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THE USE OF LOCAL AVAILABLE MATERIALS IN DEVELOPING A DIGITAL RESISTANCE BASE SOIL NITRATE METER

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ABSTRACT

The study of the nitrogen cycle has intensified, focusing on nitrogen loss pathways next to the more traditional study topics such as plant nitrogen uptake in order to maintain high productivity and healthy environment. This work presents the development of a digital soil nitrate meter for measuring the quantity of nitrate in a given soil sample. This nitrate meter was developed following the working principles of resistance based meters. It was tested by measuring the nitrate content of seven samples. For each sample, the nitrate concentration was taken at 60 seconds and 90 seconds respectively. The result obtained for sample 1, 2, 3, 4, 5, 6 and 7 at 60 seconds were 000.0, 017.5, 090.4, 057.3, 054.5, 042.0, and 041.2 respectively. Thus, at 90 seconds the following results were obtained for the same samples; 000.0, 017.7, 092.2, 058.4, 056.2, 042.8 and 041.8, all in milligram per litre (mg/l). The results obtained for these samples were validated using the ones obtained with the standard nitrate solutions and nitrate colour card. However, it was observed that the measurements obtained with the newly developed soil nitrate meter compared well with the standard nitrate solution and nitrate colour card.

KEYWORDS: Nitrate meter, Soil nitrate meter, soil remediation, standard nitrate solution.

INTRODUCTION

Nitrogen exists in the soil system in many forms and changes (transforms) very easily from one form to another. There are three major forms or state of nitrogen in the soil namely: organic nitrogen ($Org^{-}N$), ammonium nitrogen ($NH4^{+-}N$), and nitrate nitrogen ($NO_3^{-}N$). The Nitrate (NO_3^{-}) is the form of reactive Nitrogen (N) that is most susceptible to leaching and runoff; thus, a more thorough understanding of nitrification and NO3(-) availability is needed if we are to accurately predict the consequences of residential expansion for soil and water quality.

Nitrate is a vital component in all living ecosystems because it is the most readily assimilated form of nitrogen by plant. Most plants obtain the nitrogen they need as inorganic nitrate from the soil solution. Plants cannot use the nitrogen in the organic form. Nitrates are nitrogen compounds that occur naturally in the soil, but may also be introduced through fertilizer application. Plants use nitrogen in nitrates for their own metabolism and to produce proteins. Nitrate is formed from the chemical combination of nitrogen and oxygen. Nitrate is extracted from the soil through the roots and is distributed in the whole plant to be converted to protein compounds with high energy through photosynthesis. Nitrates of fresh soil samples can be extracted quantitatively using a K_2SO_4.The nitrogen cycle is biologically influenced by prevailing climatic conditions along with the physical and chemical properties of a particular soil, (John, et.al, 2014).

Furthermore, nitrate is normally extracted from soils by shaking a representative sample of known weight with a known volume of 2M KC1 (Bremner and Keeney, 1966). However, soil nitrate can be measured in the laboratory and as well in the field using an instrument called Nitrate Meter. Laboratory methods for measuring soil nitrate involve the cost of transporting samples and the delay in obtaining the results, so a field test has advantages.

However, this paper presents the Development and Testing of Digital Resistance Base Soil Nitrate Meter for use in measuring in-soil nitrate levels.

PROBLEM STATEMENT

Since the realization that excess Nitrogen (N) has negative effects on soil, water, air, ecosystem and human health, and thus may lead to significant environmental pollution or contribute to global warming, this study therefore highlights the need for employing the use of Nitrate meter in monitoring the nitrate level of soil and ensuring the effective use of Nitrogen fertilizers in Agriculture.

AIM AND OBJECTIVES OF THE STUDY

The aim of this study is to develop a Digital Resistance-Base Soil Nitrate Meter using locally available material in Nigeria for use in measuring in-soil nitrate levels. The following are the specific objectives, they include;

- To develop a nitrate meter using the working principles of resistance based meters.
- To test the nitrate meter of different soil samples and obtain results for their nitrate concentration.
- To validate the results from the newly developed nitrate meter with the standard nitrate solution and nitrate colour card.

LITERATURE REVIEW

Ezrin et al (2015) conducted a research on the development of real time soil nutrient mapping system in paddy field. This was in line with the application of advanced sensing technology in agriculture for an effective field management and improved crop yield. The used 118 lots of a paddy field located in Sawah Sempadan, Tanjung Karang, Selangor as the study area and a Veris 3100 Soil EC Sensor for measuring the soil apparent Electrical Conductivity (ECa). They also carried out the nutrient analyses of the soil samples collected from the 118 lots using Kjeldahl digestion technique. The results produced form their system was nearly identical to a Kriging map produced via ArcGIS software. They concluded that their findings indicated that the soil nutrient variability map was possible to be produced in real-time basis without engaging any tedious work in the field and it would be reliable for use in the site for best fertilizer management practices.

A study on the development of a sensor array consisting of three different ion-selective electrodes for simultaneous determination of soil macronutrients was carried out by Kim et al (2006) in ion-selective electrodes for simultaneous real-time analysis of soil macronutrients. It was in a quest for variable-rate nutrient management. They used Kelowa Solution to evaluate the macronutrients (N, P and K) of seven US Corn Belt soils and Ion-Selective Electrodes for Sensing NO_3-N and K in the Soil Extracts. Their results showed a high coefficient of determination (r^2> 0.9) and almost 1:1 relation between the levels of nitrate-N and potassium obtained with the ion-selective electrodes and standard analytical instruments.

Shaw et al (2013) assessed the potential for ion selective electrodes (ISE) and dual wavelength UV spectroscopy as a rapid on-farm measurement of soil nitrate concentration. The paper stated identified the limited accuracy of fertilizer recommendations for nitrogen which could be improved through the use on-farm soil rapid tests. They collected three soil samples from Henfaes Research Station, Abergwyngregyn, UK (53°14′ N, 4°01′ W). They determined the soils NO_3^- using Dual Wavelength UV Spectroscopy and NO_3^- ISE (ELIT 8021) - with a solid state PVC polymer matrix membrane which was pre-conditioned in a $1000mgL^{-1}NO_3^-$ solution for 4 h and calibrated using NO3− solutions of range (1000, 100, 10, 1, 0.5 mg $NO_3^-L^{-1}$). The results they got were to the internationally-approved standard laboratory method. The ISE rapid test procedure gave a near 1:1 response and coefficient of determination, r^2 = 0.978, 0.968, 0.989 respectively for the three soils and that with the dual wavelength UV spectroscopy were r^2 = 0.978, 0.983, 0.991. They gave that the accuracy with ISE rapid test was reduced at concentrations <10 mg NO_3^- L^{-1}) and they concluded that both ISE and dual wavelength UV spectroscopy have clear potential to be used for the rapid on-farm determination of soil NO_3^- concentration.

For a real-time prediction of soil nitrates using an intact core extraction procedure, Price et al (2003) researched on rapid nitrate analysis of soil cores using ISFETs. They collected four soil samples from Illinois which were Ade loamy sand, Proctor clay loam, and two drummers silty clay loams (which differed in organic carbon content). In the extraction system, they held 600g of each of the four soil samples between two filters and pushed an extraction through it. The extraction solution was sampled at the exit face of the core and routed to the ion-selective field-effect transistor/flow injection analysis (ISFET/FIA) system operating at 100Hz. at 100 Hz. Their results indicated that nitrate extraction of the soil cores was successful, and that data descriptors based on response curve peak and slope of the ISFET nitrate response curve might be used in tandem in a real–time prediction system.

Design of an economic, reliable and automated system for the acquisition of real-time data on the level nitrate nitrogen (NO_3-N) in the soil is one of the many attributes of precision agriculture technologies. Sibley et al (2008) studied field-scale validation of an automated soil nitrate extraction and measurement system. They developed soil nitrate mapping system (SNMS) for collecting the required data. The soil samples were taken from #203 and #207 fields in the Nova Scotia Agricultural College (NSAC) farm, seeded with carrot and spring wheat respectively. The results they obtained from the nitrate extraction and measurement system (NEMS) were compared with that from standard laboratory measurement using root mean squared error (RMSE), mean absolute error (MAE) and coefficient of efficiency (CE) techniques. They posited soil nitrate measurements from NEMS and standard laboratory for the variety of the field conditions tested was excellent.

Shaw (2015) in his work titled "developing in-situ and real-time methods of soil nitrogen determination", he said that excess application of nitrogen to crop can lead to environmental pollution, contributing global warming. He went further in carrying out micro dialysis-derived diffusive flux measurement of the soil nitrogen in the forms of NH_4^+ and NO_3^-. He took eight grassland soil samples up an altitudinal gradient and evaluated its nitrogen content using micro dialysis. Also, he used conventional soil core batch extraction (using 0.5 M K_2SO_4 or distilled H_2O). The two results were compared using one-way ANOVA the Fisher's least significant difference post hoc test. The two results were similar in that the dominant N-form was the same regardless of the method used.

In summary, the review shows that few researches today have been done on the development and testing of a nitrate meter for field use locally. This triggered this research work.

MATERIALS AND METHODS

LOCATION OF DEVELOPMENT OF THE NITRATE METER

The nitrate meter was developed at the laboratory unit of the Electrical and Electronics Engineering Department, Faculty of Engineering, University of Nigeria Nsukka, Enugu, Nigeria. The facilities in this laboratory were fully adopted.

MATERIALS

The materials used for this work are; Resistor, 7805 IC, Capacitor, Microcontroller(PIC16F877A), LM741 IC, Liquid crystal display (16x2), Iron steel probe, Light emitting diode (LED), 4MHZ crystal, Button, Connection wire, Mother board, 9v battery.

Equipment: Vero Board, Digital Multi meter, Soldiering iron, Screw driver, Standard nitrate kit,

METHOD

The system block diagram in figure 1, shows the working principles of the nitrate meter. This meter adopted the working principle of an impedance based meter with a microcontroller system and an insertion sensor probe to read the concentration of soil nitrate in water solution. Generally, the impedance based nitrate meters use the relationship between the resistances of Nitrate to water and when the electrode of the metering unit is in contact with soil-water solution containing nitrate, the concentration is read at the display unit.

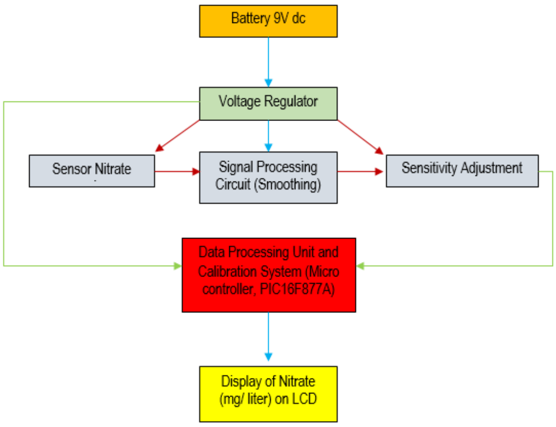

Fig. 1: Block diagram of nitrate meter

DESIGN APPROACH

The most common approach in developing nitrate meters is simply to use a voltage divided circuit to generate a voltage V_{out}, that is directly proportional to the concentration of nitrate, and then utilize a microcontroller to measure the voltage within a given period to estimate the nitrate concentration in mg/L or ppm. A voltage divided circuit was adopted for the development of this meter with an lm741 IC (operational amplifier) to obtain a smoothing output voltage respectively. The microcontroller measure and displays the corresponding concentration of nitrate in mg/litre on the LCD (Liquid crystal display) as a digital output. The output voltage generated by the system as a result of inflow of current into the system has a direct relationship with the resistance of the nitrate in the soil–water solution. The meter was calibrated to read nitrate concentration in mg/litre of water. In calibration of the system, nitrate test solutions (#1 and #2) and soil sample were used as sources of nitrate, standard solutions were prepared from 5mg/litre of distil water (H_2O) to 160mg/litre. An internationally and universally accepted fresh water nitrate colour code card was also a helpful tool during the calibration of this device. This consists of a set of individual coloured rings or bands in spectral order representing each digit of the resistors value. The colour change is an indication of the concentration of nitrate in mg/l or ppm in the soil water solution which were matched with the digital readings of the nitrate meter at the LCD unit. See plate 1 for the developed nitrate meter.

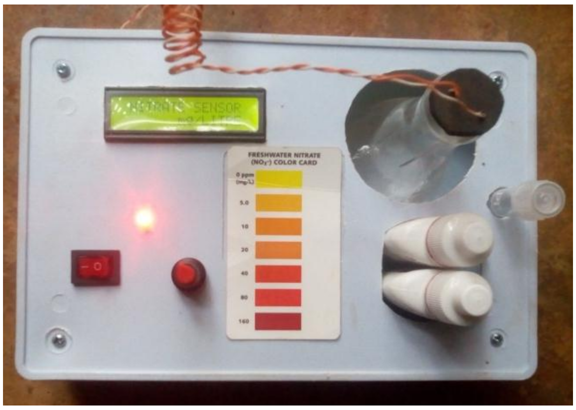

Plate 1: Developed Nitrate meter

TESTING PROCEDURE

The nitrate meter is controlled from a power button which turns on to indicate that the device has been powered. A known quantity of soil sample was poured into 150ml conical flask and the meter probe inserted into the test tube containing the soil water solution for its nitrate concentration reading. Three quarter length of the robe must be in contact with the sample in solution for accurate readings. The meter will stay for about 60seconds after being switched on before it will start to display some reading at the LCD. The probe conducts some current which causes the movement of voltage in the system. The voltage is measured directly at the analog to digital converter (A/C) of microcontroller (pic16f877a). The voltage is converted back to corresponding nitrate in mg/litre and displayed at LCD. When the probes are inserted in the soil-water solution sample of a readable level, the change in nitrate content causes change in resistances which in turn causes change in the output voltage. The voltage measured will be smoothing with op-amp comparator (LM741 IC) to remove electrical noise from the system. The voltage will be converted back to corresponding nitrate in mg/litre and display at LCD. Thus, seven samples were tested for their nitrate concentration following the procedure stipulated above and the working principles shown in figure 1.

TEST SAMPLE COLLECTION

Seven different sample were collected and assessed for their nitrate concentration in mg /l

- Sample 1(distilled water): This was obtained from Conraws scientific equipment, Presidential road Enugu.
- Sample 2 (store bore hole water in gee pee): This was obtained from Agricultural and Bio resource Engineering Department, Enugu State University of Science and Technology (ESUT).

- Sample 3(a mixture of bore hole water store in a gee pee tank and edible salt (half tea spoon full).
- Sample 4 (soil sample collected from No. 4 Federal staff quarters Independence Layout, Enugu). The sample was mixed with distilled water and was tested immediately.
- Soil sample 5 (soil sample collected from No. 4 Federal staff quarters Independence Layout, Enugu). This was allowed to settle for 20minute before it was tested.
- Soil sample 6 (soil sample collected from Agricultural and Bio-resources Engineering research farm, Faculty of Engineering, Enugu State University of Science and Technology, Enugu). The sample was mixed with distilled water and was tested immediately.
- Soil sample 7(soil sample collected from Agricultural and Bio-resources Engineering research farm, Faculty of Engineering, Enugu State University of Science and Technology, Enugu) but was allowed to settle for 20 minutes before testing.

RESULT AND DISCUSSION

The results obtained for this work were grouped into two different categories;

1. Result obtained using standard solution of sodium nitrate and colour code card in testing different samples
2. Result obtained using the developed resistor nitrate meter of this work in testing seven different samples

Table1: Standard solution of sodium nitrate and soil sample readings used for the calibration of the nitrate meter

Solution (mg/l) or ppm	V_{out} (V)	Time (sec)	Input voltage(V)
5	1.50	60	4.96
10	1.60	60	4.96
20	1.80	60	4.96
30	2.00	60	4.96
40	2.21	60	4.96
50	2.42	60	4.96
60	2.61	60	4.96
70	2.80	60	4.96
80	3.00	60	4.96
90	3.22	60	4.96
100	3.41	60	4.96
110	3.60	60	4.96
120	3.82	60	4.96
130	4.10	60	4.96
140	4.24	60	4.96
150	4.44	60	4.96
160	4.63	60	4.96

An internationally and universally accepted fresh water nitrate colour code card developed as a simple and quick way of identifying the concentration of nitrate in any given water solution was used in determination of the nitrate concentration for each sample. The colour obtained for each sample was matched with the colours in the nitrate colour code card and read as the concentration mg/lfor each sample. The colour code card consists of a set of individual coloured rings or bands in spectral order representing each digit of the resistors value. The colour change is an indication of the concentration of nitrate in mg/l or ppm in the samples these were matched with the digital readings of the nitrate meter. This consists of a set of individual coloured rings or bands in spectral order representing each digit of the resistors value. Plate 2 below is a fresh water nitrate colour card showing different colour and their corresponding concentration mg/l or ppm.

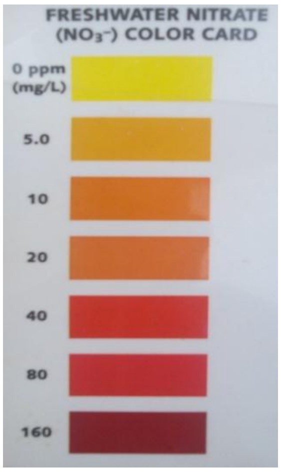

Plate 2: Fresh water nitrate colour code card

The result obtained for seven samples using the resistor nitrate meter of this work are given in Table 2 below.

Table 2: Result obtained using the developed resistor nitrate meter

Sample	Concentration at the starting point (before 60 sec.) mg/l or ppm	Concentration in 60 sec. (mg/l or ppm)	Concentration in 90 sec. (mg/l or ppm)
1.	000.0	000.0	000.0
2.	000.0	017.5	017.7
3.	000.0	090.4	092.2
4.	000.0	057.3	058.4
5.	000.0	054.5	056.2
6.	000.0	042.0	042.8
7.	000.0	041.2	041.8

The result obtained for sample 1 recorded 000.0mg/l throughout the recording time, this is an indication that the sample (distilled water) has no nitrate content. Sample 2, recorded 017.5mg/l at 60 seconds and 017.7 mg/l at 90 seconds. This showed that there are some traces of nitrate in the sample though the water seems to be clean. Trace of nitrate in the water can be attributed to algae growth in the tank. Five more samples were tested and the results obtained from them at 60 and 90 seconds respectively were recorded to be 090.4, 092.2 for sample 3, sample 4, 057.3, 058.4, sample 5, 054.5, 056.2, sample 6, 042.0, 042.8, sample 7, 041.2, 041.8 all in mg/l. The variation in the results obtained for the seven samples tested was as a result of the differences in nitrate concentration for each sample. Moreover the results obtained at 60 seconds was lower than that obtained at 90 seconds, this could be attributed to increase in time for the reading because 60 seconds is an initiation recording time for the meter and the probes have had longer contact with nitrate in the solution. However, it is expected that the meter reading will decrease at a longer time because of settling of nitrate in the solution.

CONCLUSION

In this study, a Digital Resistance Base Soil Nitrate Meter was developed and tested. It may be noted that the readings were not obtained exactly as given or stipulated in the nitrate colour code cards but were found within a very close range. The resistance base nitrate meter is used to measure concentration of nitrate in soil or water just like other nitrate meters. The advantage of this meter over other types is that, it is very easy to operate with high level of precision especially when the source of power is stable. Discrepancies in the readings may be as a result of human error during the testing of the samples or the strength of the battery use as source of power to the nitrate meter.

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