Turkish Journal of Engineering
https://dergipark.org.tr/en/pub/tuje
e-ISSN 2587-1366

Design and implementation of internet of things (IoT) based scheme for testing loamy soil

Akeem Abimbola Raji*[1], Joseph Folorunso Orimolade[2], Ibrahim Adewale Ewetola[3]

[1]Olabisi Onabanjo University, Department of Electrical and Electronics Engineering, Nigeria, rajiakeemabimbola@gmail.com
[2]Afe Babalola University, Department of Electrical and Electronics Engineering, Nigeria, orimoladejf@abuad.edu.ng
[3]Michael Okpara University of Agriculture, Department of Animal Nutrition and Forage Science, Nigeria, ewetola.ibrahim@mouau.edu.ng

Cite this study: Raji, A.A., Orimolade, J.F. & Ewetola, I.A. (2025). Design and implementation of internet of things (IoT) based scheme for testing loamy soil. Turkish Journal of Engineering, 9 (2), 323-333.

https://doi.org/10.31127/tuje.1553534

Keywords
agriculture
internet of things
microcontroller
mobile application
moisture content

Research Article

Received: 20.09.2024
Revised: 23.10.2024
Accepted: 30.11.2024
Published:01.04.2025

Abstract

Soil plays a vital role in crop production. It is therefore essential for farmers to have handy information on the quality of the soil to be cultivated. In Nigeria and many third world countries, traditional method that is based on subjective evaluation is used, where farmers utilize their past experience to adjudge the quality of the soil. This approach is ineffective and time consuming. This work presents Internet of Things (IoT) based scheme that provides farmers with real time data or information on the quality of the soil. The scheme includes IoT device that consists of NPK sensor, Dallas temperature sensor, NodeMCU (ESP8266) and capacitive soil sensor which are utilized to collect data on nutrient, moisture and temperature of the soil. These data are sent to a mobile application that is developed using DART programming language and Hyper Text Markup Language (HTML). The performance of the IoT scheme is assessed through field experiment where loamy soil samples taken from Agricultural Engineering garden, Electrical Engineering garden and open football school field of College of Engineering and Environmental Studies, Olabisi Onabanjo University, Ibogun, Ogun State are used as candidates for testing. The results of the experiment reveal that the soil sample taken from Agricultural Engineering garden retains water (80%) better than other soil samples and has the highest mineral (Nitrogen, 39mg/Kg and Phosphorous, 16mg/Kg) composition. Its potassium content (14mg/Kg) is however at par with sample taken from the school field. In addition, it is observed that soil sample from the school field has higher temperature (26.63 ^{o}C) than others. It is seen that the IoT scheme functions satisfactorily and demonstrates ability to test soil in a bid to help farmers in making right decision concerning optimal application of fertilizer for higher agricultural output.

1. Introduction

Agriculture plays an important role in the economy of many countries of the World. In fact the economic growth of a number of countries in Africa and Asia is tied to the progress and development in the agricultural sector. Agriculture may be divided into crop and livestock farming. Crop farming involves planting and harvesting of food and cash crops while livestock farming involves rearing of animals. The soil is the foundation upon which the success of every farm practice rests. Healthy soil is important not only for supporting the growth of crops but also crucial in preserving or sustaining the ecosystem and forging sustainable environment. Soil consists of major nutrients such as phosphorous, magnesium and potassium [1], [2]. It is important for farmers to be familiar with the nutrient level of the soil. This informs their decision either to apply fertilizer to replenish the soil or not. Traditional method of checking soil nutrient that is common in Nigeria and many third World countries is labour intensive, time consuming and it is based on subjective evaluation and experience. In this way, farmers usually struggle to improve soil nutrient due to lack of accurate data culminating in inefficient use of fertilizer or mineral resources.

Internet of Things (IoT) has become an emerging technology that interconnects dense networks, sensors, machines and devices via the internet and promises to revolutionize health, transportation, electricity and other facets of human needs. Hence, there is the need to adopt this innovative technology in the field of agriculture to solve problems faced by farmers in gathering data concerning the quality of the soil with a view to increasing farmers' output and eliminating wastage of resources.

Existing works in the area of soil assessment include the work of [3] which presented an IoT system based on machine learning for monitoring the soil nutrient and for recommending the type of crop to be planted on a particular soil. Authors in [4], [5] developed IoT system for irrigation and smart application of fertilizer, where control mechanism was developed using Fuzzy logic for administering fertilizer, water, alkali and acidic solutions to the soil. The system tested with Chilli plant showed superior performance to the traditional method.

An IoT system for measuring nutrient content of the soil was developed by authors in [6]. The contribution of [7] presented the design of IoT device for remote smart monitoring of crops' growth. A database for the analysis of impact of rain, humidity and air temperature on the growth of crops was created. Authors in [8], [9] focused on IoT system for checking moisture level only while authors in [10] expended efforts on developing IoT system for measuring soil moisture and environmental weather conditions. The contribution of [11-18] focussed on the construction of a device for evaluating water level, humidity and temperature of the soil.

An IoT based system was designed in [19] for checking the soil moisture which exhibited accuracy of 98.71%. Authors in [20] integrated IoT with cloud server to measure water level in the soil employed for palm oil plantation in Indonesia while the contribution of authors in [21] combined IoT with wireless sensor network to check moisture and temperature of the soil. A deep neural network trained with reinforced learning algorithm was designed for predicting the soil temperature and moisture. A review of sensor technologies to determine chemical, physical and mechanical properties of the soil was presented in [22].

A convolutional neural netowrk model for identifying and classifying diseases in cotton leaf in a bid to improve its productivity was proposed in [23] while the author in [24] proposed a model that combined convolutional neural network and biderectional long term short memory network for modelling the level of ground water in the soil. It was shown that the proposed model could predict the time series data concerning ground water level effectively. An IoT system was developed in [25] to reduce bolting due to fluctuation in temperature, humidity and light intensity in onion farm.

However, an IoT device for measuring soil's electrical conductivity was constructed in [26]. It was shown that the electrical conductivity exhibited linear relationship with temperature while the electrical conductivity and depth of the soil were inversely related. Support Vector and Random Forest Machine Learning Algorithms were implemented in [27] for predicting the crop yield based on the information from previous planting season. Authors in [28] utilized satellite imagery with different vegetable indices to assess cotton farm yield before harvest.

On the other hand, the contribution of authors in [29] investigated the impact of rice husk on the consolidation ability of soil while authors in [30] examined the performance limit of soils improved with rice husk ash.

It is clearly seen that existing works have largely focussed on developing IoT system for determining soil characteristics such as moisture content, temperature and humidity. These information are not enough for appraising the quality of the soil. This work develops an IoT scheme that monitors not only moisture and temperature of the soil but also asseses the soil nutrient. An interactive mobile application is developed for providing real time data on loamy soils used as candidates for investigation, which to the best of our knowledge has not attracted attention in this manner in the literature.

The rest of the paper is organized as follows; section 2 presents the materials and method, section 3 discusses the results of performance tests while section 4 concludes the paper.

2. Method

2.1 System design

Figure 1 presents the block diagram of IoT based scheme which interconnects a number of sensors, microntroller, buck converter, OLED screen, and mobile application via the internet. The proposed scheme is designed to measure the amount of nutrients, temperature and moisture content of loamy soil. Figure 1 is used as reference and forms the basis for the implementation of the proposed IoT scheme. Each unit of Figure 1 is described in the subsections that follow.

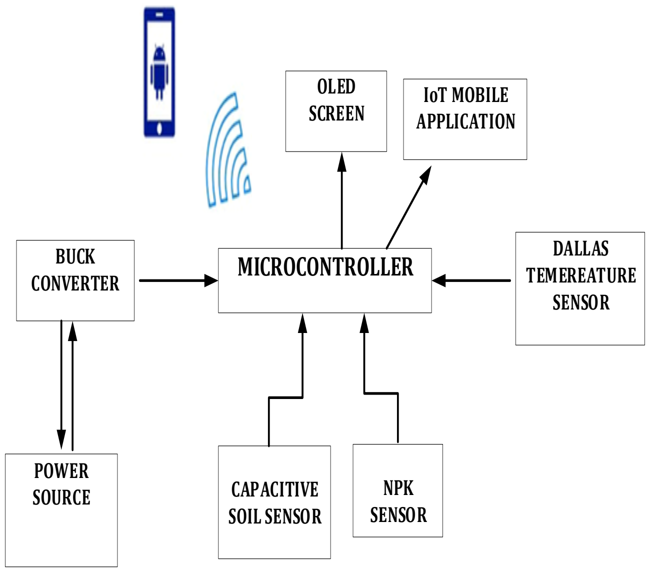

Figure 1. Block diagram of the proposed IoT scheme

2.1.1. NPK sensor

Nitrogen (N), Phosphorous (P) and Potassium (K) are essential plant nutrients needed for plant growth. NPK sensor is a specialized probe that is utilized to measure the level of these nutrients in the soil. The device provides real-time measurement of these nutrients for informed decision regarding fertilizer application for improving soil fertility, crop health and productivity. It utilizes electrochemical or ion-selective electrode (ISE) technique to detect the concentration of N,P and K in the soil by generating electrical signal which is processed and analyzed by the microcontroller. The sensor is calibrated by comparing the sensor's output with known reference values. The operating voltage of NPK sensor, its current and power consumption are respectively, 5 V, 10 mA and 50 m W, where V is Volt, A is ampere and W is Watt.

2.1.2. Capacitive soil sensor

Capacitive soil sensor is used to measure soil moisture level. It consists of two conductive plates separated by an insulating material. When it is inserted into the soil, the moisture level changes the dielectric constant between the plates, altering the capacitance which results in the generation of a signal proportional to the soil moisture level. Unlike resistive soil moisture sensor, capacitive soil sensor does not rely on direct electrical contact with the soil, making it less susceptible to corrosion and degradation. This characteristic enhances its durability in long-term field application. It provides consistent and reliable measurement of soil moisture without the need for frequent maintenance or calibration. The operating voltage of the capacitive soil sensor is 3.3 V while its current rating is 5 mA. The power consumption by the sensor is 16.5 mW.

2.1.3. Dallas temperature sensor

The Dallas temperature sensor (DS18B20) is a digital thermometer that is used to measure soil temperature. The sensor provides temperature reading in degrees Celsius, which can be converted to other units. The sensor is pre-calibrated and provides accurate temperature reading. Its digital output eliminates the need for analog-to-digital conversion, simplifying data acquisition and processing. DS18B20 is encapsulated in a waterproof case and it is suitable for use in moist soil. The operating voltage, current rating and power consumption are 3.3 V, 1.5mA, and 4.95mW, respectively

2.1.4. Organic light emitting diode (OLED) screen

The Organic Light Emitting Diode (OLED) screen is a module that is used to display real-time data such as soil moisture, temperature, amount of N,P, and K in the soil as well as system status information. It has a wide viewing angle, high contrast data representation and consumes less power which makes it ideal for use in battery-powered and portable devices. It has faster response time than conventional Liquid Crystal Display (LCD) screen. It utilizes operating voltage of 3.3 V and current of 20 mA. The total power consumption of OLED screen is 66mW.

2.1.5 Node microcontroller Unit

The Node Microcontroller Unit (ESP8266) serves as the brain of the IoT scheme. It consists of dual-core processor, IEEE 802.11, and Bluetooth connectivity modules, analog-to-digital converters (ADCs), and various digital input/output (GPIO) pins. The microcontroller has a powerful processing capability, which enables it to handle complex data processing task and supports various communication protocols. Its GPIO pins allow for easy integration with various sensors. The microcontroller collects, processes data from capacitive soil sensor, NPK sensor and temperature sensor and transmits the data using IEEE 802.11 conectivity module to the mobile application on android phones. The microcontroller is programmed using C++ programming language. The operating voltage, current rating and power consumption of the microcontroller are 3.3 V , 50 mA and 165 mW, respectively.

2.1.6. Power source

The power source is a crucial component of the proposed IoT scheme that provides a stable and reliable power for the hardware components. The power adapter converts the alternating current (AC) from the main power supply to a stable 12 V direct current (DC) output, which is used to power the entire IoT scheme. The power adapter has an overvoltage, overcurrent, and short-circuit protection mechanisms which are incorporated to improve the reliability of the system and ensure that the IoT scheme is not affected by voltage flucturation.

2.1.7. Buck converter

The buck converter is used to regulate the voltage or power supplied to the hardware components of the IoT scheme. This is important for components such as microcontroller, capacitive soil sensor, temperature sensor, and communication modules which have different voltage requirements. The buck converter operates by switching an inductor and capacitor network in a controlled manner to convert the input voltage to an output voltage of lower value. The buck converter has 80 - 95% efficiency which helps to increase the life of the battery and to reduce power consumption. By assuming an efficiency of 90%, the power (P_{in}) needed for operating the hardware components such as NPK sensor, capacitive soil sensor and OLED screen in the IoT scheme is calculated using equation 1 of the form given by:

$$P_{in} = \frac{P_{load}}{efficiency} \tag{1}$$

where P_{load} is the supply load power which is the the sum of power consumption of NPK sensor, capacitive soil sensor and OLED screen given by equation (2) as

$$P_{load} = 50mW + 16.5mW + 66mW = 132.5mW \tag{2}$$

By substituting the value of P_{load} with efficiency as 90% in equation (1), P_{in} is obtained as 147.2mW

That is

$$P_{in} = \frac{132.5\,\text{mW}}{0.9} = 147.2\,\text{mW} \tag{3}$$

This obtained value of P_{in} shows that the IoT scheme consumes less power when compared with [9] which works on IoT system with different architecture.

Figure 2 presents the circuit layout of the proposed IoT scheme. The diagram shows the circuit connection of the hardware components of the scheme.

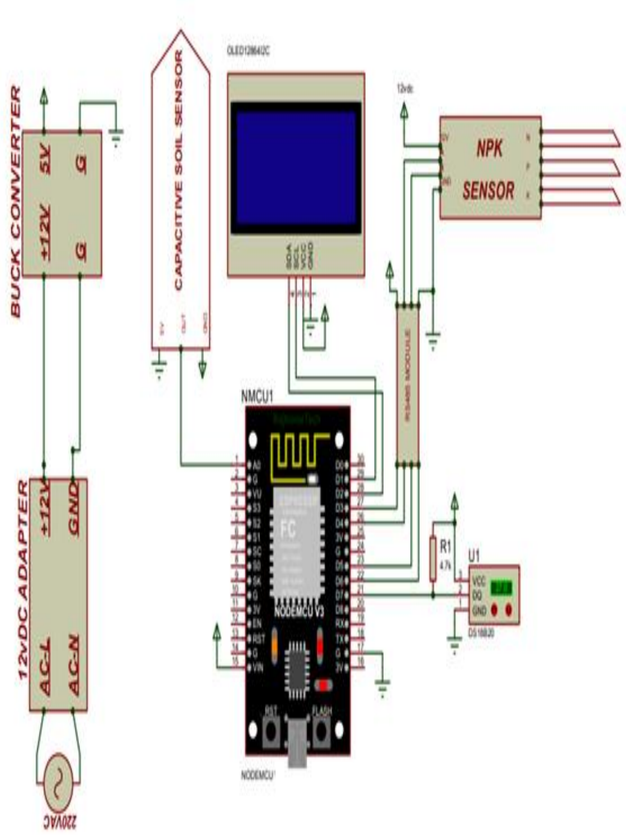

Figure 2. Circuit diagram of hardware components of the proposed IoT scheme

2.1.8. IoT mobile application

The mobile application (app.) fetches real-time data from ESP8266 microcontroller using IEEE 802.11 and displays it on android and i-Phone operating System (IoS) devices. This allows farmers to easily view and interpret the information about soil nutrient, temperature and moisture, thereby offering a responsive and interactive platform to assess the soil. Farmers can also view the results of the soil test at a distant location from the farm once there is IEEE 802.11 connectivity between Android/ IoS phones and IoT device.

Figure 3 displays the flow chart for the operation of the IoT scheme which summarizes how the IoT scheme is implemented. The flow chart is explained with the aid of sequential steps presented in section 2.2

2.2. Implementation steps of the proposed IoT scheme

Step 1: Start the process

Step 2: Read the amount of N, P and K, temperature as well as moisture of the soil

Step 3: Display the readings on OLED screen, IoS and android phones

Step 4: Take user soil input readings

Step 5: check for the difference between sensor readings and user soil input readings

Step 6: If there is difference between the two readings, adjust the sensor readings

Step 7: If there is no difference, check whether the IoT system is OFF/ON

Step 8: If the IoT system is ON, repeat the process. Otherwise,

Step 9: End the process.

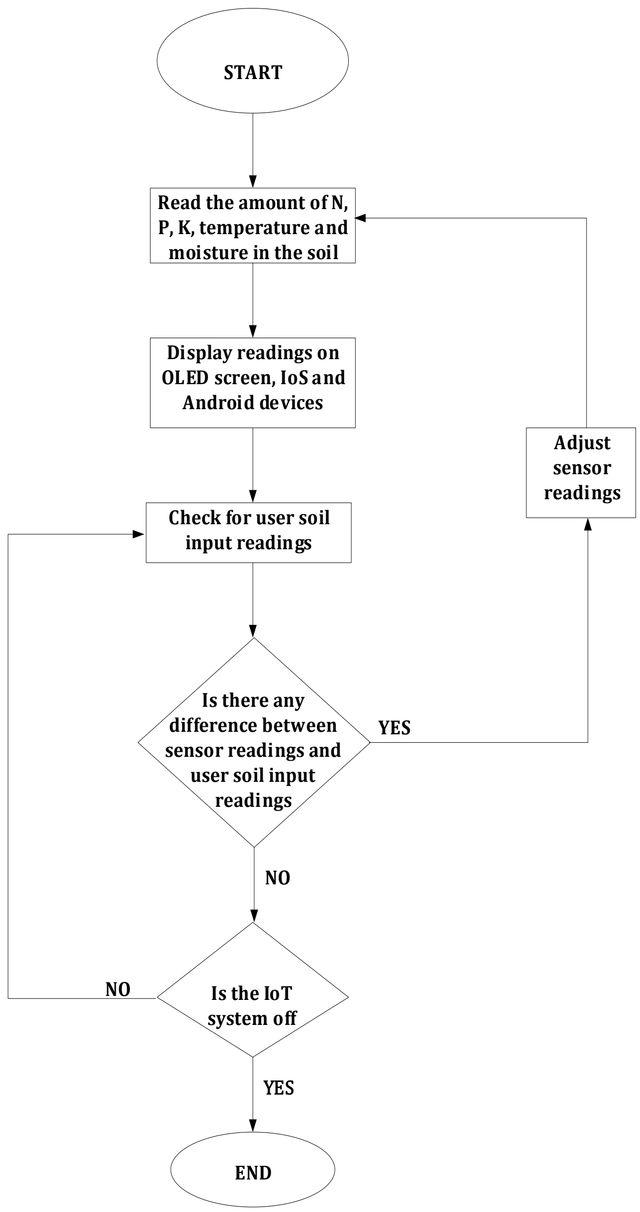

Figure 3. Flow chart for the operation of the proposed IoT scheme

2.3. Soil sample

Loamy soil is considered ideal for agriculture due to its balanced mixture of sand, silt, and clay. It has good water retention capability and is rich in nutrient. For the purpose of testing the performance of the IoT scheme, loamy soil samples are utilized. These samples are taken during raining season from Agricultural Engineering Department garden, Electrical Engineering Department garden and open football school field of College of Engineering and Environmental Studies, Olabisi Onabanjo University, Ibogun, Ogun State, Nigeria. Plate 1 illustrates the pictorial view of these soil samples.

(a)

(b)

(c)

Plate 1. Soil samples from (a) Agricultural Engineering department garden, (b) Electrical Engineering department garden and (c) school field.

2.4. System hardware development

Figure 4 illustrates the internal hardware components of the IoT scheme such as Dallas temperature sensor, ESP8266 (NodeMCU), OLED screen, connector, connecting wire, and buck converter. These components are interconnected and soldered on a veroboard. Figure 5 displays the external hardware components of the IoT scheme such as NPK sensor, casing, connecting wire and switch. The casing is weather-resistant enclosure that protects the internal components from rain, dust, and extreme temperature.

The casing has access points for sensor probe insertion and a transparent section for the OLED screen. The connecting wire is a durable and flexible wire with good insulation that connects the sensors to the microcontroller. The switch allows for easy operation of the system by enabling farmers to turn the device on and off without disconnecting the power source.

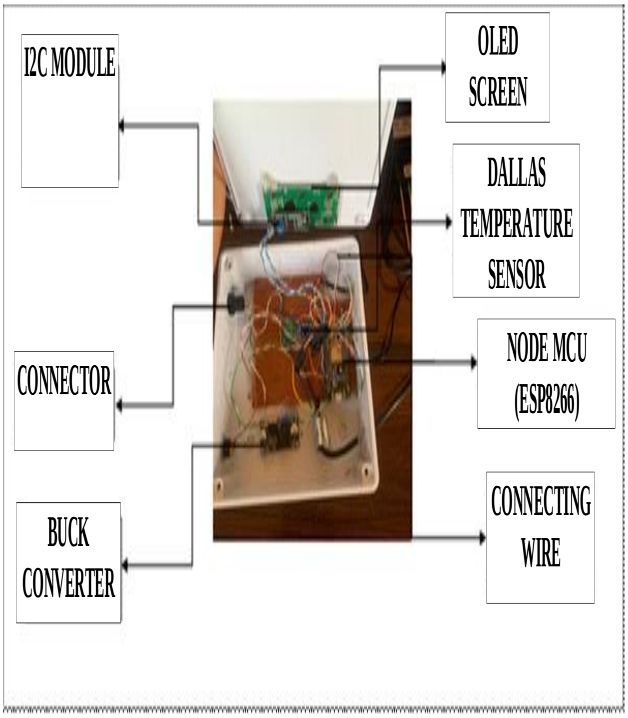

Figure 4. Internal hardware components of the proposed IoT scheme

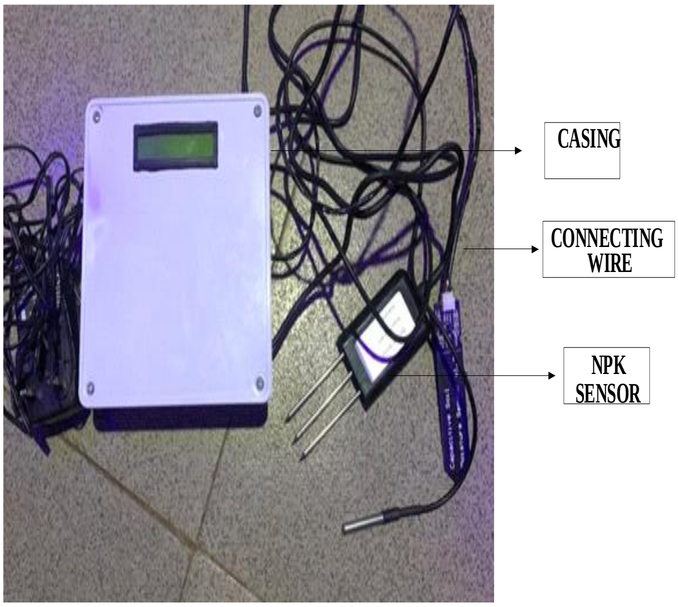

Figure 5. External hardware components of the proposed IoT scheme showcasing casing, NPK sensor, connecting wire and power switch.

2.5. Mobile application development

The mobile application is developed using DART programming language and Hypertext Markup Language (HTML). DART is used with Flutter to build the mobile app's frontend, providing a cross-platform solution that runs on both android and IoS devices. It integrates with backend via Hypertext Transfer Protocol (HTTP) request to retrieve status updates. HTML is used to create the interface of the mobile application, which includes forms, buttons, text fields. HTML also facilitates the display of real-time information concerning the quality of the soil and provides easy access to farmers to read the information. Figure 6 illustrates the log in interface of the mobile app.

Figure 6. Log in interface of mobile application.

2.6. Performance evaluation

The performance of the proposed IoT scheme is assessed using soil samples depicted in Plate 1. In this connection, Plate 2 shows the soil sample under test where the NPK sensor is inserted into the soil sample.

Plate 2. Soil sample under test

Figure 7 depicts the mobile application deployed on androoid and IoS devices displaying the results of the soil tests which indicate the amount of N, P and K, temperature and moisture content of the soil samples for easy view by the farmers.

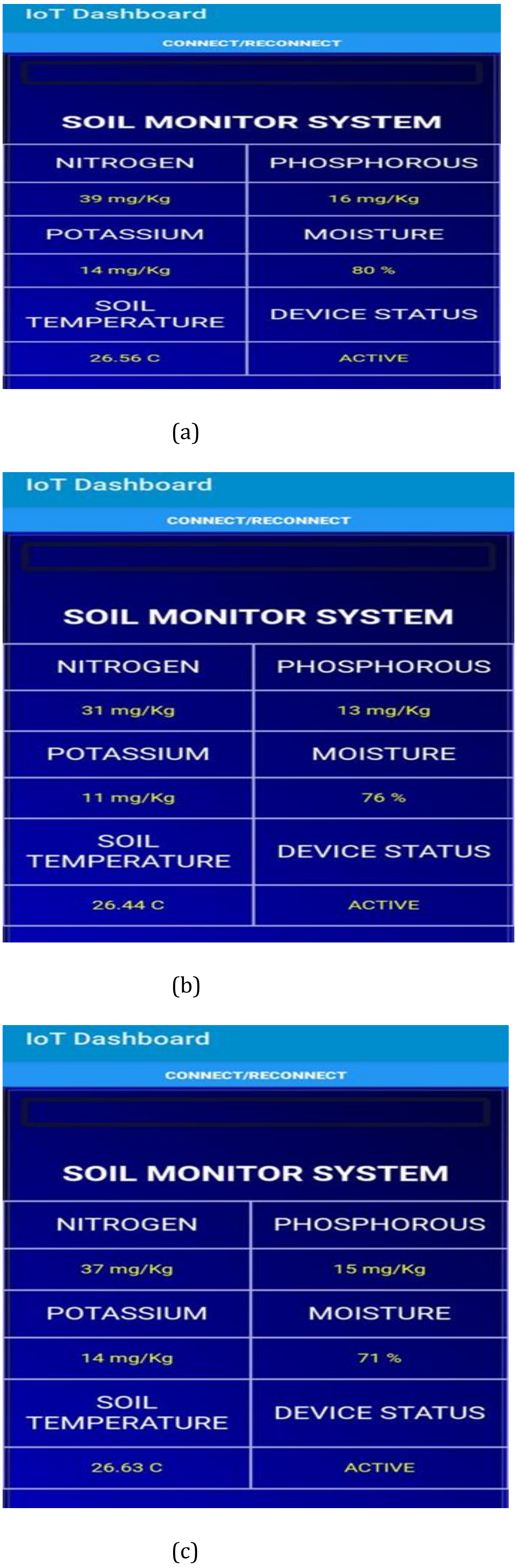

Figure 7. Mobile app. showing test results of soil samples taken from (a) Agricultural Engineering department garden, (b) Electrical Engineering department garden and (c) school field.

3. Results and discussion

In this section, graphical illustrations of the outcomes of performance tests conducted on soil samples as treated in section 2.6 were presented. These outcomes typified results of the soil test using the proposed IoT scheme which indicated the quantity or amount of N, P and K, temperature and moisture content of the soil samples. These data were used as metrics upon which the performance of the IoT scheme was evaluated. Figure 8 presented the amount of N, P and K existing in the soil sample taken from Agricultural Engineering garden while Figure 9 presented the amount of N, P and K existing in the soil sample taken from Electrical Engineering garden. Figure 10 illustrated the quantity of N, P and K present in the soil sample taken from the school field.

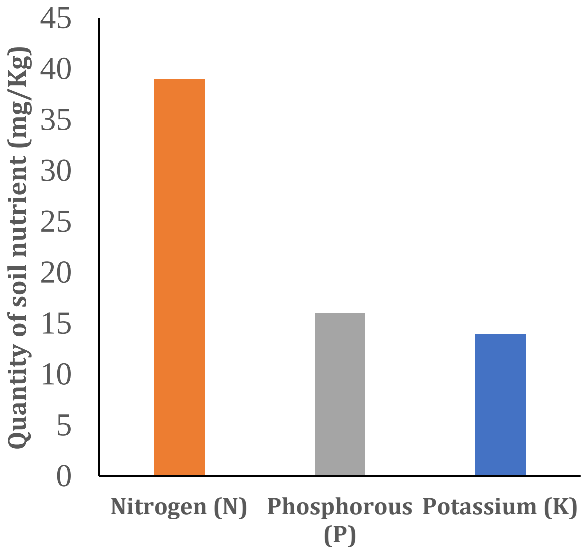

Figure 8. Amount of N, P, and K in soil sample taken from Agricultural Engineering department garden.

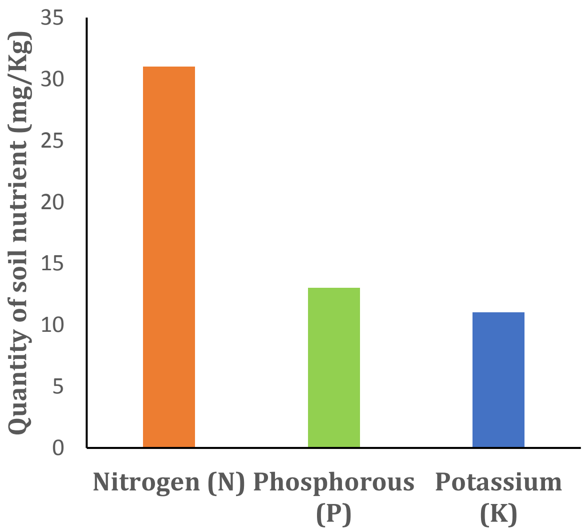

Figure 9. Amount of N, P, and K in soil sample taken from Electrical Engineering department garden

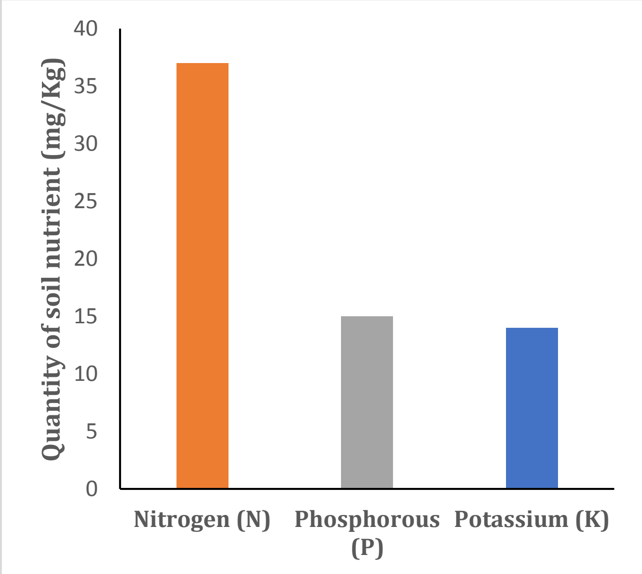

Figure 10. Amount of N, P, and K in soil sample taken from the school field

It was observed in Figure 8 that the quantities of N, P and K in the soil sample from Agricultural Engineering garden were 39, 16, and 14mg/Kg, respectively while Figure 9 revealed that the amounts of N, P and K in the soil sample from Electrical Engineering garden were 31, 13 and 11 mg/Kg, respectively. In addition, Figure 10 showed that N, P and K quantities were 37, 15 mg/Kg and 14 mg/Kg, respectively in the soil sample taken from the school field. Thus, the developed IoT scheme provided real-time data on the quantities of N, P and K in all the soil samples, indicating the system's effectiveness in testing the soil. Based on soil nutrient indices presented in [31], it was realized that all the soil samples contained adequate and essential nutrient for supporting crop production. The presence of N in these soil samples is suitable for building plant protein, supports formation of amino acids and plant growth. It is also an essential component of vitamins, chlorophyll and enzymes. Phosphorous plays great role in the formation of root and helps in better usage of water resources. It increases the rate of crop maturity and is essential in improving the quality of the grain crops. The presence of K in these soil samples plays vital role in plant's photosynthesis and metabolism. It is essential in helping plant to adjust to stress and withstand drought [32].

It was noticed also in Figures 8-10 that the amount of N was higher than P and K quantities in all the soil samples while K was the least in all the samples which was in line with the expectation as N is one component that is required in very large amount in the soil for plant growth [33]. This result lends credence to the accuracy of the proposed IoT scheme in testing the soil.

Furthermore, Figure 11 compared N, P and K compositions of all the soil samples. This is done in order to identify the soil sample that has the best mineral composition and most fertile for farm practice

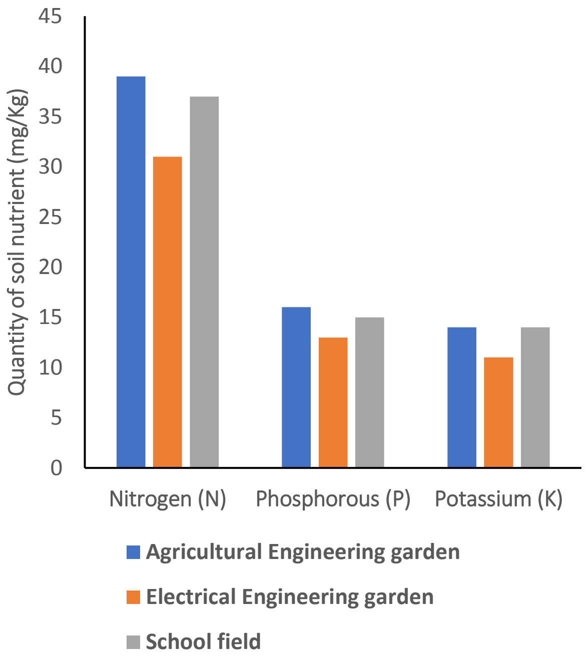

Figure 11. Comparison of amount of N, P and K in soil samples taken from Agric Engineering garden, Electrical Engineering garden and school field.

It was observed from Figure 11 that the soil sample from Agricultural Engineering garden had the highest amount of Nitrogen and Phosphorous with 39 and 16 mg/Kg, respectively. This was closely followed by soil sample from the school field which had Nitrogen and Phosphorous contents of 37 and 15 mg/Kg, respectively. It was also noticed in Figure 11 that Agricultural Engineering garden and school field soil samples had the same amount of Potassium, which was 14mg/Kg. The Electrical Engineering garden soil sample had the least amount of nutrient with N, P and K as 31, 13 and 11 mg/Kg, respectively. These results indicated that soil sample from Agricultural Engineering garden had the best soil nuitrient and could be said to be the most fertile of the samples considered.

However, Figure 12 compared the moisture retention abilities of the soil samples taken from Agric Engineering garden, Electrical engineering garden and school field. This result was also product of performance evaluation earlier presented. It was clearly seen in Figure 12 that the amount or quantity of moisture in the soil sample from Agricultural Engineering garden was higher than the quantity of moisture in the soil samples from Electrical Engineering garden and school field. This showed that the soil sample from Agricultural Engieneering garden retained moisture better than the two other samples. Moreover, Figure 13 presented the temperature readings of all the soil samples used as candidates for assessment in this work. It was revealed in Figure 13 that the soil sample from the school field had the highest temperature reading of 26.63 ^{o}C while the Electrical Engineering garden soil sample had the least temperature reading of 26.44 ^{o}C. The temperature of the soil sample from Agric Engineering garden was intermediate with the value of 26.56 ^{o}C

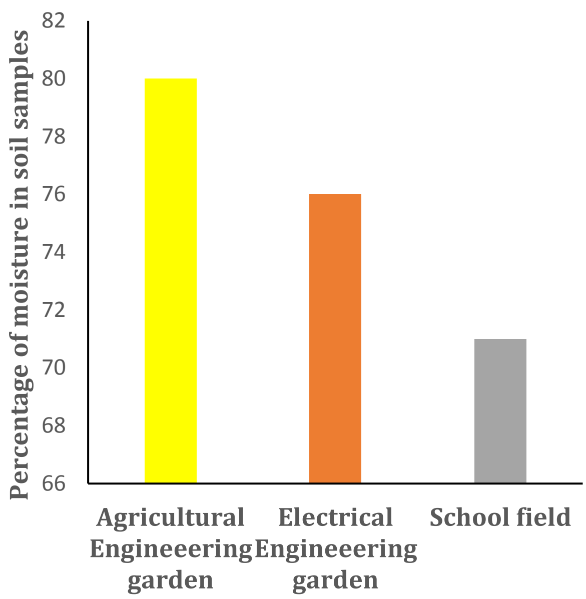

Figure 12. Comparison of moisture present in the soil samples.

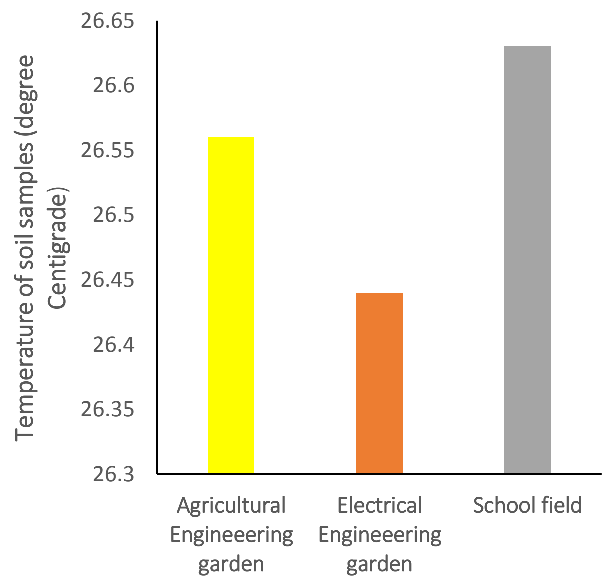

Figure 13. Comparison of temperature readings of the soil sample

.

Table 1 compared the performance of the proposed IoT scheme with existing works in the literature. The performance indices utilized as basis for comparison were power consumption, technology used, mobile application deployment, network connectivity, automation and nutrients monitoring.

Table 1. Perfomance comparison of the proposed IoT scheme with existing works in the literature

Performance indices	Reference [3]	Reference [4]	Reference [9]	Reference [11]	Proposed IoT scheme
Power Consumption	Medium	Low	High	High	Low

Technology used	IoT	IoT	IoT	IoT	IoT
Mobile application deployment	No	No	No	No	Yes
Network connectivity	IEEE 802.11	Bluetooth	Bluetooth	Bluetooth	IEEE 802.11
Automation	Smart	Smart	Smart	Smart	Smart
Nutrients monitoring	NO	No	No	No	Yes

It could be seen from table 1 that the proposed system improved on the existing works in terms of power consumption, nutrient monitoring and mobile application deployment for easy tracking of the results of the soil test by the farmers.

4. Conclusion

This work developed an IoT-based scheme that integrated hardware components like NPK sensor, capacitive soil sensor, Dallas temperature sensor, and ESP8266 microcontroller with software components including mobile application and communication module. The proposed scheme utilized less power and provided information such as nutrient, moisture, and temperature of the soil which improved on the existing works in the literature that focused largely on IoT system for measuring moisture and temperature of the soil. Tests conducted to examine the performance of the proposed scheme using soil samples from Electrical Engineering garden, Agricultural Engineering garden and football school field of College of Engineering and Environmental Studies, Olabisi Onabanjo University, Ogun State, Nigeria, demonstrated the system's capability in providing accurate and reliable data on soil nutrient, temperature and moisture.

Analysis of the results of the performance test viewed through the mobile application deployed on IoS and android devices, revealed that the mineral compositions of soil sample taken from Agricultural Engineering garden were higher than the soil samples taken from Electrical Engineering and school field. It was found that N= 39mg/Kg and P= 16mg/Kg in the soil sample from Agricultural Engineering garden while N=37mg/Kg and P=15mg/Kg in the soil sample from the school field. It was however found that N= 31mg/Kg and P=13mg/Kg in the soil sample from Electrical Engineering garden. It was seen that the potassium content of the soil samples from Agricultural Engineering garden and school field was the same with K=14mg/Kg in the two samples. Furthermore, comparison of the soil nutrient of these soil samples with nutrient indices presented in the literature revealed that those soil samples contained adequate nutrient for crop production.

It was observed that the school field soil exhibited the highest temperature reading of 26.63 ^{o}C. It was seen that the amount of moisture (80%) in the soil sample from Agricultural Engineering garden was better than others. This indicated that Agricultural Engineering soil sample had better moisture retention capability than others. The proposed IoT scheme demonstrated ability to operate in various loamy soils and highlighted potential for widespread adoption in agricultural practices for soil testing. Though the proposed system was suitable for small and medium scale agriculture, future work should focus on scaling up the system for large scale agricultural operation. In addition, future development could incorporate additional sensors for monitoring pH level, salinity, and soil organic matter.

Acknowledgement

The authors acknowledge the valuable comments of anonymous reviewers which greatly help in improving the first draft of this manuscript.

Author contributions

Akeem Abimbola Raji: Conceptualization, Methodology, Investigation, Writing the Original Manuscript, **Joseph Folorunso Orimolade:** Investigation, Review, and Correction of Grammar, **Ibrahim Adewale Ewetola:** Investigation, Writing, Review and Editing.

Conflicts of interest

The authors declare no conflicts of interest

.

References

1. Pandao, M.R., Thakare, A.A., Choudhari, R.J., Navghare, N.R., Sirsat, D.D. & Rathod, S.R. (2024). Soil health and nutrient management. International Journal of Plant and Soil Science, 36(5), 873-883.
2. Olivares, B.B., Araya, M.A., Rey, J.C., Salnas, P.C., Kurina, F.G., Balzarini, M., Lobo, D., Navas-Cortes, J.A.,Landa, B.B., & Gomez, J.A. (2020). Relationship between soil properties and Banana productivity in the two main cultivation areas in Venezuala. Journal of Soil Science and Plant Nutrition, 20, 2512-2524.
3. Islam, M-R., Oluliah, K., Ksbit, M-M., Alom, M., & Mridha, M.F. (2023). Machine Learning enabled IoT system for soil monitoring and crop recommendation. Journal of Agriculture and Food Research, 14, 1-12.
4. Mohammad Shamiur, R-A., Arnab, P.S., Tsou, J.C., Rahman, H. (2021). IoT based soil monitoring and automatic irrigation system in rural area of Bangladesh. Acta Mechatronica-International Scientific Journal about Mechatronics, 6(3), 29-40.
5. Pizol, N.S., Adnan, R. ,& Tajjudin, M. (2020). Design of an Internet of Things (IoT) based smart irrigation and fertilizer system using fuzzy logic for Chilli plant. In Proceedings of 2020 International Conference on Automatic Control and Intelligent Systems, 69-73.
6. Pyingkodi, M., Thenmozhi, K., Karthikeyan, M., Kalpana, T., Palarimath, S., & Ajith Kumar, G.B. (2022). IoT based soil nutrients analysis and monitoring system for smart Agriculture. In Proceedings of the Third International Conference on Electronics and Sustainable Communications Systems (ICESC 2022), 459-494.
7. Nisar, A., Ali, H., Ihsan, U., & Bizzart, H. (2019). IoT based wireless sensor network for precision

agriculture. In Proceeding of 2019 7th International Electrical Engineering Congress (iEECON). https://doi.org.10.1109/iEECON45304.2019.8938854.

8. Sakpale, M-S., & Patil, R. (2019). Soil monitoring using IoT technology. CIKITUS Journal for Multidisciplinary Research, 6 (5), 457–461.

9 Bhaskar, C.V., Lakshmipriya, A., Hemapriya, K., HemanthKumar, A., & Kireeti, V.T. (2022). Soil Moisture Detection and Monitoring through IoT, Journal of Electronics and Communication Engineering Research, 8 (4), 10-13.

10 Dahou Idrissi, A., Abouabdillah, A., Chikhaoui, M., & Bouabid, R. (2024). Low cost IoT based monitoring system for precision Agriculture. In Proceedings of E3S Web of Conferences, 492, 1-9.

11, Debashi, M-S., & Rehana, K. (2022). Smart monitoring of soil parameters based on IoT. International Journal of Advanced Technology and Engineering Innovation, 9 (88), 401-412.

12. Laha, S-R., Pattanayk, B-K., Pattnaik, S., Mishra, D., KumarNayak, D-S. & Dash, B-B. (2023). An IoT based soil moisture management system for precision agriculture: real –time monitoring and automated irrigation control. In Proceedings of the Fourth International Conference on Smart Electronics and Communication, 451-455

13. Ananthi, N., Diyya, J., Diyyya, M., & Janani, V. (2017). IoT based smart soil monitoring for agricultural production. In Proceedings of IEEE International Conference on Technological Innovations in ICT for Agriculture and Rural Development, 209-214.

14. Sathishkumar, R. & Rathinavel, S. (2024). Harvesting precision: A holistic approach to sustainable Agriculture through advanced water management and crop health optimization. International Journal of Progressive Research in Engineering Management and Sciences, 4(3), 882-900.

15. Muthukumarasamy, S., Balakrishnan, C., Anusha, P., & Neena, S. (2022). A sensor-based IoT for precision Agriculture. International Journal of Creative Research Thoughts (IJCRT), 10 (6), 15-20.

16. Odey, J.O., Anunuso, J.C., Alkali, B., Agonga, F.O., & Lawal, S.S. (2021). Soil monitoring and irrigation system. In Proceedings of 6th National Engineering Conference of the Nigerian Institution of Mechanical Engineers, Minna Chapter, 151-165.

17. Placidi, P., Morbidelli, R., Fortunati, D., Papini, N., & Gobbi, F. (2021). Monitoring soil and ambient parameters in the IoT precision Agriculture scenario: an original modelling approach dedicated to low-cost soil water content. Sensor Journal, 21 (5110), 1-28. https://doi.org.10.3390/s21155110.

18 Rifat, A., Prince Patel, & Baba, B.S. (2022). The Internet of Things (IoT) in Agriculture monitoring. European Journal of Information Technologies and Computer Science, 2 (1), 14-18.

19 Muthmanah, M., Mulyadi, M.F., Agusmulyono, I.T., Tazi, I., Mulyono, A., Hananto, F.S., Chamidah, N., & Kusari (2024). Development of an automated monitoring system for soil moisture and temperature in smart Agriculture to enhance Lettuce farming productivity based on IoT. Multidisciplinary Science Journal, 6, 1-7.

20. Nugroho, A.P., Kusumawati, N.B., Murtiningrum Wiratmoko, A., Haryadi, I.M., Pradana, Suwardi, F.A., Sukarman, S., Primandanda, & Sutiarso, L. (2023). Development of soil moisture content monitoring system for precision measurement of soil moisture in sub-optimal land for palm oil plantation. In Proceedings of BIO Web Conference, 69, 1-10.

21. Wu, Y., Yang, Z., & Liu, Y. (2023). Internet of things based multiple sensor monitoring system for soil information diagnosis using a smart phone. Micromachines, 14 (1395), 1-20. https://doi.org/10.3390/mi14071395

22. Adamchuk, V.I., Hummel, J.W., Morgan, M.T., & Upadhayaya, S.K. (2004). On the-go soil sensors for precision Agriculture. Computing and Electronics in Agriculture, 44, 71-91.

23. Hyder, U., & Talpur, M.R.H. (2024). Detection of cotton leaf disease with machine learning model. Turkish Journal of Engineering, 8(2), 380-393.

24. Othman, M.N(2023). Modelling of daily ground water level using deep learnign neutral network. Turkish Journal of Engineering, 7(4), 331-337.

25. Pomeroy, S.L., Tamayo, P., Gaasenbeek, M., Sturla, L.M., & Angelo, M. (2002). Prediction of central nervous system embryonal tumor outcome based on gene expression. Letter to Nature, 436-442

26. Othaman, N.N.C., M.D. Isa, M.N., Hussin, R., Zakaria, S.M.M.S., & Isa, M.M. (2021). IoT based soil nutrient sensing system for Agriculture applications. International Journal of Nanoelectronics and Materials, 14, 279-288.

27. Bondre, D.A., & Mahagaonkar (2019). Prediction of crop yield and fertilizer recommendation using machine learning algorithm. International Journal of Engineering Applied Sciences and Technology, 5(5),371-376.

28. Babashli, B., Badalova, A., Shukurov, R., & Ahmadov, A. (2024). Cotton yield estimation using several vegetable indices. Turkish Journal of Engineering, 8(1), 139-151.

29. Karakurt A.B., & Ertugruk, O.L. (2023). Effect of rish husk ash addition on the consolidation characteristics of cohesive soils. Engineering Applications, 2(1), 7-15.

30. Karakurt A.B., & Ertugruk, O.L. (2023). A laboratory study on the liquid limits of cohesive soils improved with rice hush ash. Advanced Engineering Science, 3, 8-14.

31. Abdul Mohammed, M., & Abdu Yusif, S. (2020). Evaluation of soil fertility for maize (MUZEA MAYSL) production in Dawakin Kudu, Kano, Nigeria. FUDMA Journal Series, 4(1), 617-622.

32. Ubwa, S.T., Anhwange, B.A., Igbum, G.O., & Asemave, K. (2012). Contents of nutrient in soil form selected parts in Nigeria. International Journal of Modern Chemistry, 1(1), 36-44.

33. Silva, J.A. & Uchida, R. (2000). Essential nutrient for plant growth: Nutrirent functions and deficiency symptoms. In plant Nutrient management in Hawaii soils, approaches for tropical and subtropical Agriculture. In College of Tropical Agriculture and Human resources, University of Hawaii ed., 31-39.

.