



## EVALUATING KEY COMPONENTS OF SOIL NUTRIENTS AND THEIR DYNAMICS UNDER MANGO CROPS IN PART OF SUDAN SAVANNA, NIGERIA

<sup>1</sup>Abdulkadir, M., <sup>2</sup>Sanusi, A, and <sup>3</sup>Asuku, M. M.

<sup>1</sup>Department of Geography, Federal University Lokoja, P.M.B. 1154, Lokoja, Nigeria

<sup>2</sup>Department of Geography, Modibbo Adama University Yola, P.M.B. 2076, Yola, Nigeria

<sup>3</sup>Department of Mathematics, Kogi State College of Education, Ankpa,  
P.M.B. 1033, Ankpa, Kogi State, Nigeria

\*Corresponding Author's Email: [abdulkadir.musa@fulokoja.edu.ng](mailto:abdulkadir.musa@fulokoja.edu.ng); [abdul2kaka@gmail.com](mailto:abdul2kaka@gmail.com),  
GSM: +2348038331937

### ABSTRACT

The study evaluated key components of soil nutrients and their dynamics in mango (*Mangifera indica*) cultivated field of the Sudan Savanna, North-eastern Nigeria. Forty (40) representative soil samples were used to form eight (8) composite samples collected from eight (8) 20 x 20m quadrats at the depth of 0-30cm from mango cultivated field. These samples were prepared and tested using standard routine laboratory techniques for the analyses of particle size distribution, OM, TN, soil pH, EA, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>, AP, CEC, and BS. Principal Component Analysis (PCA) was employed to identify the main soil variables influencing nutrient dynamics under the crop. The results indicated that, only the first two components were retained for the explanation of the variables which accounted for 76% of the variance in mango cultivated field. The first component was named nutrient gradient, highlighting the dynamics of nutrient availability. The second component was named texture gradient, demonstrating the importance of soil texture in nutrient and moisture retention. Coefficient of variation and mean were also used to complement the result of the PCA. All the variables revealed relative homogeneity within the mango cultivated field. These insights are most importantly vital for smallholder farmers aiming to optimize crop yields while maintaining soil health. The study therefore, advocates the need for organic amendments and sustainable practices to improve soil fertility and structure.

**Keywords:** Nutrient, Dynamics, Texture Gradient, Mango, Savanna

### INTRODUCTION

The age-long desire by man to provide, basically for himself, food, medicine, shelter, clothing, and feed; coupled by his ever-increasing population at alarming rate, pose challenges in agricultural practices and their impact on soil resource. Crop production is the main activity to achieve most of the needs, though it is greatly impacted by complex interaction of biophysical and socioeconomic variables that cause changes in soil properties leading to variability of soil nutrients in agricultural systems (Mhoro *et al.*, 2023). Soil nutrients are fundamental to crop productivity, influencing crop growth, yield, and overall ecosystem health. Poor crop yield and inappropriate management practices have resulted from a failure to comprehend the intricacies of nutrient dynamics (Ololade *et al.*, 2010), especially and mostly by local farmers.

The Savanna region is characterized by its unique climatic conditions, vegetation, and land use practices, which influence soil formation and nutrient availability different to other vegetation zones. The predominant soil types in this zone are Arenosols and Plinthosols. The Arenosols are chiefly sandy thus having low nutrient retention, poor water holding capacity; while the Plinthosols are characterized by hardpans that restrict root growth and water movement (FAO, 2012), thus inefficient in supporting and sustaining crop production. Soil fertility in the Sudan Savanna region is ordinarily low, thus lacking in the capacity to enhance crop productivity to achieve SDGs 1, 2, 13 and 15 (Oku *et al.*, 2021). The fertility of soils in this zone is significantly influenced by organic matter (OM), cation exchange capacity (CEC), and soil pH (Ayuba *et al.* 2000). Low OM content could lead to decreased CEC, thereby making the soil poor in retaining nutrients such as nitrogen and phosphorus (in their different compound forms), exchangeable bases (Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup> and K<sup>+</sup>), as well



as other essential macro and micro nutrients. Moreover, high sand fractions, and erratic rainfall patterns, severely affect soil moisture and nutrient availability for crops (MacCarthy *et al.*, 2018; Oku *et al.*, 2021; Anka *et al.*, 2021). However, there is widespread poor cultivation practices among small and medium-scale farmers.

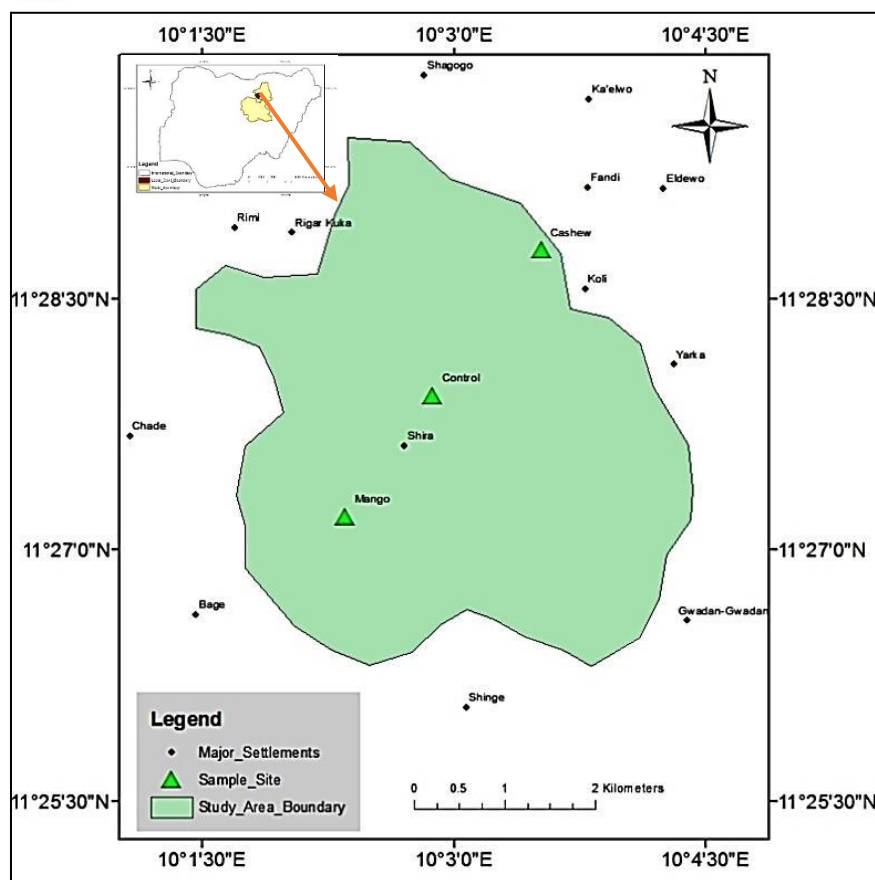
In Nigeria, the cultivation of mango (*Mangifera indica*) has gained prominence due to their economic significance to local livelihoods (Musa & Adamu, 2019). It is noteworthy that where a cultivation of tree crops is consciously and properly designed and practiced, it leads to increased soil fertility and improved crop yield (FAO, 2018; Chavez *et al.*, 2024). However, extensive cultivation, coupled with improper and unmonitored practices of growing these tree crops have proven to alter the natural nutrient balance, leading to soil fertility degradation and poor crop yield over time (Musa & Adamu, 2019). In addition, government agricultural extension services are either not available in most cases, or inefficient to guide the famers on best cultivation practices peculiar to environmental conditions, and variety of mango crops grown in those places. Thus, understanding the nutrient dynamics, specifically the variations in essential nutrients, is crucial for developing effective soil management practices that enhance crop productivity while maintaining soil health (Al-Shammary *et al.*, 2024).

Related researches were conducted in the Sudan Savanna region such as Ayuba *et al.*, (2000); MacCarthy *et al.* (2018); Aliyu *et al.* (2020); Oku *et al.* (2021); Anka *et al.* (2021) Musa among others, however they did not assess nutrient dynamics under mango in the region. Therefore, as the soil nutrient dynamics in the Sudan savanna region of Nigeria are shaped by the complex interactions between soil types, vegetation, climate, and different forms of land use practices, this study is aimed at evaluating the key components of soil nutrients and their dynamics under mango in part of Sudan Savanna, North-eastern Nigeria. Therefore, understanding these dynamics will help farmers and land managers make informed decisions to optimize soil fertility and ensure sustainable agricultural practices in the region.

## **MATERIALS AND METHODS**

### **STUDY AREA**

The study area, Shira, is situated within the Sudan savanna region of Bauchi State, Nigeria, covering an approximate landmass of 64 km<sup>2</sup> (Musa and Adamu (2019). Geographically, it extends between latitudes 11°26' 18" and 11°29' 58" N, and longitudes 10°01' 27" and 10°04' 26' E. The terrain is characterized by a range in elevation from 407 m (1335 ft) to 624 m (2047 ft) above sea level, with the highest point located at the peak of one of the inselbergs in the south-eastern part of the area (Musa & Adamu, 2019). The landscape consists of rounded hills and boulders of granitic origin, resulting in a rugged relief that facilitates excellent drainage. Water flows through a network of rivulets towards the south-western region, discharging into surrounding farmlands and eventually into the tributary of River Zigau, which feeds into River Jama'are (Musa & Adamu, 2019).



**Figure 1:** Shira, the Study Area

Source: Ministry of Lands and Survey, Bauchi State/ Google Image (2025)

The climate of Shira is classified as tropical continental according to Köppen's classification, characterized by distinct wet and dry seasons (Arnfield, 2025). The total annual rainfall averages around 810 mm, with August being the wettest month, receiving approximately 284 mm of rain. Following August, July also contributes significantly with over 200 mm of rainfall. Rainfall typically ceases in the first two weeks of October, leading into a dry season most often from November to March/April.

Vegetation in Shira significantly influences soil development and, consequently, agricultural practices. The area is predominantly covered by Sudan savanna vegetation, which consists primarily of short grasses, shrubs, and deciduous trees. Notable species include tamarind (*Tamarindus indica*), *Acacia albida*, baobab (*Adansonia digitata*), neem (*Azadirachta indica*), *Moringa oleifera*, guava (*Psidium guajava*), mango (*Mangifera indica*), and cashew (*Anacardium occidentale*). While some of these trees grow naturally, others are cultivated by locals, although they could propagate through natural seed dispersal (Musa & Adamu, 2019).

Geology and soil characteristics are critical to this research, as they directly influence soil development and agricultural productivity. The geology of Shira falls under the basement complex of the Hausa Plains in northern Nigeria, primarily consisting of deeply weathered Precambrian granitic rocks that have formed boulders and colluvium. Alongside these crystalline rocks, deposits of fine sands of the Lantewa sand dunes occur (Thiemeyer, 2000).

The soils in the area belong to the ferruginous soil category, exhibiting brown and reddish-brown hues. This classification aligns with the Arenosols and Plinthosols identified by Jones *et al.* (2013). Specifically, hypoluvic Arenosols and petric Plinthosols dominate the region, indicating the characteristics of the soil types that influence agricultural practices.



In terms of agriculture, Shira supports the cultivation of various crops, including cereals such as millet, sorghum, and rice. Other crops include groundnut, cowpea, beni seed, watermelon, tomato, and pepper. Tree crops like mango, cashew, and guava (though only traces are found these days) are also significant to the local agricultural landscape. Most farming activities in the area are rainfed, although irrigation practices are employed during dry season for the cultivation of crops such as rice, sugar cane and vegetables.

#### **SAMPLING PROCEDURE**

A mango cultivated field was purposively selected for the collection of soil samples. From the mango cultivated field, a 40 x 80m sample plot was marked out, and further subdivided into eight (8) quadrats measuring 20 x 20m (400 m<sup>2</sup>). To select sample points, each quadrat was sub-divided using 10 x 10m grids where five (5) representative soil samples were collected from. These 5 representative samples from each grid were collected, such that, 1 at the centre of each grid (making 4), and 1 at the adjoining point of the 4 grids at the depth of 0-30cm. The five representative samples from each quadrat were thoroughly mixed to form one composite sample for each of the 20 x 20m quadrats. Thus, a total of 40 representative samples were used to form 8 composite samples. These composite samples were then placed in a labelled polyethylene bags. The soil samples were air-dried, ground, and sieved through a 2 mm mesh before being sent to the laboratory for analysis.

#### **LABORATORY ANALYSIS**

The laboratory analysis focused on key soil properties that influence nutrient dynamics and crop productivity, including particle size distribution, soil pH, exchangeable cations (Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>), available phosphorus, cation exchange capacity (CEC), base saturation, organic matter (OM), and total nitrogen.

Particle size was determined using hydrometer method (Liebens, 2007). Organic matter was determined using Walkley-Black titration method, which is commonly adopted in research (Liebens, 2007). Total nitrogen was analyzed using the Kjeldahl method (Jones, 2001). Soil pH was measured potentiometrically in a 0.01m CaCl<sub>2</sub> solution at a 1:2 soil-to-solution ratio (Jones, 2001). Exchangeable acidity (EA) was quantified by potassium chloride (KCl) extraction and titration method (Hoskins, 1997; Robarge, 2008). Exchangeable calcium, potassium, and sodium were analyzed using flame photometry (Maniyunda *et al.*, 2013), while exchangeable magnesium was determined by absorption spectrophotometer method (Moges *et al.*, 2013). Available phosphorus was assessed using Bray one method (Jones, 2001). Cation exchange capacity was calculated by summing the exchangeable cations and exchange acidity; while base saturation was determined by dividing the total exchangeable bases by CEC and then multiplied by 100 (Jones, 2001; Havlin *et al.*, 2005).

#### **DATA ANALYSIS**

The data on soil physico-chemical properties were subjected to principal component analysis (PCA) technique to ascertain the main properties responsible for variability in the soils under the mango field in Shira. PCA is a multivariate statistical technique which enables one to reduce a large data matrix in to smaller ones, and also useful as an explanatory tool to enable a researcher find out what could possibly be the effective number of dimensions in a set of data, and aids in eliminating those variables which contribute relatively little information in a given study (Udofia, 2011). Hence IBM SPSS v.29 was employed to analysed the data.

In addition, coefficient of variation (C.V) and mean were also employed to complement the explanation of the principal components. Meanwhile, C.V is defined as a ratio of standard deviation to the mean of a population, and expressed in percentage form (Visser & Jones, 2010). When the value of C.V is high, a variability or heterogeneity is high, and homogeneity exists when it is low. Thus, where the value of C.V (fiducial limit) is 0 – 15% it is regarded as low variability, 16 – 35% as moderate variability, and greater than 35% is considered as high variability as proposed by Wilding (1985).

Thus, the formula below was used in calculating the coefficient of variation:

$$C.V = \frac{S}{\bar{x}} \times 100 \dots\dots\dots (i)$$

Where:



C.V = coefficient of variation;

S = standard deviation of each soil physical or chemical property;

$\bar{X}$  = the mean of each soil physical or chemical property; and

100 is a constant value.

## RESULT AND DISCUSSIONS

The result of the PCA and descriptive statistics for the cultivated field of mango is presented in Table 1. Variables with loadings  $\geq \pm 0.7$  from the rotated component matrix were considered significant (threshold) and used in the interpretation of the PCA as employed by Ifabiyi *et al.* (2010); Iwara *et al.* (2011).

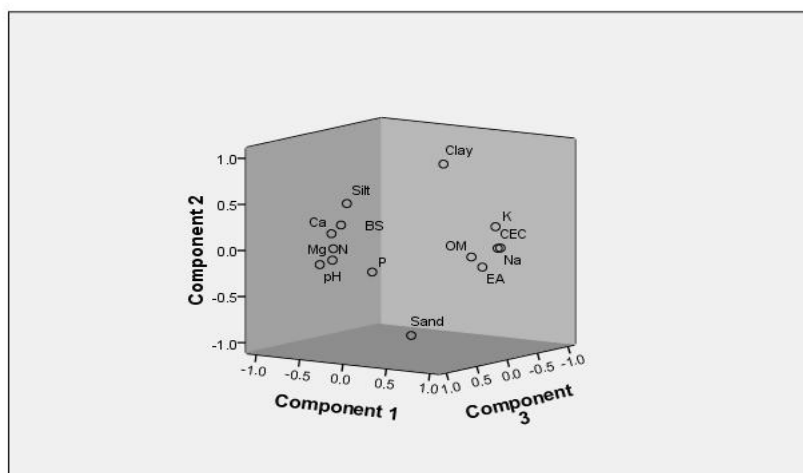
**Table 1:** Principal Component Analysis of the Soil Physico-chemical Properties in Mango Cultivated Field

Soil Properties	Components			Descriptive Statistics		
	Nutrient Gradient	Texture Gradient	Sand	Mean	Std. Dev.	CV
% Sand	-.061	-.990*	-.099	69.98	1.13	1.62
% Silt	-.300	.520	.620	11.13	0.53	4.80
% Clay	.235	.884*	-.206	18.87	0.89	4.70
Organic Matter (OM)	.758*	-.031	.080	2.27	0.08	3.69
Total Nitrogen (TN)	-.853*	-.230	.068	0.16	0.02	13.01
Soil pH	-.898*	-.262	.210	6.41	0.06	0.89
Exchangeable Acidity (EA)	.956*	-.106	.182	0.41	0.05	11.05
Exchangeable Calcium (Ca <sup>2+</sup> )	-.974*	.023	-.090	1.33	0.07	5.02
Exchangeable Magnesium (Mg <sup>2+</sup> )	-.854*	-.108	.052	0.19	0.02	9.98
Exchangeable Potassium (K <sup>+</sup> )	.891*	.282	-.128	0.17	0.01	5.78
Exchangeable Sodium (Na <sup>+</sup> )	.968*	.062	-.100	0.70	0.09	12.17
Cation Exchange Capacity (CEC)	.927*	.053	-.112	2.80	0.06	2.16
Available Phosphorus (AP)	.151	-.144	.847*	9.27	0.31	3.29
Base Saturation (BS)	-.945*	.103	-.204	85.50	1.37	1.60
<b>Component Defining Variables</b>	<b>Ca<sup>2+</sup></b>	<b>% Sand</b>	<b>A. P</b>			
<b>Total Eigen Values</b>	8.356	2.295	1.333			
<b>% Variance Explained</b>	59.685	16.396	9.520			
<b>% Cumulative Explained</b>	59.685	76.080	85.601			

Key: \* = significant loadings  $\geq 0.7$  used in interpreting the components; Std. Dev. = Standard Deviation, CV = Coefficient of Variation



**Component Plot in Rotated Space**



**Figure 2: Component Plot in Rotated Space Showing the Soil Physico-chemical Properties in Mango Field**

The result of the principal component analysis with varimax rotation and eigenvalues greater than unity reveals that, redundant variables in the soil physico-chemical properties were knocked down and reduced to three main components that can best explain the variability in the soils. However, to determine meaningful number of components for explanation of the PCA result, some criteria must be satisfied, which include eigenvalue-one, scree test, proportion of variance accounted for, and the interpretability criteria.

Therefore, taken all these criteria in to consideration, component 3 was not considered in the explanation, for the fact that it did not conform to the interpretability criteria of the PCA. It is suggested that a component cannot provide a satisfactorily solution if it has less than 3 defining variables (Principal Component Analysis, n.d). Thus, component 3 under mango field has only one variable (available phosphorus) that was highly loaded.

However, component 2 under mango field has only 2 highly loaded variables (percent sand and clay), but is still retained, because component 1 alone with total variance explained as 59.685% could not satisfy the recommendation as reported by Keho (2012) of minimum of 60% or 70% by Lehman *et al.* (2013) for total variance to be retained in the explanation of the variance. Moreover, the 2 highly loaded variables are closely related and could give meaningful explanation on the component.

#### **PHYSICO-CHEMICAL PROPERTIES OF SOIL IN MANGO CULTIVATED FIELD**

The first two components (Table 1) were retained, and altogether accounted for about 76% of the variance explained. It is recommended that when components account for at least 60% (Keho, 2012) or 70% (Lehman *et al.*, 2013), the total variance could be retained in the explanation of the variance. Hence, the cumulative 76% variance is sufficient enough to explain the variability in the physico-chemical data for mango cultivated field. Thus, Table 1 and Figure 2 presents the component plot in rotated space showing the soil physico-chemical properties and the main components in the mango field.

#### **COMPONENT 1 (NUTRIENT GRADIENT) IN MANGO CULTIVATED FIELD**

This component accounted for 59.69% to the total variance explained (Table 1). It has the highest negative loading on  $\text{Ca}^{2+}$  (-0.974). It also has high negative loadings on  $\text{Mg}^{2+}$ , TN, BS and pH, while high positive loadings on OM,  $\text{Na}^+$ ,  $\text{K}^+$ , CEC, and EA. The result further implies that, a direct relationship, on one hand, between OM,  $\text{Na}^+$ ,  $\text{K}^+$ , CEC, EA, and inverse relationship with  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , TN, BS and pH, on the hand. Thus, all variables under this component are related, in one way or the other to nutrient availability. For example, organic matter provides organic colloids with high net negatively charged surfaces per unit mass (Weil & Brady, 2017) which adsorbs most of the positively charged nutrient elements (e.g.  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$ , and  $\text{Na}^+$ ). More so, OM harbours nitrogen, though not



readily available to plants until the litter undergoes mineralisation process. However, the result implies that, even though OM increases, the levels of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and TN decrease. This is likely due to excessive absorption of these macronutrients (Hort Innovation [HI], 2018; Saúco, 2017) by the mango crops beyond the level of replenishment, especially as the crops are highly matured and there was no fertilizer application by the farmers.

Moreover, as OM increases, CEC equally increases. This is not surprising because CEC is essentially the total quantity of (-) surface charge on minerals and OM available to attract cations in solution (Hoskins, 1997; Havlin *et al.*, 2005). As such, the CEC having a positive strong loading (0.927) entails that, as it increases, more negative surfaces are added to harbour more cations readily available for absorption by the roots of the mango crops. Such increase in CEC, however, lowers BS which is referred to as the percentage of total CEC occupied by  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^{+}$ , and  $\text{Na}^{+}$  (Havlin *et al.*, 2005). This might be due to the decrease in the content of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  being absorbed more, compared to  $\text{K}^{+}$ , and  $\text{Na}^{+}$ . Thus these nutrients are likely removed in large quantities. However, levels of all these cations (Table 2) are below the requirement for optimum growth and productivity of the mango trees (Saúco, 2017).

In addition, the result also shows that, with increase in CEC, EA also increases, while pH decreases. EA is the acidity that develops due to adsorbed hydrogen ( $\text{H}^{+}$ ) and aluminium ( $\text{Al}^{3+}$ ) ions on the soil colloids (Das, 2011). Thus, this is undoubtedly, because as  $\text{H}^{+}$  and  $\text{Al}^{3+}$  are increasingly adsorbed, the relative proportion of hydroxyl ions ( $\text{OH}^{-}$ ) increase in the soil solution, thereby lowering the level of the pH. Hence, even though the mean value of the pH is 6.41 (Table 2) there is need to ensure that it does not fall short or exceed the required range (5.5 to 7.5) for mango crops (USDA NRCS, 2014).

Therefore, this component gives an idea about the soil properties that require special consideration for the improvement of soil fertility in the fields where mango crops are cultivated in the study area. As such, efforts to improve in the general soil nutrient in the mango field should be centred on organic treatment processes, coupled with proper management practices and conscious monitoring mechanisms.

#### **COMPONENT 2 (TEXTURE GRADIENT) IN MANGO CULTIVATED FIELD**

Component 2 contributes about 16% of the total variance explained (Table 1). The highest loaded variable is on percent sand (-0.990). However, it has high positive loading on percent clay (0.884). Hence, the component is named '*texture gradient*'. It is named as such, because the result showed that sand had high negative loading as opposed to percent clay. Clay provides the mineral portion of the soil colloids which provide the adsorbent capacity for cationic nutrients. The result therefore entails that any decrease in percent sand leads to increase in percent clay which likely affects the available colloids that give room to micelles (Foth, 2006) for the adsorption of cationic nutrients in the field. This could lead to improvement in the soil texture of the field. This is because Musa & Adamu (2019) assessed it as sandy loam, and mean percent sand of 68% almost quadrupled that of clay (Table 2). More so, under this high sand content, there could be leaching of some nutrients, especially  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and TN from A horizon as observed in the *nutrient gradient* (component 1). In addition, result of C.V reveals low variability in both sand (1.62) and clay (4.70) within the field, however, the latter was still a little more heterogeneous than the former.

Therefore, this component is closely related to that of nutrient gradient. Therefore, if the clay content increases, the texture will improve to promote better adsorption capacity for nutrients and water retention in the mango field. Thus, in the same vein with that of component 1 (*nutrient gradient*), the structure of the soils can be improved using organic amendments, and zero-tillage practices in the pockets around the mango trees.

#### **CONCLUSION AND RECOMMENDATION**

The Principal Component Analysis (PCA) conducted on the soil physico-chemical properties of mango cultivated field revealed significant insights into the nutrient dynamics and soil texture gradients affecting these crops. The analysis highlighted two primary components accounting for a substantial proportion of the variance explained (76%) in the soil properties.



The first component indicated a direct relationship between OM and nutrient availability, despite a decrease in calcium, magnesium, and total nitrogen, most likely due to excessive uptake by matured mango trees without adequate replenishment effort by the farmers.

The second component, soil texture (revealed as sandy loam), particularly the ratios of sand, silt, and clay. High sand content correlated with potential nutrient leaching, while the presence of clay was associated with improved nutrient retention. The findings suggest that maintaining an optimal balance between these soil components is essential for enhancing soil fertility and preventing nutrient loss.

The results advocate for targeted soil management strategies, emphasizing the need for organic amendments and sustainable practices, such as zero-tillage to enhance soil structure and fertility. Regular monitoring of soil properties is critical to ensure that nutrient levels remain within optimal ranges, thereby supporting healthy growth and productivity of mango crops in the study area. Thus, the findings provide valuable insights that both nutrient management and soil texture play a pivotal roles in the cultivation of mango. Effective management practices tailored towards specific nutrient dynamics and associated variables identified in this study could lead to improved crop yields and sustainability in such agricultural system.

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