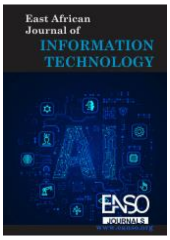

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Original Article

Real-Time Monitoring of Parameters Contributing to Soil Quality in Palm Oil Plantation

Beatrice Eugen Mayowela[1] & Dr. Juma Said Ally, PhD[1]*

[1] Mbeya University of Science and Technology, P. O. Box 131, Mbeya, Tanzania.
* Correspondence ORCID ID: https://orcid.org/0000-0002-0805-6178; email: bmayowela@gmail.com.

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Real-time Monitoring, Soil Quality, Sensor, Soil Parameter

ABSTRACT

Soil sustains the life of both animals and plants in the world. Most agriculture activities are conducted in soil. Real-time soil parameter data were collected in three villages of Kyela district (Kisare, Lupaso, and Mabunga) lowland zones during the September 2023 dry season. Observed real-time parameters were soil pH, Electric conductivity, temperature, Nitrogen, Phosphorous, Potassium, and humidity. Soil sensor, multifunctional converter, solar panel, 4G WIFI, and cloud platform (USRIOT) were used. The result shows that nitrogen, potassium, phosphorus, pH, and Electric conductivity have a positive correlation with each other while demonstrating a negative correlation to pH and temperature. Although outliers were observed in real-time nitrogen, phosphorus, potassium, and electric conductivity datasets, they denote a wide variation of such parameters in selected villages. Furthermore, the selected study area demonstrates a relatively low amount of phosphorus compared to other macronutrients.

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INTRODUCTION

Soil is the unconsolidated outer layer of the Earth's crust soil (Funk, 1983). Soil supplies nutrients, water, and air to plants and act as a medium for the decomposition of plants and animal residual. It comprises macronutrients (Nitrogen, Phosphorus, and Potassium), micronutrients (magnesium, calcium, boron, zinc), and organic matter. Ali et al. (2020), Chukwu et al. (2023), and Bagnall et al. (2023) reveal that soil macro and micronutrients, soil organic matter, pH level, soil water potential, pesticides, pathogens, and temperature are the important parameters to analysis the quality of soils. Many farmers embark on crop cultivation without doing real-time soil monitoring. An excess of nutrients and inorganic pollutants can also be taken up through the root system and accumulate in grain or fruit (Lehmann et al., 2020), causing environmental risk (Argento et al., 2021), while insufficient levels of nutrients constrain yields (World Food and Agriculture, 2022). For sustainable and precision agriculture, real-time soil monitoring is inevitable.

Soil testing laboratories take time to give the analysis report, are labour-intensive, and do not truly represent soil conditions (Salam et al., 2019; Peng et al., 2019; Angelopoulou et al., 2019; Zhang et al., 2019). Farmers are unable to decipher the scientific and technical information provided in the report, and this process is not instantaneous; therefore, it is ineffective for day-to-day analysis (Sandeep, 2022).

Plants absorb water and nutrients through roots. Soil parameters such as pH, electric conductivity, temperature, humidity (Luo et al., 2019), and nutrients contribute to soil's chemical and physical properties. Various sensors such as pH sensor, humidity sensor, electric conductivity sensor, soil insect/pest sensor, soil pollutants sensor, plant wearables, and nutrients sensors facilitate real-time monitoring (Yin et al., 2021; Lu et al., 2020; Sehrawat & Gill, 2019). These sensors, such as solar energy, consume low energy (Kumar et al., 2019) and can be integrated with cloud applications even in constrained environments.

Real-time monitoring is the process of collecting, observing, and analysing data at regular intervals for immediate decision-making. This approach facilitates a wide investigation of soil health at specified times from multiple locations.

Real-time soil monitoring is growing widely with the aid of the advancement of cost-effective technology. The global market for soil moisture sensors was estimated at $147.5 million in 2020 and is projected to reach $360.9 million by 2027 (Yin et al., 2021). Next-generation electronics should be applied to enable cheap and distributed sensor deployment, fast data transmission, storage, and handling, and need to make use of the rapid development in the computing and smart-grid sector to develop internet-of-things sensor networks for soil-health monitoring (Lehmann et al., 2020).

Initially, the precision agriculture field used ground-buried sensors to identify organic matter in the soil, but nowadays, satellites, aircraft, and vehicle-mounted sensors are employed (Ramesh & Rajeshkumar, 2021). This innovation has made the real-time monitoring of soil to be possible at large. IoT technologies such as Arduino sensors and modules, mobile applications, and ZigBee techniques have been used for monitoring soil properties. Various real-time irrigation systems (Filgueiras et al., 2020; Jamroen et al., 2020) and fertilisation systems (Argento et al., 2021) have been designed to simplify intensive farming activity, especially for large-scale farmers.

LITERATURE REVIEW

Misbah et al. (2022) review the state of the art of the use of remote sensing to monitor Nitrogen, Phosphorus, and Potassium content in selected African countries. Airborne imaging technology was used. The hyperspectral data-based research protocol was proposed to quantify the variability of NPK in soil and crop at the field scale for the sake of optimising fertiliser application. The study focuses only on macronutrients and excludes other soil parameters such as pH, electrical conductivity, humidity, and temperature.

Sandeep (2022) developed a CropsIT- portable soil analysis and crop suggestion system. DHT11 was used for measuring temperature and humidity, a colour sensor for pH, Arduino Uno for integrating all activities done by the sensor, and LEDs for NPK based on their wavelength. The output was sent to the web server and can be viewed by farmers in real-time logs.

Salam et al. (2019) used the Internet of Underground of Things (IOUT). They developed the model Di-Sense for real-time soil moisture and permittivity estimation based on wireless underground communication (WUC). Antennae were buried at a certain depth in the soil and propagated the signal; thereby, measurement of these signals will determine the path loss that will act as input to the model for estimation.

A low-cost platform was implemented for real-time soil moisture and environmental parameters monitoring. Soil moisture sensor, environmental sensor, drone, and web server were used. Data were gathered from IoT sensor using LoRa and 4G; thereafter, the farmer can view real-time analysis report through a web application/smart device for decision-making. Monitored parameters were soil moisture, and weather parameters were temperature, humidity, rain, and solar radiation (Almalki et al., 2021).

Arduino UNO-based onion growth monitoring system that uses Thing Speak (an Open-source cloud computing tool) was used to reduce labour costs. Smartphones, sensors, tablets and cameras were used. Soil moisture, humidity and temperature sensors were used to monitor the soil's onion area, then integrated into Arduino board, Arduino IDE, GSM module, and cloud storage. Other parameters, such as soil nutrient pH, were not monitored; however, onions' leaf colour change was observed periodically (Gadde et al., 2022).

Deng et al. (2020) proposed a novel soil environment monitoring system to monitor soil temperature, moisture content, and chloride ion concentration. The monitoring system comprises an RFID sensor, patrol car, farmland monitoring centre, and cloud platform. The patrol car collects information on the RFID sensors embedded in the soil and then communicates with the monitoring centre through Lora.

A review was done on smart environment monitoring (SEM) systems involving monitoring of air quality, water quality, radiation pollution, and agriculture systems. The authors have critically studied how the advances in sensor technology, IoT, and machine learning methods make environment monitoring a truly smart monitoring system. The author finds that the number of publications on WSN and IoT has increased compared to machine learning and IoT from 1995 to 2020 (Ullo & Sinha, 2020).

Said Mohamed et al. (2021) in Egypt reviewed how a 5G mobile network can help in interactive real-time monitoring in developing smart systems, as it leads to high-speed data transfer, up to 20 Gbps, and can link many devices/sensors per square kilometre. The author reveals how developing countries face challenges in implementing smart farming and the significant contribution of government.

A review of publications over the past ten years (2008 and 2021) in selected African countries reveals that only 26 publications explicitly aimed to quantify soil NPK content using remote sensing. Regarding the studied nutrients covered in the 26 retained studies, N has ranked first with 23 publications in total, followed by P with 12 papers and K with six papers. However, among these publications, none consider other soil parameters like humidity, pH, and temperature, which are essential in the real-time monitoring of soil health (Misbah et al., 2022).

Madhumathi et al. (2020) in India used a Wireless Sensor Network to enable remote monitoring of soil parameters (Nitrogen, Phosphorus, Potassium, temperature, humidity, and pH) from selected soil samples. Arduino microcontroller, ESP8266 Wi-Fi module, and cloud application (Amazon web service) were used. However, Electric conductivity was not monitored.

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Various research was done on real-time monitoring of soil quality using sensors and Arduino microcontroller, and various soil parameters like temperature, pH, humidity, nitrogen, phosphorous and potassium were investigated. However, the research on soil parameters contributing to palm oil plantations was not addressed. Therefore, this study aims to investigate temperature, humidity, electric conductivity, nitrogen, phosphorous and potassium in palm oil plantations.

RESEARCH METHODS

Data collection instruments

Data is very important in any research. This study was based on observation of real-time data in selected villages' locations. Actual readings of pH, temperature, humidity, electric conductivity, nitrogen, potassium and phosphorous were observed in the monitoring screen of the user cloud platform. Real-time sensor readings were observed every second, and any variation could be observed clearly on the user monitoring screen. Furthermore, historical data in CSV (comma-separated value) format was downloaded for further data processing and analysis.

Plate 1: Screenshot observation of real-time monitoring screen

Source: Field data, 2023

Study Area

The study was conducted in three villages of Kyela (9° N, 33° E) in arable land with palm oil plantations. Lupaso (altitude 481 m), Kisare (altitude (512 m) and Mabunga altitude (540 m). The selected villages are lowland zones, and they were chosen because they possess some soil moisture, making it easy for the sensor probe to penetrate.

Collection of Field Data

Data were collected from September 1, 2023. Three pairs of sensors were used around a given palm oil plantation to obtain various soil parameters (nitrogen, phosphorus, potassium, pH, electrical conductivity, temperature, and humidity). The topsoil of 0 cm to 25 cm was dug (near the palm roots' tree). A soil depth of 10 cm to 60 cm has a holding capacity of 60 mm (for sand soil) and 140 mm (for clay soil) (Funk, 1983).

Villages were located remotely, far from the electric power supply source. A solar panel (10V) was assembled to supply power to the sensor and multifunctional converter. 4G pocket WIFI was used to enable the sensor to send data to the cloud platform (USRIOT) and view them in real-time from the laptop screen.

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Plate 2: Field data collection (a): device setup, (b): sensor mounted horizontally, (c): sensor mounted vertically

a **b** **c**

Source: Field data, 2023

Data presentation

The data presented were a mixture of both integer and float. Soil temperature was measured in °C, soil humidity in %, soil electric conductivity in uS/cm, soil nitrogen in mg/kg, soil phosphorous in mg/kg and soil potassium in mg/kg.

Plate 3: data type

#	Column	Non-Null Count	Dtype
0	Nitrogen (N)	230 non-null	int64
1	Phosphorous (P)	230 non-null	int64
2	Potassium (K)	230 non-null	int64
3	pH	230 non-null	float64
4	Humidity	230 non-null	float64
5	Temperature	230 non-null	float64
6	Electric conductivity (EC)	230 non-null	int64

Data processing

Historical data in CSV format were downloaded from each pair of sensors. It was observed that there were slight variations in sensor readings within the same mounted location. The average was calculated to obtain the mean value for analysis.

$$\overline{Sensor\_readings} = \frac{\sum(Sensor\_readings)}{N}$$

Downloaded data may contain null values that are not required for data analysis. Jupyter Notebook with Python 3 was used for data analysis. Libraries that were used include numpy for numerical analysis, pandas for reading CSV files from specified storage locations, matplotlib and seaborn for plotting boxplots and heatmaps.

RESULTS

pH is a measure of how acidic/basic soil is. It ranges from 0 to 14, whereby pH below 7 is acidic soil, pH 7 is neutral, and pH above 7 is base. The ideal land condition for Oil palm is fertile, loose soil and a pH of 5.0 to 5.5 (Satriawan et al., 2021). Soil pH in field data ranges from 3 to 7.5, which indicates that the study area has both acidic and basic soil.

Humidity is another important factor that determines soil quality. Even though real-time soil monitoring was in the dry season, findings

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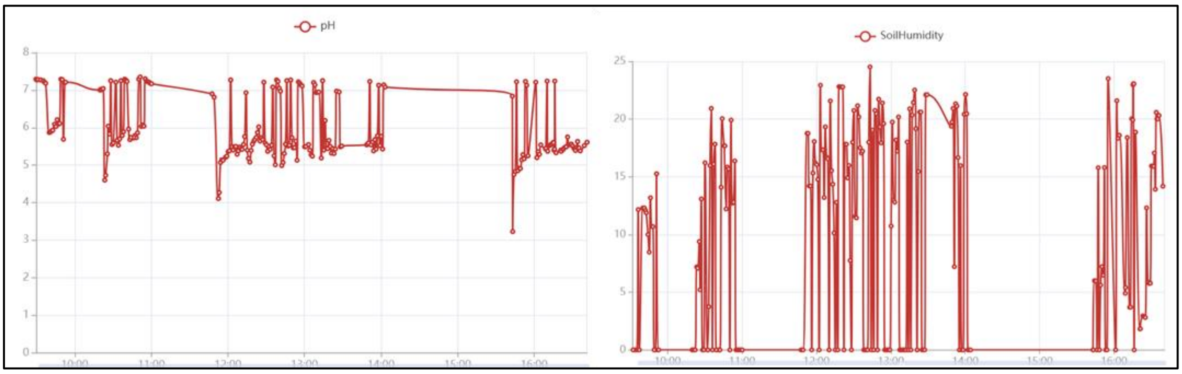
demonstrate that soil humidity ranges from 0 to 25.

Figure 1: (a) indicates real-time monitoring of soil pH, (b) shows real-time monitoring of soil humidity



Source: Field data

Electric conductivity EC measures the amount of fertiliser available for plant growth or indicates an accumulation of salts in the media (Camberato et al., 2001). Both macronutrients and micronutrients dissolve in soil and create positive and negative charges. Factors influencing the electrical conductivity of soils include the amount and type of soluble salts in solution, porosity, soil texture (especially clay content and mineralogy), soil moisture, and soil temperature (Conductivity, n.d.). From the findings, EC varies from 0 to 320 while soil Temperature ranges from 23 ˚C to 33 ˚C.

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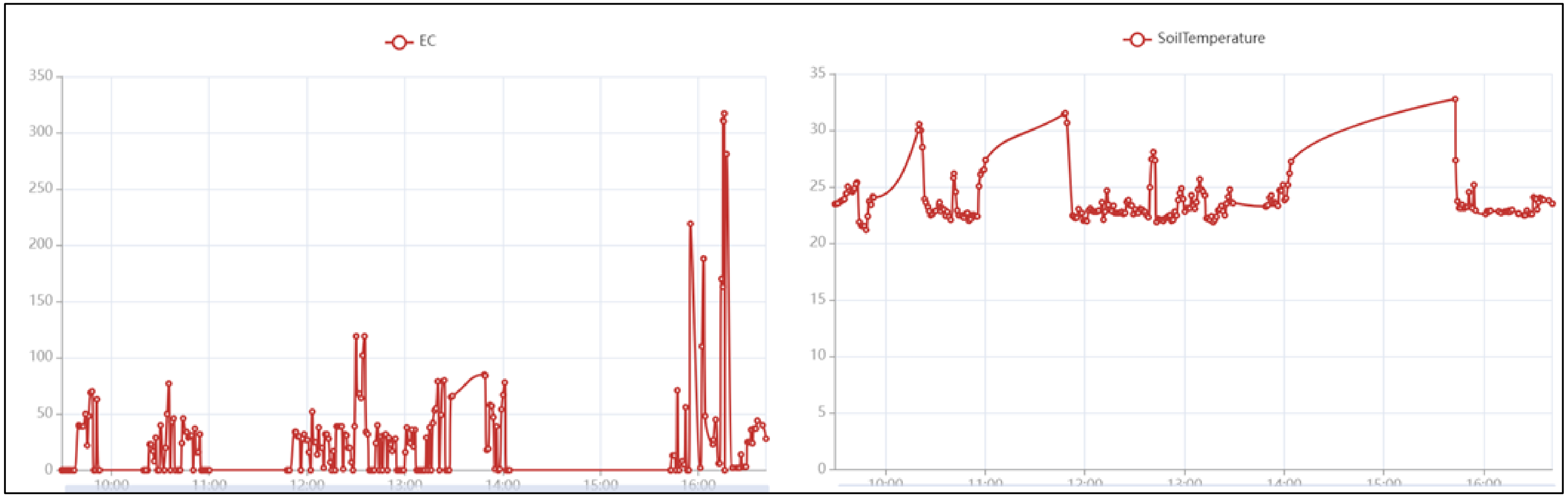
Figure 2: Real-time monitoring of Electric conductivity and Soil Temperature

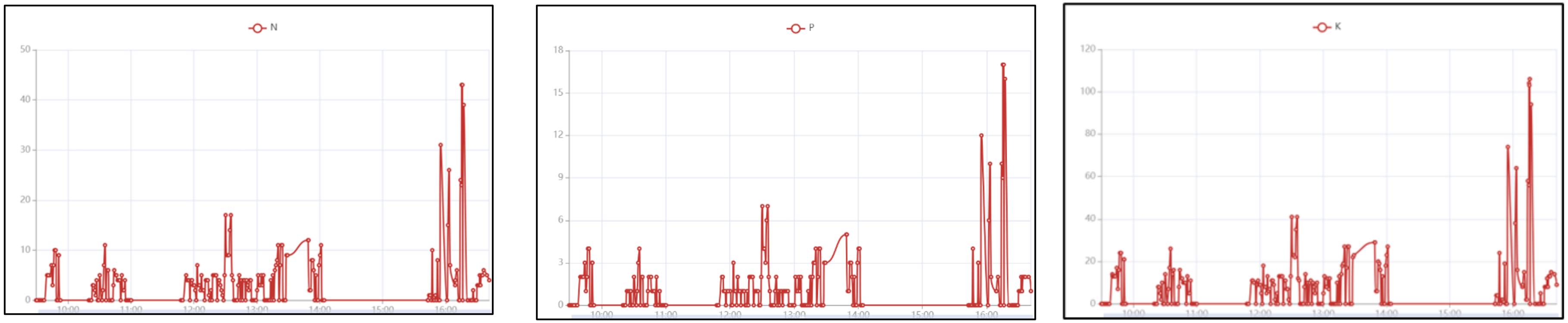
a **b**



Source: Field data

Figure 3: Real-time data of (a) Nitrogen (N), (b) Phosphorus (P), and (c) Potassium(K)

a **b** **c**



Source: Field data

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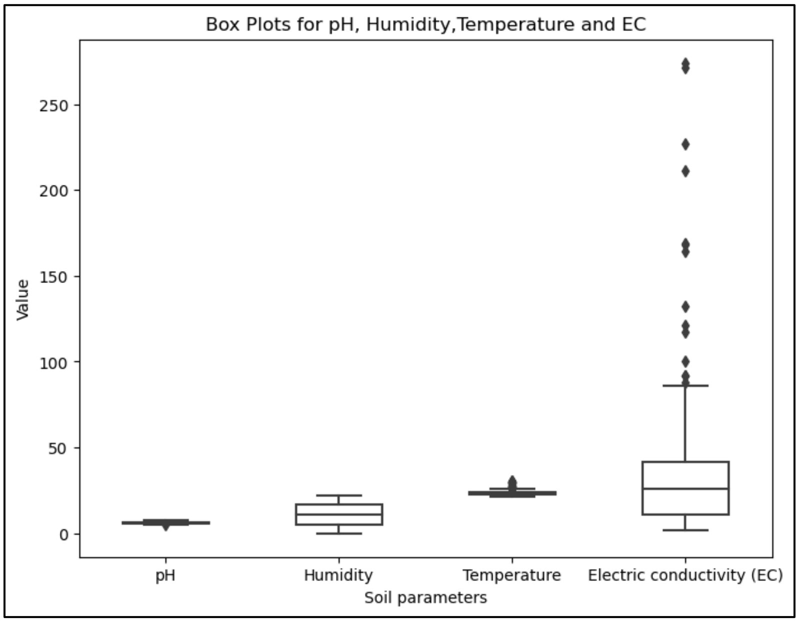
Nitrogen, Phosphorus, and Potassium are known as soil macronutrients. These nutrients are required in large amounts. Nitrogen gives plants a green colour, hence responsible for chlorophyll production. Phosphorus helps the development of plants' roots and flowers, while potassium helps plants to fight diseases and retain water.

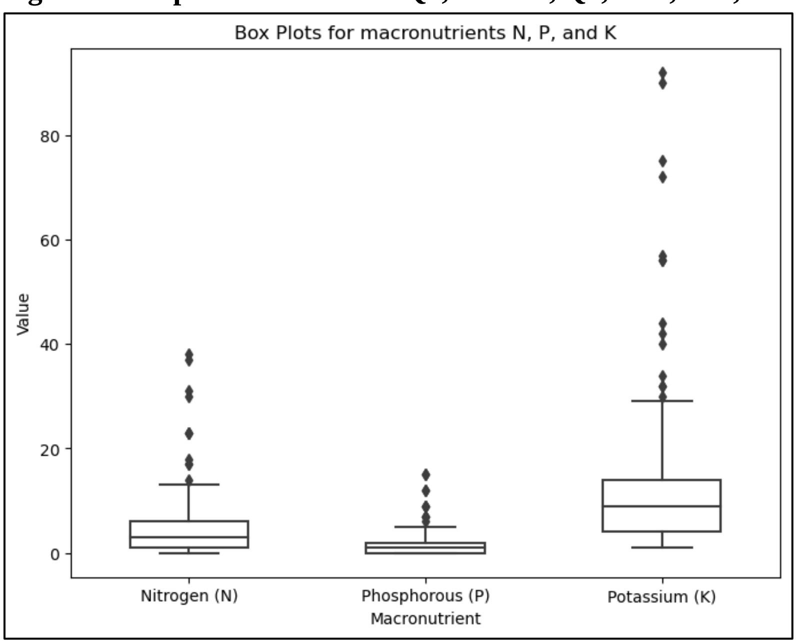
The results clearly show that there is a high variation of all seven factors as observed in real-time. The box plot below shows the first quantile (Q1), median second quartile (Q2), maximum, minimum, and outlies of gathered real-time data.

Figure 4: Box plot Indicate Q1, Q2, median, and outliers for pH, Humidity, Temperature, and EC



Source: Author, 2023

Figure 5: Boxplot demonstrates Q1, median, Q2, max, min, and outlier for N, P, and K



Source: Author, 2023

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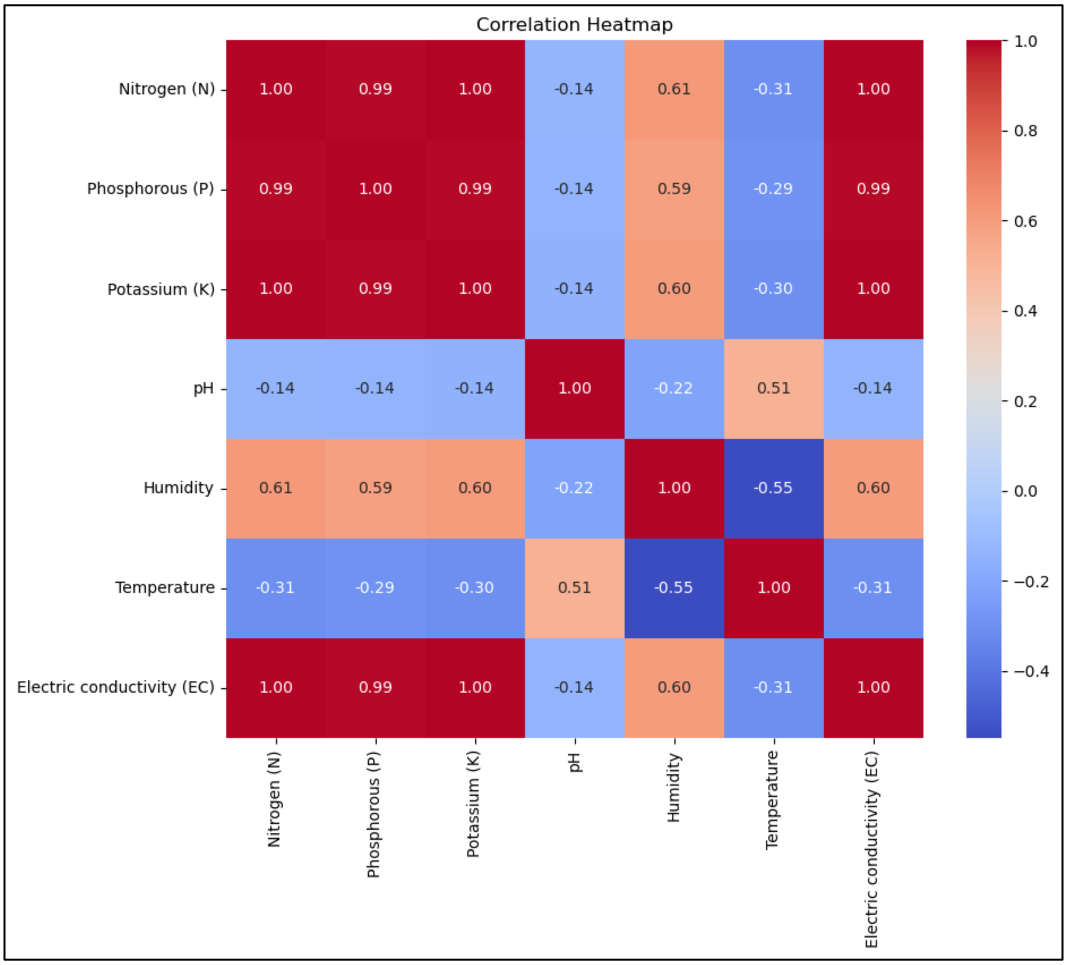
The box shape within the plot demonstrates the greater distribution of data points found within that range (50%). Extension lines from the box indicate other real-time data points greater/less than available data points in a box. Gathered real-time data suggest that factors such as N, P, K, and EC showed outliers. Outliers are data points that extend beyond the maximum. This indicates that soil from field data significantly varies in the given soil parameters. Outliers, in this case, illustrate the real scenario from field data. Even if outliers are often considered a miscalculation or noise, they may bring significant information (Smiti, 2020).

Figure 6: Heat map showing a correlation in factors contributing to soil quality in palm oil



Source: Author, 2023

Correlation ranges from positive (1) one to negative one (-1). The value in the diagonal running from the top left corner to the bottom right corner denotes a highly correlated value; however, all the boxes with a 1.00 (red colour) represent the most highly correlated values. All macronutrients have a high value of positive correlation to one another. This indicates that they are required for optimal palm oil cultivation and need to be monitored more often. Humidity shows a positive correlation with EC, N, P, and K while demonstrating a negative correlation to temperature and pH. This illustrates that an increase in humidity/soil moisture leads to a decrease in soil temperature and pH. EC shows a high positive correlation to N, P, K, and humidity while a negative correlation to pH and temperature. N, P, and K demonstrate a negative correlation between temperature and pH. The findings clearly show that such variation in soil parameters is challenging and cannot be monitored by physical eyes. Real-time monitoring is vital to ensure soil quality and should be done routinely.

CONCLUSION

Real-time monitoring of soil parameters enhances soil quality for optimal palm oil yield. Technological advancement, low-cost sensors, and high-speed internet will make such applications feasible, especially in developing countries. Moreover, the availability of cloud platforms has, at large, improved real-time applications. As plants frequently consume nutrients, it is very significant to monitor them for sustainable decision-making on farmland. In the future, this research can be extended to more study areas (geographical regions) and a variety of weather seasons.

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