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Physicochemical Analysis of Soil before Planting, Growth and Harvest Stage of Yam (*Dioscorea* spp.)

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ABSTRACT

Physicochemical assessment of soil during yam cultivation (*Dioscorea* spp.) is essential for understanding nutrient dynamics, soil fertility, and crop productivity in tropical farming systems. This study evaluated the physicochemical properties of soils collected from three yam farms within the University of Benin community, Ovia North-East Local Government Area, Edo State, Nigeria. Soil samples were collected from a depth of 0-15 cm across the three different farms from pre-planting, during growth and harvest stage and analyzed. Standard laboratory procedures and Atomic Absorption Spectrophotometry were used to determine soil physical and chemical characteristics. Data obtained were analyzed using one-way Analysis of Variance at $p < 0.05$. Soil pH ranged from moderately acidic to near-neutral, with values between 5.55 and 7.21 across the farms. Temperature increased progressively from about 25.90°C at pre-planting to 29.10°C at harvest. Moisture content and organic matter declined during the growth stage before increasing slightly at harvest. In Farm 1, moisture content decreased from 12.65% to 10.13%, while organic matter reduced from 3.06% to 2.40% during growth. Nitrogen concentrations increased markedly, reaching peak values of 792.62 mg/kg, 632.21 mg/kg, and 1124.00 mg/kg in Farms 1, 2, and 3, respectively. Potassium and electrical conductivity declined during growth but improved slightly at harvest. Farm 3 also recorded increased phosphorus content of 27.19 mg/kg. The findings indicate active nutrient utilization and emphasize the importance of sustainable soil fertility management for improved yam production. Continuous organic matter supplementation, balanced fertilization, and routine soil monitoring are therefore necessary for maintaining productivity and long-term sustainability in farms.

Keywords: Yam cultivation, Crop productivity, Soil fertility, Nutrient dynamics, Tropical agricultural soils.

Introduction

Soil is defined as the upper weathered layer of the Earth's crust that can support life, providing essential water and a reservoir of various nutrients for plant and animal life. Soil is formed through the combined effects of climatic factors, including water, light, and temperature, alongside biotic factors like plants, animals, and microorganisms (Malik, 2017). Soil consists of various components, including inorganic and organic materials, along with living organisms, which depend on natural conditions and the type of soil. Based on soil properties, several types are identified, such as sandy soil, clay, loamy soil, calcareous soil, laterite, and peat soil. Soil quality is closely linked to agricultural activities and includes its physical, chemical, and biological properties.

These characteristics are essential for making soil suitable for farming (Wagh *et al.,* 2019). Composed of various minerals, organic matter, water, and air, soil demonstrates a complex nature. Soil quality also relates to environmental concerns, as agricultural soils often face contamination from synthetic fertilizers and pesticides. Additionally, industrial effluents discharged in agricultural regions and runoff from water sources significantly contribute to soil contamination. Soil quality is assessed through soil nutrients, while physicochemical parameters serve as good indicators of soil fertility. Continuous fertilizer use has been shown to decrease soil quality. Hence, evaluating the fertility status of agricultural soils is crucial for sustainable agricultural practices, as soil quality directly affects crop production and yield.

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Nutritional quality of crops relies heavily on the soil nutrients available in the soil profile (Sonaimuthu, 2016). In agriculture, soil compaction often occurs due to the use of mechanized equipment and heavy machinery (Arévalo-Gardini *et al.,* 2015). Effective soil management is essential for maintaining quality, and soil organic carbon is particularly important in boosting crop production while alleviating environmental challenges in agriculture (Takele *et al.,* 2014). Overall, soil quality is a critical factor that determines crop suitability and indicates a healthy environment; good soil should support a diverse range of plant growth. A study by Junge (2010) found that intensive agricultural practices often lead to a decline in organic matter and nutrients in the soil, which subsequently reduces crop production. This is evident in poor crop yields resulting from soil erosion and nutrient loss, compounded by flooding due to inadequate construction near waterways and pollution of water bodies from industrial and agricultural runoff (Lal, 2015).

The physicochemical impact of soil on yam cultivation was specifically investigated in this study because yam (*Dioscorea* spp.) is a highly soil-dependent tuber crop whose growth, yield, and quality are strongly influenced by soil physicochemical properties such as pH, nutrient availability, moisture content, organic matter, and texture, as reported in recent soil–crop interaction studies by Nwankwo and Akinola (2021).

Yam was selected over other crops for several important reasons. Firstly, yam is a major staple food and economic crop in Nigeria, particularly in Edo State, where it plays a key role in food security and rural livelihoods, as highlighted by the Food and Agriculture Organization (FAO, 2022). Understanding the soil conditions that support its production is therefore of high agricultural and socioeconomic importance.

Secondly, yam is very sensitive to changes in soil structure and fertility. Unlike some crops that can tolerate poor soil conditions, yam requires loose, well-drained, fertile soils with adequate organic matter for proper tuber expansion, a requirement consistently emphasized in agronomic studies by Akinde *et al.* (2020). This makes it an ideal indicator crop for assessing changes in soil quality over time, especially across different growth stages.

Thirdly, yam cultivation involves a long growth period, typically several months, during which soil properties may change due to plant nutrient uptake, microbial activity, and farming practices. Studies by Bello & Adegbulugbe (2023) have shown that such temporal soil dynamics significantly influence tuber development and final yield, making stage-based soil assessment particularly relevant. Lastly, yam is widely cultivated in the University of Benin community area, making it a practical and relevant crop for field-based soil analysis. Its presence in the study area ensures that findings are realistic and applicable to local agricultural practices, as noted in regional agricultural assessments by Afolabi *et al*. (2023).

The aim of this study therefore is to determine the physicochemical constituents of the soil before planting, growth and harvest stage of yam (*Dioscorea* spp.).

Materials and Method

Description of the study area

The study was carried out in the University of Benin community located within Ovia North-East Local Government Area, in the southern region of Nigeria. Ovia North-East Local Government Area is one of the eighteen local government areas in Edo State, with its administrative headquarters situated at Okada. The area lies approximately between latitude 5°54′N and 6°53′N and longitude 5°14′E and 5°21′E. The study area falls within the tropical rainforest belt of southern Nigeria and is characterized by a humid tropical climate with two distinct seasons: the rainy season, which usually extends from April to October, and the dry season, which spans from November to March. Annual rainfall is generally high, while average temperature ranges between 26°C and 30°C with relatively high humidity throughout the year. The vegetation of the area is predominantly rainforest vegetation interspersed with secondary forest, shrubs, grasses, and cultivated farmlands. The soil in the region is mainly sandy loam to loamy soil, suitable for the cultivation of root and tuber crops such as yam, cassava, and cocoyam. Farming constitutes one of the major occupations of the inhabitants, and yam cultivation is widely practiced due to the favorable climatic and edaphic conditions of the area.

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The University of Benin community and its surrounding environments possess extensive agricultural lands used for experimental and subsistence farming. The area experiences significant anthropogenic activities such as cultivation, organic waste deposition, and fertilizer application, which may influence soil physicochemical properties during different stages of crop growth. This study area was selected because of its active agricultural practices, accessibility, and suitability for evaluating variations in the physicochemical characteristics of soil before planting, during growth, and at harvest stages of yam cultivation.

Collection of soil samples

Soil samples were collected by first removing surface soil to a depth of 0 to 15 cm with a spade (Gupta, 2007). Five-hundred grams (500 g) of soil samples were placed in a plastic bucket, thoroughly mixed on a clean bowl, and prepared by breaking lumps. The samples were air-dried (Tandon, 1993), sieved through a 10-mesh screen, and labeled for subsequent analysis.

Measurement of physicochemical parameters

Temperature

The temperature of the water sample was determined using Mercury-in-glass Thermometer (thermometric Method).

pH

The pH was measured using a pH meter, following the procedure outlined by Jackson (1967). A 20 g soil sample was mixed with 40 ml of distilled water at a ratio of 1:2, stirred intermittently with a glass rod for 30 minutes, and allowed to settle for one hour. The combined electrode was immersed in the supernatant to record the pH, with electrode washed with distilled water before each reading.

Soil Moisture

Soil moisture content was determined by the oven-drying method (Jackson, 1967). A 10 g composite soil sample was placed in a hot air oven set to 105 ^{0}C for 24 hours. The dry weight was recorded after it reached a constant weight. The moisture percentage was calculated using the formula:

$$\text{Moisture content (\%)} = \frac{\text{Weight of wet soil} - \text{Weight of dry soil}}{\text{Weight of dry soil}} \times 100$$

Organic Matters

Soil organic matter was measured using previously described method (Walkley and Black, 1934). A 1 g finely ground dry soil sample was passed through a 0.5 mm sieve into a 500 ml conical flask. Then, 10 ml of 1M potassium dichromate and 20 ml of concentrated sulfuric acid were added. The mixture was shaken for one minute and allowed to stand for 30 minutes, followed by the addition of 200 ml distilled water, 10 ml phosphoric acid, and 1 ml diphenylamine indicator. The solution was titrated against a standard solution of ferrous ammonium sulfate until a color change from blue-violet to green was observed, with a blank titration performed without soil.

Nitrogen

The total amount of nitrogen in the soil sample was determined using regular macro-Kjeldahl method (ASTM, 2007). Exactly 5.00 g of soil sample was weighed into 500 mL Macro Kjeldahl flask and 20.0 mL of distilled water was added. The flask was swirled for a few minutes, and allowed to stand for 30 minutes. Exactly 1.00 g of the K_2SO_4 - HgO mixture and 10.0 g of K_2SO_4 with 30.0 mL of Conc H_2SO_4 (18.0 M) were added through a pipette. The flask was heated cautiously at low heat on the digestion stand. After the water has been removed and frothing has ceased, the heat was increased until the digest became clear. The mixture was then boiled for 5 hours. The heat was regulated during the boiling such that the H_2SO_4 condensed about half way up the neck of the flask. The flask was cooled and 100 mL of water was slowly added to the flask. The digest was transferred into another clean Macro Kjeldahl flask (750 mL). All the sand particles in the original digestion flask were retained and washed with 50.0 mL of distilled water 4 times and the aliquot was transferred into the same flask. Exactly 50.0 mL H_3BO_3 indicator solution was added into 500 mL Erlenmeyer flask through pipette which is then placed under the condenser of the distillation apparatus. The 750 mL Macro Kjeldahl flask was attached to the distillation apparatus. And 150 mL of 0.100 M NaOH was poured through the distillation flask by opening the funnel stopcock.

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The condenser was kept cooled (below 30.0 ^{0}C) by allowing sufficient cold water to flow through and regulate heat to minimize frothing and prevent suck-back. Exactly 150 mL distillate was collected and then the distillation was stopped. The NH_4-N in the distillate was determined by titrating with 0.01 M standard HCl using 25.0 mL burette graduated at 0.1mL intervals. The colour changed from green to pink at the end point and the percentage of Nitrogen (% N) content in soil was calculated.

Phosphorus

The determination of phosphorous in each of the soil samples was done using Olsen's Method (ASTM, 2007). Exactly 2.00 g of air-dried soil sample (passed in a 2 mm sieve) was weighed into a 125 mL Erlenmeyer flask and 5.00 mL of 18.0 M of sulphuric acid was added with 0.400 g of ammonium persulfate and boiled until a final volume of about 10.0 mL was reached. The solution was filtered and made up with distilled water to 40.0 mL. And 5.00 mL of Antimony Molybdate was added to the solution, followed by the addition of 2.00 mL of ascorbic acid.

The blank and standard solutions were subjected to the same treatment as above. After about 10-20 minutes, the absorbance of the sample, standard and blank solutions were measured with Ultra violet spectrophotometer at a wavelength of 680 nm.

The calibration curve was obtained for a standard solution of 1.00, 2.00, 3.00, 4.00 and 5.00 ppm phosphate and the concentration of the samples were obtained from the calibration curve using the absorbance of the samples.

Potassium

The flame photometric method (Jackson, 1967) was utilized to estimate the available potassium in the samples. A 5 g air-dried sample was placed in a 150 ml Erlenmeyer flask, and 25 ml of 1 M ammonium acetate was added.

The mixture was shaken for 5 minutes on a mechanical shaker and subsequently filtered through dry Whatman No. 1 filter paper. A 5 ml aliquot of the filtrate was diluted with 25 ml of distilled water, atomized in a flame photometer to record the potassium concentration, reported as kg per hectare of soil.

Electrical Conductivity

The method described by Wagh (2011) for the determination of electrical conductivity of a soil sample was adopted. This was determined using an Equiptronics digital electrical conductivity bridge for which 20.0 g soil was added in 40.0 mL distilled water. The suspension was stirred intermittently for half an hour and was kept for 30 minutes without any disturbances for complete dissolution of soluble salts. The soil was allowed to settle down and the conductivity cell was inserted in the solution and the EC values were read and recorded.

Results

The results presented in Tables 1 to 3 shows the physicochemical properties of analyzed soil samples at pre-planting of yam across Farm 1, Farm 2 and Farm 3 respectively.

The physicochemical characteristics of Farm 1 soil samples obtained at pre-planting, growth, and harvest stages are presented in Table 1. Variations were observed across the different stages of cultivation, indicating changes in soil quality and nutrient dynamics during crop development. Organic matter content showed significant variation, decreasing from 3.06 ± 0.04% at pre-planting to 2.40 ± 0.12% during growth before rising marginally to 2.88 ± 0.03% at harvest. Nitrogen concentration demonstrated marked statistical significance ($p < 0.05$), with an exceptionally high value recorded during the growth stage (792.62 ± 0.68 mg/kg) compared to pre-planting (155.00 ± 5.00 mg/kg) and harvest (122.50 ± 2.50 mg/kg). Phosphorus levels showed slight increases during growth (14.72 ± 0.03 mg/kg) but the differences were not statistically significant. Potassium concentration significantly declined during the growth stage (88.67 ± 0.88 mg/kg) relative to pre-planting (212.50 ± 2.50 mg/kg) and harvest (192.50 ± 2.50 mg/kg).The superscript notation indicated that parameters marked with "b" exhibited statistically significant differences, whereas those with "a" showed no significant variation at $p < 0.05$.

The physico-chemical characteristics of Farm 2 soil samples obtained at pre-planting, growth, and harvest stages are presented in Table 2.

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Table 1: Physico-chemical constituents of Farm 1 soil samples at pre-planting, growth and during harvest

Parameter	Pre-planting Mean ± SD	Growth Mean ± SD	During harvest Mean ± SD
pH	5.85 ± 0.05^{a}	27.80 ± 0.00^{a}	5.65 ± 0.05^{a}
Temperature (^{0}C)	26.60 ± 0.10^{a}	7.04 ± 0.00^{a}	11.90 ± 0.10^{a}
Moisture Content (%)	12.65 ± 0.15^{a}	32.27 ± 0.03^{b}	28.60 ± 0.10^{a}
Organic Matter (%)	3.06 ± 0.04^{a}	10.13 ± 0.26^{b}	2.88 ± 0.03^{a}
Nitrogen (mg/kg)	155.00 ± 5.00^{b}	2.40 ± 0.12^{b}	122.50 ± 2.50^{b}
Phosphorus (mg/kg)	12.50 ± 0.10^{a}	792.62 ± 0.68^{b}	11.60 ± 0.10^{a}
Potassium (mg/kg)	212.50 ± 2.50^{b}	14.72 ± 0.03^{a}	192.50 ± 2.50^{b}
Electrical Conductivity (µS/cm)	252.50 ± 2.50^{b}	88.67 ± 0.88^{a}	232.50 ± 2.50^{b}

Legend: a is no significant, b is significant

In Table 2, variations were observed across the different growth periods for most of the parameters evaluated. Organic matter decreasing sharply from 2.88 ± 0.03% at pre-planting to 0.90 ± 0.00% during growth before increasing slightly to 2.73 ± 0.03% at harvest. Nitrogen concentration increased substantially during the growth stage, recording the highest value of 632.21 ± 2.06 mg/kg compared with 142.50 ± 2.50 mg/kg and 112.50 ± 2.50 mg/kg at pre-planting and harvest respectively. Phosphorus values remained relatively stable throughout the sampling periods, ranging from 12.10 ± 0.10 mg/kg during harvest to 14.41 ± 0.24 mg/kg during growth. Potassium concentration varied significantly ($p < 0.05$) across the planting stages. The highest potassium value was observed at pre-planting (202.50 ± 2.50 mg/kg), while the lowest value was recorded during growth (99.33 ± 0.33 mg/kg). Potassium concentration increased again during harvest to 182.50 ± 2.50 mg/kg. Statistical analysis showed that potassium concentration differed significantly ($p < 0.05$) during the growth stage, whereas other parameters showed no significant difference ($p > 0.05$), as indicated by similar superscript letters.

Table 2: Physico-chemical constituents of Farm 2 soil samples at pre-planting, growth and during harvest

Parameter	Pre-planting Mean ± SD	Growth Mean ± SD	During harvest Mean ± SD
pH	6.05 ± 0.05^{a}	7.05 ± 0.03^{a}	5.95 ± 0.05^{a}
Temperature (^{0}C)	27.10 ± 0.10^{a}	27.80 ± 0.00^{a}	29.10 ± 0.10^{a}
Moisture Content (%)	12.00 ± 0.10^{a}	6.77 ± 0.38^{a}	11.60 ± 0.10^{a}
Organic Matter (%)	2.88 ± 0.03^{a}	0.90 ± 0.00^{a}	2.73 ± 0.03^{a}
Nitrogen (mg/kg)	142.50 ± 2.50^{a}	632.21 ± 2.06^{a}	112.50 ± 2.50^{a}
Phosphorus (mg/kg)	13.10 ± 0.10^{a}	14.41 ± 0.24^{a}	12.10 ± 0.10^{a}
Potassium (mg/kg)	202.50 ± 2.50^{a}	99.33 ± 0.33^{b}	182.50 ± 2.50^{a}
Electrical Conductivity (µS/cm)	242.50 ± 2.50^{a}	27.53 ± 0.03^{a}	222.50 ± 2.50^{a}

Legend: a is no significant, b is significant

The physico-chemical characteristics of Farm 3 soil samples at pre-planting, growth, and harvest stages are presented in Table 3. The results showed noticeable temporal variations in several soil parameters during the cultivation period. Soil pH ranged from 5.55 ± 0.05 to 7.21 ± 0.00. The soil was moderately acidic at pre-planting (5.75 ± 0.05) and harvest stages (5.55 ± 0.05), while a neutral condition was observed during the growth stage (7.21 ± 0.00).

However, no significant difference ($p > 0.05$) was recorded in pH across the sampling periods.

Nitrogen exhibited a statistically significant variation ($p < 0.05$), with an exceptionally high value during the growth stage (1124.00 ± 0.00 mg/kg) compared to pre-planting (167.50 ± 2.50 mg/kg) and harvest (132.50 ± 2.50 mg/kg). Phosphorus content also varied significantly ($p < 0.05$), increasing from 12.10 ± 0.10 mg/kg at pre-planting to 27.19 ± 0.58 mg/kg during growth before decreasing to 11.30 ± 0.10 mg/kg at harvest. Potassium concentration significantly decreased ($p < 0.05$) during the growth stage, with values reducing from 222.50 ± 2.50 mg/kg at pre-planting to 90.00 ± 0.58 mg/kg during growth and increasing to 202.50 ± 2.50 mg/kg at harvest.

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Table 3: Physico-chemical constituents of Farm 3 soil samples at pre-planting, growth and during harvest

Parameter	Pre-planting Mean ± SD	Growth Mean ± SD	During harvest Mean ± SD
pH	5.75 ± 0.05^a	7.21 ± 0.00^a	5.55 ± 0.05^a
Temperature (^{0}C)	25.90 ± 0.10^a	27.80 ±0.00^a	27.90 ± 0.10^a
Moisture Content (%)	13.10 ± 0.10^a	5.90 ± 0.07^a	12.35 ± 0.15^a
Organic Matter (%)	3.18 ± 0.03^a	1.55±0.00^a	3.03 ± 0.03^a
Nitrogen (mg/kg)	167.50 ± 2.50^b	1124.00 ±0.00^b	132.50 ± 2.50^b
Phosphorus (mg/kg)	12.10 ± 0.10^a	27.19 ± 0.58^b	11.30 ± 0.10^a
Potassium (mg/kg)	222.50 ± 2.50^b	90.00 ± 0.58^a	202.50 ± 2.50^b
Electrical Conductivity (µS/cm)	262.50 ± 2.50^b	34.77 ± 0.03^b	242.50 ± 2.50^b

Legend: a is no significant, b is significant

Discussion

The physicochemical composition of soil is an important determinant of soil fertility, nutrient availability, and microbial activities that support plant growth. The present findings in Farm 1 revealed dynamic changes in soil properties across the pre-planting, growth, and harvest stages, suggesting active nutrient transformation and utilization during crop development. The slightly acidic pH observed at pre-planting and harvest in Farm 1 is consistent with the characteristics of many tropical agricultural soils in Nigeria. During the growth stage, however, the soil pH shifted toward neutrality. Neutral pH conditions generally enhance nutrient solubility and microbial activities, thereby supporting optimal plant growth. Reports from the Food and Agriculture Organization (2023) also emphasized that soil pH strongly influences nutrient bioavailability and crop productivity. The progressive increase in soil temperature across the cultivation stages in Farm 1 may reflect increased solar radiation exposure and biological activities within the rhizosphere. Soil temperature affects microbial decomposition, nutrient mineralization, and enzymatic activities. According to Lal (2021), moderate increases in soil temperature can accelerate organic matter decomposition and nutrient release, particularly in tropical agroecosystems. Moisture content showed significant reduction during the growth stage, likely due to increased water uptake by plants and enhanced evaporation. Adequate soil moisture is essential for nutrient transport and microbial functioning, while moisture depletion may reduce microbial activity and nutrient mobility. The subsequent increase at harvest may be linked to reduced plant water demand toward the end of the cultivation cycle. Similar trends were documented by Prasad *et al.* (2020), who reported that crop growth stages significantly influence soil water dynamics and nutrient interactions. Organic matter content decreased significantly during growth, suggesting active decomposition and utilization of organic substrates by soil microorganisms and plants. Organic matter serves as a reservoir for essential nutrients and contributes to soil structure and water retention. In Farm 1, the slight increase at harvest may be attributed to the accumulation of plant residues and decaying root materials. Recent studies by Chenu *et al.* (2021) highlighted the importance of organic matter turnover in maintaining soil fertility and supporting sustainable agricultural productivity. Nitrogen exhibited the most pronounced variation among all measured parameters, with a remarkably high concentration during the growth stage. This increase may be associated with fertilizer application, enhanced mineralization, or nitrogen fixation processes occurring during active crop development. Nitrogen is a critical component of chlorophyll and proteins, making it essential for vegetative growth. The significant decline observed at harvest suggests nutrient uptake by crops and possible leaching losses. Phosphorus concentrations in Farm 1 remained relatively stable throughout the study period, indicating moderate phosphorus availability in the soil. The absence of significant variation may suggest balanced phosphorus utilization and replenishment within the farm system. Phosphorus is essential for root development, energy transfer, and flowering in plants. Potassium levels significantly declined during the growth stage before increasing again at harvest. Potassium is highly required during plant growth since it regulates enzyme activation, osmoregulation, and photosynthesis. The sharp reduction during growth likely reflects substantial plant uptake.

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The increase at harvest may be associated with mineral weathering and release from decomposing plant residues. Similar observations were reported by Greenfield *et al*. (2020), who stated that potassium depletion commonly occurs during periods of rapid vegetative growth. Electrical conductivity values in Farm 1 were significantly lower during the growth stage compared to pre-planting and harvest. Electrical conductivity reflects the concentration of soluble salts in soil. Reduced conductivity during growth may indicate nutrient absorption by plants and reduced ionic concentration in the soil solution. The elevated conductivity at pre-planting and harvest suggests greater availability of dissolved ions before nutrient uptake and after residue decomposition. Recent findings by Arora *et al*. (2023) showed that changes in electrical conductivity are closely associated with fertilizer application, nutrient cycling, and crop nutrient demand. Overall, the results demonstrate that farming activities and plant growth stages significantly influenced the physicochemical characteristics of Farm 1 soil. The observed fluctuations in nutrient levels, organic matter, and conductivity indicate active biological and chemical processes within the soil ecosystem. These findings further emphasize the importance of regular soil monitoring and sustainable nutrient management practices for maintaining soil fertility and improving agricultural productivity

The observed variation in soil pH in Farm 2 across the planting stages suggests dynamic changes in soil chemical conditions during crop development. The near-neutral pH recorded during the growth stage may have enhanced nutrient availability and microbial activity within the soil environment. According to Soil Science studies by Adekiya *et al*. (2022), soil pH strongly influences nutrient solubility, microbial metabolism, and plant nutrient uptake. The slight reduction in pH during harvest may be linked to nutrient depletion and root exudate accumulation during crop maturation. The gradual increase in soil temperature from pre-planting to harvest could be associated with seasonal climatic conditions and reduced canopy cover toward harvest. Soil temperature plays an important role in regulating microbial decomposition, nutrient mineralization, and enzymatic activities. Similar findings were reported by Lal (2021), who noted that warmer soil conditions often accelerate biological and biochemical processes within agricultural soils.

The sharp decline in moisture content of Farm 2 soil during the growth stage may be attributed to increased water utilization by growing plants and enhanced evapo-transpiration. Soil moisture is a critical determinant of nutrient mobility and microbial survival. Reduced moisture during active crop growth may limit the movement of soluble nutrients and temporarily affect microbial functions. Recent findings by Bai *et al*. (2023) demonstrated that fluctuations in soil moisture significantly alter nutrient cycling and microbial biomass in cultivated soils. Organic matter content also decreased substantially during the growth stage. This reduction may have resulted from rapid decomposition and utilization of organic substrates by soil microorganisms and plants during active growth. Organic matter is essential for maintaining soil structure, water retention, and nutrient reserve capacity. The subsequent increase during harvest may indicate accumulation of plant residues and decomposed biomass after crop maturity. Similar observations have been documented by Xu *et al*. (2022), who reported that organic matter dynamics are closely linked to crop developmental stages and microbial turnover. The remarkable increase in nitrogen concentration during the growth stage in Farm 2 suggests enhanced nitrogen mineralization or fertilizer availability within the soil. Nitrogen is a major macronutrient required for chlorophyll formation and vegetative development. The elevated nitrogen level observed during growth may have supported vigorous crop performance at this stage. However, the decline during harvest may reflect nutrient uptake by plants and possible leaching losses. Research by Zhang *et al*. (2023) emphasized that nitrogen availability commonly peaks during active vegetative growth and declines as crops approach maturity. Phosphorus concentrations remained relatively stable throughout the planting stages, indicating moderate phosphorus buffering capacity within the soil. Stable phosphorus availability is beneficial for root development, energy transfer, and reproductive growth in plants. The slight increase during growth may have resulted from fertilizer application or enhanced mineralization of phosphorus-containing compounds. According to Sharma *et al*. (2022), phosphorus mobility in soil is generally lower than nitrogen, resulting in less pronounced fluctuations during cultivation cycles. Potassium was the only parameter that showed significant variation ($p < 0.05$).

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The significant reduction during the growth stage may be linked to intensive uptake by plants during metabolic and physiological activities. Potassium is essential for enzyme activation, osmotic regulation, and photosynthesis. The subsequent increase during harvest could indicate reduced uptake and redistribution within the soil matrix after crop maturity. Similar findings were reported by Wang *et al*. (2023), who observed substantial potassium depletion during peak plant growth due to increased nutrient demand.

The marked reduction in electrical conductivity during the growth stage may reflect depletion of soluble salts and nutrients by actively growing crops. Electrical conductivity is commonly used as an indicator of dissolved ionic substances within soil. The recovery observed during harvest may be due to decomposition of crop residues and reduced nutrient absorption by plants. Overall, the results demonstrate that crop growth stages significantly influenced the physico-chemical properties of Farm 2 soil, particularly potassium dynamics. The observed changes highlight the importance of continuous soil monitoring and nutrient management in maintaining soil fertility and sustainable agricultural productivity.

The observed fluctuations in the physico-chemical properties of Farm 3 soil across the planting cycle reflect the dynamic interactions between soil nutrients, plant uptake, microbial activities, and environmental conditions. Soil pH remained within slightly acidic to neutral ranges throughout the study. The temporary increase to near-neutral pH during the growth stage may be associated with fertilizer application, mineralization processes, or microbial decomposition activities that altered hydrogen ion concentration in the soil solution. According to Food and Agriculture Organization reports, soils with pH values between 5.5 and 7.5 generally support optimum nutrient availability and microbial activity essential for crop development.

The gradual increase in soil temperature observed during growth and harvest stages could be attributed to increased solar radiation exposure and reduced canopy moisture retention. Elevated soil temperature enhances microbial metabolism and organic matter decomposition, thereby influencing nutrient cycling processes. Similar observations were reported by Nwachukwu and Eze (2022), who noted that warmer tropical soils promote accelerated mineralization and nutrient release. Moisture content declined substantially during the growth stage, likely due to increased water uptake by actively growing crops and evapotranspiration losses. The subsequent increase during harvest may have resulted from reduced plant water demand and seasonal moisture replenishment. Soil moisture is an important determinant of microbial activity and nutrient mobility, and reductions during intensive crop growth can temporarily limit nutrient diffusion within the rhizosphere. This observation agrees with the findings of Ibrahim *et al*. (2024), who reported seasonal declines in soil moisture during peak vegetative growth in cultivated tropical soils. The reduction in organic matter during the growth stage suggests active decomposition and utilization of organic substrates by soil microorganisms and plants. Organic matter later increased slightly during harvest, possibly due to root residues and plant litter accumulation. Organic matter plays a vital role in improving soil structure, nutrient retention, and microbial biomass. Nitrogen exhibited the most pronounced increase during the growth stage and differed significantly across sampling periods. The sharp increase may be linked to fertilizer application, nitrogen mineralization, and microbial nitrification processes during active plant growth. Nitrogen is essential for chlorophyll synthesis and vegetative development, and its availability commonly peaks during periods of active cultivation. The subsequent reduction at harvest suggests nutrient depletion due to crop uptake.

Conclusion

The physicochemical properties of soils from Farms studied varied across pre-planting, growth, and harvest stages, reflecting active nutrient transformations during crop development. Although pH and temperature remained relatively stable, the sharp increase in nitrogen and decline in potassium during growth suggest intense nutrient utilization and microbial activity associated with plant development. The recovery of several parameters at harvest further indicates partial restoration of soil conditions. Overall, the findings demonstrate dynamic soil nutrient interactions that influence soil fertility and crop productivity throughout cultivation.

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