENSOR TESTING RESULTS BEFORE CALIBRATION								
MUSANZE	Soil pparameters	Amount of water added in the sample	Moisture Content	Temperature	Electrical Conductivity	pH	Nitrogen (N)	Phosphorus (Av P)	Potassium (K)
	Unit	(ml)	%	oC	µS / Cm	-	%	mg/kg	meq/100g
	sensor reading in the air	0	0.00	26.8	0.00	8.2	0.00	0.00	0.00
	sensor reading when inserted in the sample	0	14.20	25.3	0.00	7.8	0.00	0.00	0.00
		0	14.20	25.4	0.00	7.6	0.00	0.00	0.00
	sensor reading after adding water	50	53.8	25.3	491	7.7	35	48	119
		50	53.8	25.3	491	7.7	35	48	119
	sensor reading after adding more water	70	73.4	25.5	743	6.7	53	72	180
		70	73.4	25.5	760	6.7	55	75	182
	sensor reading after adding more water	80	82.3	25.3	825	6.8	59	81	200
		80	82.3	25.3	825	6.8	59	81	200
		80	82.3	25.3	825	6.8	59	81	200
		80	**82.3**	**25.3**	**825**	**6.8**	**59**	**81**	**200**
KICUKIRO	sensor reading in the air	0	0	27	0	7.9	0	0	0
	sensor reading when inserted in the sample	0	14.5	25.5	0	6.7	0	0	0
		0	14.5	24.4	0	6.7	0	0	0
	sensor reading after adding water	50	61.7	25.3	400	6.5	30	40	100
		50	61.7	25.3	400	6.5	30	40	100
		70	62	25.2	404	6.3	30	40	100
		70	62	25.2	410	6.3	29.5	40.5	100
		80	63.7	25.2	422	6.1	30	41	102
		80	63.7	25.2	422	6.1	30	41	102
		80	63.7	25.2	422	6.1	30	41	102
		80	**63.7**	**25.2**	**422**	**6.1**	**30**	**41**	**102**

Fig. 3: Soil sensor testing results before calibration

Fig. 3 displays sensor values from two distinct geographic locations prior to the sensor being calibrated.It shows sensors reading at optimum moisture level. Based on values displayed, we draw the conclusion that those are the accurate sensor readings when soil EC, N, P, and K remain constant. All parameters are being read by the sensor, and the values are constant, but they do not match with the results from the lab. Therefore, calibration needs to be applied.

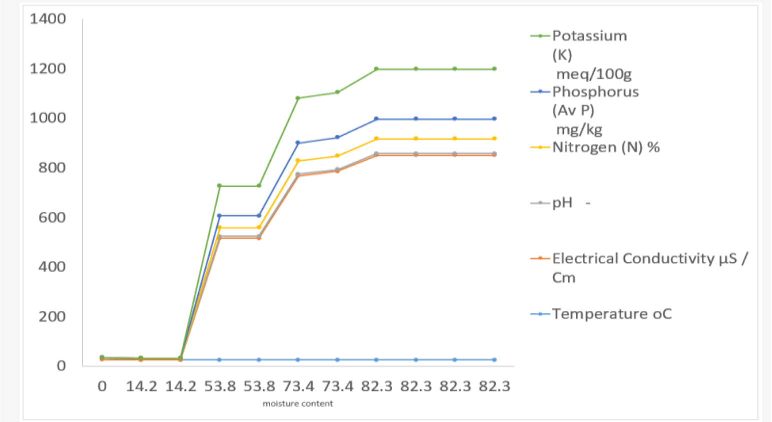


Fig. 4: Relationship between moisture content and EC,N,P,K,temperature and pH

Fig. 4 shows that When soil moisture is greater than 20%, the sensor starts to read the N, P, K, and EC parameters, according to its functioning.

Table 1: Laboratory results

Laboratory results of soil samples from Musanze and Kicukiro District							
Location	pH	Moisture	Temperature	NO3-	AvP	K	EC
		%	◦C	%	ppm	meq/100g	µS / Cm
Musanze	6.86	38.2	19	0.88	8.98	20.5	193
Kicukiro	6.1	36	26	3.38	7.4	1.36	78

Table 1 shows soil results analyzed from the laboratory following standard procedures of soil analysis in laboratory form two geographical location.

3.3 Sensor calibration

A sensor or group of sensors needs to be calibrated in order for an instrument to perform as correctly or error free as feasible. In this work, sensors were calibrated using laboratory-analyzed data on soil parameters as a reference. The soil’s temperature, moisture content, electrical conductivity, nitrate, potassium, and phosphorus concentrations, as well as pH, were the seven variables that were examined in the lab. Sensor was calibrated using the following formulas: For calibration of EC, The equation 1, which shows the ratio of electrical conductivity between electrical conductivity from the sensor and laboratory as correlation coefficient of electrical conductivity.

$$REC = ECs/EClab \tag{1}$$

ECs is Electrical Conductivity measurement form the sensor EClab is Electrical Conductivity values analyzed from laboratory.

$$CalEC = ECs/REC \tag{2}$$

The equation 2, which shows the calibrated electrical conductivity which is the ratio of electrical conductivity from the sensor and the ratio of electrical conductivity Turning the calibrated EC into NPK is calculated as follow;

$$EC/N \tag{3}$$

The equation3, which shows the ratio of electrical conductivity and nitrogen content (laboratory result).

$$EC/P \tag{4}$$

The equation4, which shows the ratio of electrical conductivity and phosphorus content (laboratory result).

$$EC/K \tag{5}$$

$$N = CalEC / (EC/N) \tag{6}$$

$$P = CalEC/ (EC/P) \tag{7}$$

$$K = CalEC/ (EC/K) \tag{8}$$

The equation 6, 7, 8, shows the nitrogen, phosphorus and potassium that have to be measured by the calibrated sensor based on Electrical conductivity. The C programming language is used in the Arduino integrated development environment to create all of the procedures related to the calibration formula. Seven soil parameters are measured using a sensor after calibration, and the numbers are compared to laboratory findings to see if the sensor is functioning properly.

4. Results and Discussion

Table 2: Calibration Results

Calibration Results								
Location	REC	CalEC	EClab/N lab	EClab/P lab	EClab/Klab	N	P (mg/kg)	K
	(µS/Cm)	(µS/Cm)	(mg/kg)	(mg/kg)	ppm	(mg/kg)	µS / Cm	(meq/100)
Musanze	4.3	192	218.18	21.38	0.023	0.88	8.98	20.4
Kicukiro	5.41	78	23.07	10.54	57.34	3.38	7.4	1.363

Table 2 shows the results got from equation1, 2, 3, 4, 5, 6,7and 8 for sensor calibration.

Fig. 6 shows the sensor reading after calibration whereas Fig. 7 shows the sensor readout after 10g of NPK fertilizer was added. Based on the additions of 1.7g (N), 1.7g (P), and 1.7g (K) to the soil sample, the sensor was reacting. The sensor responded by raising the amount of NPK for validation reasons. As a result, if you follow the steps, you can make NPK decision based on what the sensor detects.

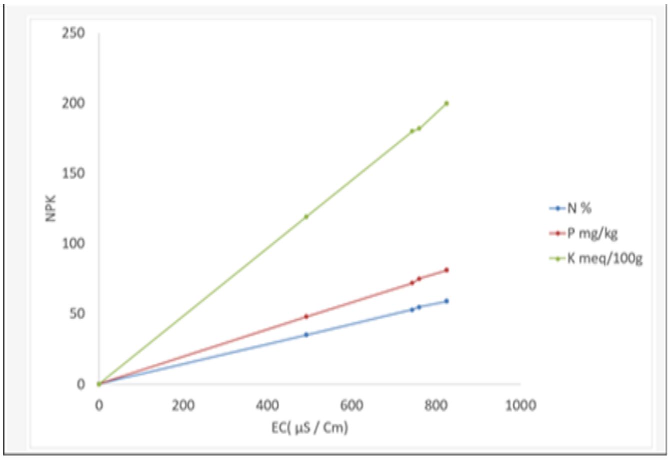


Fig. 5: Relationship between electrical conductivity (EC) and nitrogen, phosphorus, potassium (NPK) for

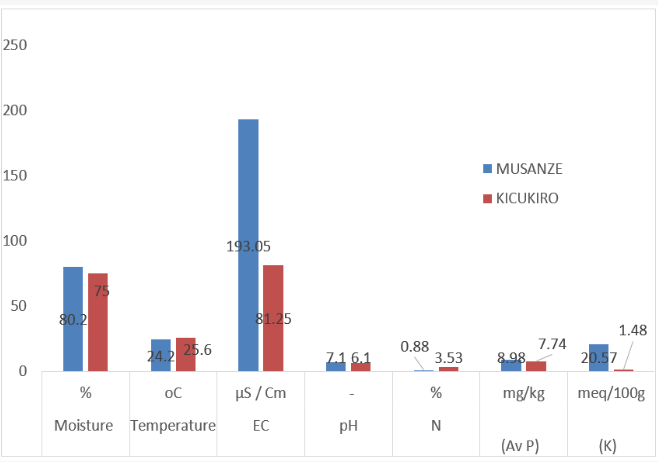


Fig. 6: Sensor reading after calibration

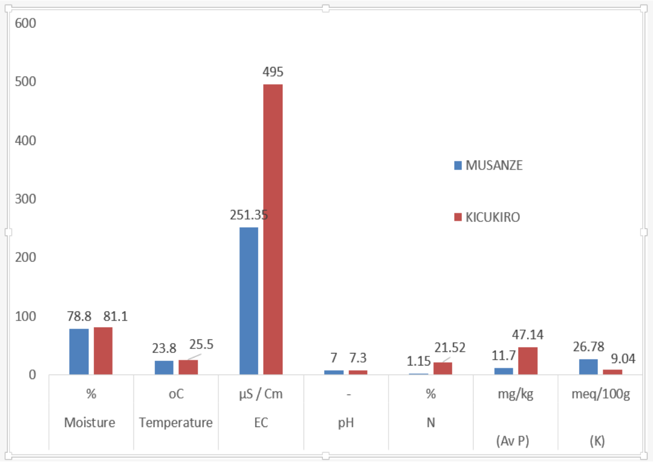


Fig. 7: Sensor reading after adding NPK fertilizer

5. Conclusions

We tested the low-cost 5-pin sensor's precision and reliability using soil samples. For the analysis of seven soil parameters, a sensor calibration function specific to the soil was created. This finding implies that the sensor's accuracy is dependent on the outcomes of the lab analysis results. The established correlations between EC and NPK were used to create a sensor for real-time measurement of soil N, P, and K availability, allowing farmers to apply fertilizer precisely. Further studies should be undertaken to assess its behaviour in a real working scenario under field conditions

6. Acknowledgements

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