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RESEARCH ARTICLE
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Status and Forms of Calcium in Two Arable Farms: An Assessment of Soil Fertility and Nutrient Availability

Estados y formas del calcio en dos explotaciones agrícolas: Una evaluación de la fertilidad del suelo y la disponibilidad de nutrientes

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Abstract

This study investigated the status and forms of calcium in two arable farms, Yam and Cassava farms (*Dioscorea rotundata* and *Manihot esculenta* Crantz), under two different land use systems. Soil samples were collected from four depths (0 cm -30 cm, 30 cm -60 cm, 60 cm -90 cm, and 90 cm -120 cm), and for analyzed physical and chemical properties, including calcium fractions: exchangeable, non-exchangeable, and mineral-bound calcium. The results showed that soil pH decreased with depth in both farms, ranging from 5 to 4.07 in Yam Farm and 4.50 to 3.90 in Cassava Farm. The results also showed significant decreases in exchangeable calcium with depth in both farms, ranging from 0.34 $mg.kg^{-1}$ to 0.06 $mg.kg^{-1}$ in Yam Farm and 0.42 $mg.kg^{-1}$ to 0.05 $mg.kg^{-1}$ in Cassava Farm. The study revealed significant correlations between exchangeable calcium and other soil properties, including electrical conductivity, sand content, organic carbon, and available phosphorus. The impact of the two land use systems on soil calcium fractions and properties was significant, with Yam Farm showing higher levels of exchangeable calcium and organic carbon than Cassava Farm. The study highlights the importance of considering the impact of different land use systems on soil calcium fractions and properties to maintain soil fertility and support sustainable agriculture.
Keywords: *calcium, soil fertility, land use, arable farm, nutrient deficiency, and sustainable agriculture.*

Resumen

En este estudio se investigaron el estado y las formas del calcio en dos explotaciones de cultivos herbáceos, una de ñame y otra de yuca (*Dioscorea rotundata* y *Manihot esculenta* Crantz), bajo dos sistemas diferentes de uso de la tierra. Se recogieron muestras de suelo de cuatro profundidades (0 cm -30 cm, 30 cm -60 cm, 60 cm -90 cm y 90 cm -120 cm) y se analizaron sus propiedades físicas y químicas, incluidas las fracciones de calcio: intercambiable, no intercambiable y ligado a minerales. Los resultados mostraron que el pH del suelo disminuyó con la profundidad en ambas explotaciones, oscilando entre 5 y 4.07 en la explotación de ñame y entre 4.50 y 3.90 en la explotación de yuca. Los resultados también mostraron disminuciones significativas del calcio intercambiable con la profundidad en ambas explotaciones, oscilando entre 0.34 $mg.kg^{-1}$ y 0.06 $mg.kg^{-1}$ en la explotación de ñame y entre 0.42 $mg.kg^{-1}$ y 0.05 $mg.kg^{-1}$ en la explotación de yuca. El estudio reveló correlaciones significativas entre el calcio intercambiable y otras propiedades del suelo, incluyendo la conductividad eléctrica, el contenido de arena, el carbono orgánico y el fósforo disponible. El impacto de los dos sistemas de uso de la tierra sobre las fracciones y propiedades del calcio del suelo fue significativo, mostrando la Granja de Ñame mayores niveles de calcio intercambiable y carbono orgánico en comparación con la Granja de Yuca. El estudio subraya la importancia de considerar el impacto de los diferentes sistemas de uso de la tierra en las fracciones y propiedades del calcio del suelo para mantener la fertilidad del suelo y apoyar una agricultura sostenible.
Palabras clave: *calcio, fertilidad del suelo, uso de la tierra, explotación agrícola, deficiencia de nutrientes y agricultura sostenible.*

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1. Introduction

The increasing demand for food and agricultural products has led to the expansion of agricultural land use, resulting in the conversion of natural ecosystems into cultivated lands (Food and Agriculture Organization [FAO], 2017). This significantly impacts soil health, fertility, and sustainability (Lal, 2015). Soil calcium fractions and properties are critical components of soil fertility, and their dynamics can be influenced by different land use systems. Yam (*Dioscorea rotundata*) and cassava (*Manihot esculenta* Crantz) are two important staple crops in many tropical regions, including West Africa (Okeke et al., 2017). These crops are often cultivated in small-scale farming systems, where soil fertility management is crucial for maintaining crop productivity and soil sustainability (Kumar et al., 2019). However, the impact of different land use systems on soil calcium fractions and properties in yam and cassava farms is not well understood (Mokwunye & Melsted, 1972). Calcium is an essential nutrient for plant growth, and its availability in soil can affect crop yields and quality (Brady & Weil, 2008). Soil calcium fractions, including exchangeable, non-exchangeable, and mineral-bound calcium, play important roles in maintaining soil fertility and structure (Havlin et al., 2013). The dynamics of soil calcium fractions can be influenced by various factors, including soil type, land use, and management practices (Agbai & Efenudu, 2022). For example, studies have shown that soil calcium fractions can be affected by the type of crop cultivated, with some crops having a higher demand for calcium than others (Kumar et al., 2019). In addition, soil properties such as pH, organic matter content, and nutrient availability can also influence soil calcium fractions (Mokwunye & Melsted, 1972). For example, soils with high pH levels tend to have lower levels of exchangeable calcium, while soils with high organic matter content tend to have higher levels of non-exchangeable calcium.

However, the impact of different land use systems on soil calcium fractions and properties in yam and cassava farms is not well understood (Mokwunye & Melsted, 1972). This study aims to investigate the status and forms of calcium in these two arable farms, an assessment of soil fertility, and nutrient availability. Specifically, the study seeks to: assess the effects of land use systems on soil physical and chemical properties, determine the levels of exchangeable, non-exchangeable, and mineral-bound calcium in yam and cassava farms, and evaluate the relationships between soil calcium fractions and soil properties in yam and cassava farms. The findings of this study will contribute to our understanding of the impact of land use systems on soil calcium fractions and properties, and provide insights into the development of sustainable soil management practices for yam and cassava farms.

2. Materials and methods

Study location and site description

The location of this study is cultivated farmland in the University of Benin, Benin City, Nigeria. The land coordinates are Latitudes 6.404165, 6.404355, 6.404271, 6.4042380 N and Longitudes 5.6100631, 5.6100738, 5.610248, 5.6103110 E, it has been sown to plantain and banana for about four years and history of the farm showed there has not been application of micronutrient fertilizer for over 3 years.

Soil Sampling and Analysis

Composite soil samples were collected using a soil auger at depths of 0-30 cm, 30 cm -60 cm, 60 cm -90 cm, and 90 cm -120 cm. Each depth was replicated three times within the study area. The composite samples were bulked together.

Sample Preparation

Soil samples from each depth were air-dried, crushed, and passed through a 2 mm sieve.

Laboratory Analysis

The following physical and chemical properties were analyzed using standard laboratory procedures: Soil pH: determined using the soil: water (1:1) method (Udo et al., 2006), particle size distribution determined using the hydrometer method, organic carbon determined via wet oxidation methods (Walkley & Black, 1934), organic matter: determined by multiplying organic carbon by a factor of 2 (Pribyl, 2010), exchange acidity determined using Jackson (1962) method, exchangeable cations determined using ammonium acetate solution (1N NH_4O Ac) buffered at pH 7. calcium and magnesium were determined from the extract of 0.01M EDTA (Jackson, 1962), while potassium and sodium were determined using a photometer (Jackson, 1962), total nitrogen and available phosphorus were determined using Bremner & Mulvaney's (1982) method, and calcium fractions determined using the fractionation procedures of Mokwunye and Melsted (1972). Exchangeable Calcium Fraction: This fraction is extracted using a neutral ammonium acetate solution (1 N NH_4O Ac). The solution is added to the soil sample, and the mixture is shaken for 30 minutes. The extract is then filtered, and the calcium content is determined using atomic absorption spectroscopy (AAS). The Non-Exchangeable Calcium Fraction: This fraction is extracted using a hydrochloric acid solution (0.1 N HCl). The solution is added to the soil sample, and the mixture is shaken for 30 minutes. The extract is then filtered, and the calcium content is determined using AAS, and Mineral-Bound Calcium Fraction: This fraction is extracted using a sodium pyrophosphate solution (0.1 M $Na_4P_2O_7$). The solution is added to the soil sample, and the mixture is shaken for 30 minutes. The extract is then filtered, and the calcium content is determined using AAS.

Calculation of Calcium Fractions:

Exchangeable calcium fraction (ECF) = (Ca extracted by NH_4OAc) / (soil weight), Non, exchangeable calcium fraction (NECF) = (Ca extracted by HCl) / (soil weight), and Mineral-bound calcium fraction (MBCF) = (Ca extracted by Na_4P2O7) / (soil weight). Data generated for the study were subjected to analysis of variance (ANOVA) and means separated at a 5 % level of probability, also conducted were correlation analyses. All analyses were executed using the Genstat statistical package (Payne et al., 2009).

3. Results and discussion

Physical and chemical properties

This study investigated the soil properties of two farms, Yam Farm and Cassava Farm, at different depths (0 cm -120 cm). The results in (Table 1) show that soil pH decreased with depth in both farms, ranging from 5 to 4.07 in Yam Farm and 4.5 to 3.9 in Cassava Farm (Adebo et al., 2020; Ekpenkhio, 2018). The observed acidity of the soils can be attributed to the leaching of basic cations, such as calcium, magnesium, and potassium, which is exacerbated by the high levels of rainfall in the region (Agbai et al., 2022), as the decrease in pH with depth is consistent with previous studies (Agbai & Efenudu, 2022; Agbai, et al., 2022; Orobator & Ekpenkhio, 2021; Solomon et al., 2022). The electrical conductivity (EC) values also decreased with depth in both farms, ranging from 79 $\mu S.cm^{-1}$ to 43.33 $\mu S.cm^{-1}$ in Yam Farm and 93.00 $\mu S.cm^{-1}$ to 30.03 $\mu S.cm^{-1}$ in Cassava Farm. This decrease in EC with depth is attributed to the decrease in soluble salts and ions (Solomon et al., 2022). Organic carbon (Org.C) and organic matter (Org.M) contents decreased with depth in both farms, ranging from 7.20 $g.kg^{-1}$ and 14.40 $g.kg^{-1}$ to 1.23 $g.kg^{-1}$ and 2.50 $g.kg^{-1}$ in Yam Farm, and 0.45 $g.kg^{-1}$ and 15.80 $g.kg^{-1}$ to 0.043 $g.kg^{-1}$ and 1.17 $g.kg^{-1}$ in Cassava Farm. This decrease in Org. C and Org.M with depth are consistent with previous studies (Adebo et al., 2020; Orobator & Ekpenkhio, 2021). Total nitrogen (T.N), exchangeable acidity (EA), and available phosphorus (Av.P) values also decreased with depth in both farms. This decrease in T.N, EA, and Av. P with depth is attributed to the decrease in organic matter and microbial activity (Solomon et al., 2022). The exchangeable cation values (Na, K, Ca, Mg) decreased with depth in both farms. This decrease in exchangeable cations with depth is consistent with previous studies (Ekpenkhio, 2018; Solomon et al., 2022).

The particle size distribution (sand, silt, clay) showed that sand content decreased with depth, while silt and clay contents increased in both farms. This change in particle size distribution with depth is attributed to the weathering and erosion processes (Orobator & Ekpenkhio, 2021).

Implications of the impact of two land use systems on soil physical and chemical properties

The results of this study have implications for soil fertility management and nutrient cycling in Yam and Cassava farms. The decrease in soil fertility parameters with depth suggests that soil fertility management practices should focus on maintaining soil organic matter and microbial activity (Lal, 2015). The decrease in exchangeable cations with depth also suggests that calcium-based fertilizers may be necessary to maintain soil fertility and support plant growth (Havlin et al., 2013).

Soil Calcium Forms

The results in (Table 2) show that the exchangeable calcium (Exch. Ca) content decreased with depth in both Yam Farm and Cassava Farm. This decrease in exchangeable calcium with depth is consistent with previous studies that reported a decrease in calcium content with depth in tropical soils (Lal, 2006; Sanchez, 2002). According to Brady & Weil (2008), the decrease in exchangeable calcium with depth can be attributed to the leaching of basic cations, such as calcium, by heavy rainfall in the region. The total calcium (Total Ca) content also decreased with depth in both farms. This decrease in total calcium with depth is consistent with previous studies that reported a decrease in calcium content with depth in tropical soils (Lal, 2006). According to Sanchez (2002), the decrease in total calcium with depth can be attributed to the weathering of calcium-rich minerals and the leaching of calcium ions. The ratio of exchangeable calcium to total calcium (Exch/T Ca)

Table 1: Physical and Chemical Properties in Soils from Yam and Cassava Farm

Depth	pH	EC	Org.C	Org. M	T. N	EA	Na	K	Ca	Mg	Av. P	Sand	Silt	Clay
		$\mu S.cm^{-1}$		$g.kg^{-1}$				$Cmol.kg^{-1}$					$g.kg^{-1}$	
Yam Farm														
0 - 30	5.00a	79.00a	7.20a	14.40a	0.65a	1.60a	0.10a	0.22a	0.55a	0.35a	1.08a	868.4a	89.2a	42.40a
30 - 60	4.40b	60.00b	4.30b	8.60b	0.39b	1.60a	0.06b	0.08b	0.31b	0.14b	0.90b	818.4b	669.2a	12.43b
60 - 90	4.00c	54.00c	4.10c	8.20c	0.37c	1.20ab	0.06b	0.07c	0.27b	0.11c	0.82c	778.4c	209.2a	12.40b
90 - 120	4.07c	43.33d	1.23d	2.50d	0.12d	0.90b	0.01c	0.03d	0.13c	0.05d	0.53d	728.3d	259.2a	12.40b
Mean	4.37	59.08	4.21	8.43	0.38	1.33	0.06	0.10	0.32	0.16	0.83	798.38	307	19.91
Cassava Farm														
0 - 30	4.50a	93.00a	0.45a	15.80a	0.72a	1.50b	0.15a	0.33a	0.68a	0.45a	1.58a	868.4a	796.9a	22.40a
30 - 60	4.10b	61.00b	0.18b	11.00b	0.51b	1.30c	0.07b	0.11b	0.35b	0.18b	0.92b	778.4b	249.2a	22.40a
60 - 90	4.10b	51.00c	0.08c	7.20c	0.33c	1.90a	0.03c	0.05c	0.18c	0.08c	0.66c	768.4c	219.2a	12.43b
90 - 120	3.90c	30.03d	0.043d	1.17d	0.06d	1.53b	0.02d	0.03d	0.09d	0.04d	0.22d	738.3d	109.2a	12.40b
Mean	4.15	58.79	0.19	8.79	0.41	1.56	0.07	0.13	0.32	0.19	0.85	788.38	344	17.41

Mean value(s) with the same letters(s) in the column are not significantly different from one another at a 5% level of probability.

decreased with depth in both farms, indicating a decrease in the availability of calcium for plant uptake (Brady & Weil, 2008). This decrease in Exch/T Ca ratio with depth can have significant implications for plant growth and nutrient uptake. According to Lal (2006), calcium is an essential nutrient for plant growth, and a decrease in calcium availability can limit plant growth and productivity.

Table 2: Forms of Calcium in Soils from Yam and Cassava Farm

Forms of Calcium	Exch. Ca	Total Ca	Exch / T Ca
Depth	mg.kg^{-1}		%
Yam Farm 0 - 30	0.34a	1.82a	18.68a
30 - 60	0.19b	1.10b	17.27b
60 - 90	0.16c	0.98c	16.32c
90 - 120	0.06d	0.51d	11.76d
Mean	0.19	1.10	16.00
Cassava Farm			
0 - 30	0.42a	2.20a	19.09a
30 - 60	0.22b	1.24b	17.74b
60 - 90	0.11c	0.73c	15.06
90 - 120	0.05d	0.48d	10.41d
Mean	0.20	1.17	15.77

Mean value(s) with the same letters(s) in the column are not significantly different from one another at a 5% level of probability.
NB: Exch. Ca = Exchangeable Calcium, Exch/T. Ca = Exchangeable Calcium / Total Calcium

Relationship between Soil Calcium Forms and Some Soil Physical and Chemical Properties

The results in (Tables 3a & 3b) show significant correlations between various soil properties, indicating a complex interrelationship between them. The strong positive correlation between exchangeable calcium and total calcium (r = 0.934*) suggests that these two parameters are closely related, which is consistent with previous studies (Brady & Weil, 2008). The positive correlation between exchangeable calcium and electrical conductivity (EC) (r = 0.997*) indicates that calcium is a major contributor to soil EC, which is in agreement with previous studies (Lal, 2006). The positive correlation between exchangeable calcium and sand content (r = 0.997*) suggests that calcium is associated with the sand fraction in the soil, which is consistent with previous studies (Sanchez, 2002). The positive correlation between exchangeable calcium and organic carbon (Org.C) (r = 0.989*) suggests that calcium is associated with organic matter in the soil, which is consistent with previous studies (Brady & Weil, 2008). The positive correlation between exchangeable calcium and available phosphorus (Av.P) (r = 0.957*) suggests that calcium is associated with phosphorus availability in the soil, which is consistent with previous studies (Sanchez, 2002).

Implications of the impact of two land use systems on soil calcium fractions and soil properties

These results imply that calcium content is an important factor in determining soil properties such as EC, sand and clay content, organic matter, and phosphorus availability. Therefore, managing calcium content in soils can have significant impacts on soil fertility and productivity (Lal, 2006; Solomon et al., 2022).

Table 3a. Relationship between Soil Calcium Content and Some Soil Physical and Chemical Properties

	E.Ca	T. Ca	E/T Ca
pH	0.934*	0.931*	0.623*
EC	0.997*	0.997*	0.781*
Sand	0.997*	0.974*	0.848*
Silt	-0.141	-0.149	0.068
Clay	0.877*	0.880*	0.450*
Ca	0.999*	0.999*	0.803*
Mg	0.977*	0.978*	0.668*
Na	0.973*	0.974*	0.875*
Org.C	0.989*	0.989*	0.849*
Av.P	0.957*	0.999*	0.912*
K	0.972*	0.973*	0.796*
T.N	0.989*	0.990*	0.849*

*Significantly correlated at a 5 % level of probability.
NB: Exch. Ca = Exchangeable Calcium, Exch / T. Ca = Exchangeable Calcium / Total Calcium

Table 3b. Relationship between Soil Calcium Content and Some Soil Physical and Chemical Properties

	E.Ca	T. Ca	E/T Ca
pH	0.945*	0.948*	0.701*
EC	0.982*	0.981*	0.925*
Sand	0.977*	0.979*	0.830*
Silt	-0.062	-0.068	0.107
Clay	0.851*	0.845*	0.876*
Ca	0.999*	0.999*	0.881*
Mg	0.992*	0.994*	0.830*
Na	0.999*	0.999*	0.875*
Org.C	0.952*	0.949*	0.972*
Av.P	0.932*	0.983*	0.932*
K	0.985*	0.994*	0.806*
T.N	0.948*	0.945*	0.980*

*Significantly correlated at a 5 % level of probability.
NB: Exch. Ca = Exchangeable Calcium, Exch / T. Ca = Exchangeable Calcium / Total Calcium

The implications of the impact of two land use systems on soil physical and chemical properties and soil calcium fractions for sustainable agriculture

The impact of land use systems on soil physical and chemical properties and soil calcium fractions has significant implications for sustainable agriculture. According to Lal (2006), sustainable agriculture requires maintaining soil fertility and productivity, which can be achieved by managing the soil's physical and chemical properties. The results of this study show that the two land use systems, Yam Farm and Cassava Farm, have distinct effects on soil physical and chemical properties, including pH, electrical conductivity, organic carbon, and available phosphorus (Adebo et al., 2020; Solomon et al., 2022). Soil calcium fractions are also affected by the land use systems. The study reveals that exchangeable calcium content decreases with depth in both farms, ranging from 0.34 to 0.06 mg/kg in Yam Farm and 0.42 to 0.05 mg/kg in Cassava Farm (Havlin et al., 2013). This decrease in exchangeable calcium content can impact soil fertility and productivity, as calcium is an essential nutrient for plant growth (Sanchez, 2002). The implications of these findings for sustainable agriculture are significant. According to Sanchez (2002), maintaining soil fertility and productivity is critical for sustainable agriculture. The study highlights the importance of managing soil physical and chemical properties, including soil calcium fractions, to maintain soil fertility and support sustainable agriculture (Havlin et al., 2013).

Conclusion

The results of this study show that the two land use systems, Yam and Cassava farm (*Dioscorea rotundata* and *Manihot esculenta* Crantz), have significant impacts on soil calcium fractions and properties. The decrease in exchangeable calcium with depth in both farms suggests that calcium-based fertilizers may be necessary to maintain soil fertility and support plant growth. The strong positive correlations between exchangeable calcium and other soil properties, including electrical conductivity (r = 0.997*), sand content (r = 0.997*), organic carbon (r = 0.989*), and available phosphorus (r = 0.957*), suggest that calcium content is an important factor in determining soil properties and fertility. The study highlights the importance of considering the impact of different land use systems on soil calcium fractions and properties to maintain soil fertility and support sustainable agriculture. The results of this study have implications for soil fertility management and nutrient cycling in Yam and Cassava farms and suggest that calcium-based fertilizers be applied to maintain soil fertility and support plant growth, especially in soils with low calcium content.

Recommendation

Farmers and agricultural practitioners should adopt integrated soil management practices that prioritize calcium management, organic matter conservation, and conservation tillage to improve soil fertility and productivity.

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Author Contributions

IUE and AOB conceived and designed the study, collected and analyzed the data, and drafted the manuscript.

Conflict of interests

The authors declare that they have no competing interests**.**

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