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EVALUATION OF SOIL PROPERTIES UNDER CITRUS ORCHARD LAND USE IN SOUTHERN GUINEA SAVANNA AGRO-ECOLOGY

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Abstract

Viable citrus production requires good soil management practices. Evaluation of soil properties under citrus orchard land use (CLU) will provide information on soil productivity potential for sustainable citrus production. This necessitates this study, which was carried out at Kabba, Southern Guinea Savanna agro-ecological zone of Kogi State, Nigeria. Five undisturbed core and auger samples of soil were collected at random, from four soil depths (0-15, 15-30, 30-45 and 45-60 cm) from CLU for laboratory analysis. The result of the soil analysis revealed that CLU soil texture was sandy loam, bulk density was ideal (1.31 gcm^{-3}), pH was moderately acidic (5.7) and total nitrogen was high (0.32%). These soil properties support citrus growth and yield, while soil organic matter (SOM, 1.41%), available phosphorus (AP, 6.11 mg kg^{-1}), exchangeable potassium (K, 0.27 cmol kg^{-1}), exchangeable calcium (Ca, 3.05 cmol kg^{-1}), total exchangeable bases (TEB, 4.88 cmol kg^{-1}) and effective cation exchange capacity (ECEC, 5.87 cmol kg^{-1}) were low. The low soil properties therefore, demand better soil management practices geared toward optimum SOM level, in order to improve CLU soil nutrient storage and supply for sustainable, profitable and good quality citrus production.

Keywords: Citrus orchard, Citrus production, land use, Soil management, Soil properties

Introduction

Citrus consists of flowering short and tall perennial woody plant in the rue family, Rutaceae. Citrus is native to Australia and Asia ("Citrus," 2022). Asia led the world citrus production by region with 80,081 thousand metric tonnes compare to 20,344 thousand metric tonnes (Shahbandeh, 2022).

The genus Citrus includes oranges, grapefruits, lemons, limes and various hybrids. Among the genus citrus, sweet orange is the most cultivated fruit tree in the world and predominantly in subtropical and tropical climates. The orange fruit yield can be eaten fresh or processed for its juice. Typical orange flesh has a water content of 87%, carbohydrates of 12%, protein of 1%, and negligible amount of fat. Based on a 100 gram serving of orange flesh, it provides 47 calories and 64% of the Daily Value for vitamin C ("Orange (fruit)", 2022). Fresh citrus has a low average calorie value (between 60 and 80 kcal), which can be crucial for consumers who are worried about having too much body fat (Allotey et al., 2013).

Antioxidants such as flavonoids, carotenoids, and polyphenols are abundant in oranges, lemons, limes, and grape fruits. They give fruits their vibrant colours and powerful smells. In addition to protecting the human body, they also prevent many health problems. Abundant Vitamin C in citrus fruits helps to strengthen the immune system, which helps to fight infections through the production of white blood cells (WebMD Editorial Contributors, 2020).

A wide variety of soil types are suitable for growing citrus. The deep, well-drained sandy loam soils are considered better for citrus production (Agustí et al., 2014). A minimum two feet depth, coarser texture with slightly heavier sub-surface, well drained, moderately level soil may be appropriate for any commercial citrus. No hardpan should be present within one meter of soil depth (Srivastava and Kohli, 1997).

Citrus orchard land use simply means the human agricultural use of land for citrus production. Citrus production is heavily influenced by soil condition, both in terms of yield and fruit quality (Srivastava and Singh, 2009; Allotey et al., 2013). High yield and nutrient concentration of citrus fruits are dependent on adequate supply of nutrients to the crop. Essential nutrient elements needed by the crop are nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca) and sulphur (S). Better soil management, through chemical fertilizer and farmyard manures, significantly increase yield and fruit quality in sweet orange (Allotey et al., 2013).

The process of evaluating soil fertility is to estimate how much native and residual nutrients present in the soil could be used by crops to grow (Sanchez et al., 1997). This is important to check soil condition, in order to investigate any subsoil constraints, monitor changes to soil fertility over time, take necessary soil management measures to enhance improved soil health and productivity for a particular land use.

It is important to note that soil physical properties such as clay gradients, drainage, irrigation, water logging and soil fertility constraints caused by pH in soil, as well as salinity are key pedological factors affecting sweet orange production (Srivastava and Singh, 2009). Critical soil limitations include reduced soil depth from slicing of fertility layer, water stress, low soil air temperature, nutrient deficiency, aluminium (Al) and magnesium (Mg) toxicity, and induced zinc (Zn) deficiency (Srivastava and Singh, 2006).

The growth of citrus tree will be impaired by nutrient imbalances and/or excesses, resulting yield reduction and/or poor fruit quality (Obreza et al., 2020a). In citrus orchard land use (CLU), the balance of accessible nutrients is a crucial factor in citrus production's profitability because it promotes beneficial nutrient interactions. Soil nutrient management such as fertilization makes up a small percentage of citrus production costs, yet can greatly affect profit margins (Obreza et al., 2020b). The main objective of the study was to evaluate properties of CLU soil for sustainable citrus production.

Materials and Methods

Site Description

This study was carried out at Citrus orchard land use (CLU) of the Horticulture section of the teaching and research farm of Kabba College of Agriculture, at Kabba, Southern Guinea savannah agro-ecological zones of Nigeria. The soil of the site was classified as Plinthic Kandiustalf (Fasina et al., 2021). It was located in the southern part of Kogi State and lies between latitude 7° 52'N and 7° 34'N and longitude 6° 02'E and 7° 42'E. The citrus orchard is about 1.25 hectare and was established in 2005. The site is located at low land with river (*Ọpẹẹ*) as the boundary on the tail side of the landscape slope. The citrus orchard is dominated with sweet orange (*Citrus sinensis*), with very few other varieties/species like grape, tangelo, which serve as planting materials for budding/grafting for teaching and research. The main agronomic practice since the inception of fruiting has been slashing using tractor/manually, to keep weed off the orchard. There have been very minimal soil management practices which involve return of plant residue from slashing and fire tracing of the orchard to prevent bush burning hazard. Average annual temperature, relative humidity and rainfall of past five years were 26°C, 74% and 1,314 mm per annum respectively. The temperature ranges between 11°C and 40°C, the coldest period is between December and January and hottest period is between February and March (NASA Power, 2022).

Soil sampling and analysis

Five undisturbed core and auger samples of soil were collected at random from four soil depths (0-15, 15-30, 30-45 and 45-60 cm) for laboratory analysis. Twenty soil samples were prepared for laboratory analysis through air-drying, crushing (with porcelain pestle and mortar) and sieving by 2 mm sieve. Gravel (soil material greater than 2 mm) percentage weight was calculated. Soil particle size analysis was determined by the Bouyoucos hydrometer method (Bouyoucos, 1951) and bulk density (BD) by method of Blake and Hartge (1986). Soil reaction (pH) was measured using pH meter (Thomas, 1996). Total Nitrogen was determined using macro-Kjeldahl method (Black, 1965). Available Phosphorus (AP) was determined using the Bray-P1 extraction procedure (Bray and Kurtz, 1945). Soil organic carbon (SOC) was determined by the wet oxidation method (Walkley and Black, 1934). Exchangeable Bases (sodium -Na, potassium -K, calcium -Ca and magnesium -Mg) were extracted with 1.0 M ammonium acetate solution at pH 7.0 (Thomas, 1982). The extracts, Na and K contents were measured by flame photometer while Ca and Mg were determined with Atomic Absorption Spectrophotometer. Thomas (1982) titration of the extract with standard sodium hydroxide (NaOH) solution method was used for the determination of Exchangeable Acidity (EA).
Total exchangeable bases (TEB) was obtained as the sum of exchangeable cations and effective cation exchange capacity (ECEC) was obtained as the sum of the TEB and EA. Base saturation (BS) percentage was calculated by the formula (F1):

$$\% \text{ BS } = \frac{\text{TEB}}{\text{ECEC}} \times \frac{100}{1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ F1}$$

Statistical analysis

Soil data were analysed using SPSS IBM Statistics 19.0 (SPSS, 2010). Statistical parameters calculated include, mean, minimum, maximum, skewness, kurtosis and coefficient of variation (CV). Ranking of CV of soil properties into different classes; low (<15%), moderate (15 – 35%), and high (>35) variation according to Wilding (1985) was used.

Results

Soil physical properties

Table 1 shows the soil of citrus orchard land use (CLU) particle size distribution (PSD), texture class and bulk density across four different depths, i.e. 0-15, 15-30, 30-45, and 45-60 cm. Across the soil depths, mean sand, silt and clay particles proportion ranged from 580.0-680.0 gkg^{-1}, 248.0-272.0 gkg^{-1} and 136.0-148.0 gkg^{-1} respectively. The soil texture was predominantly sandy and the textural class of the soil is sandy loam. Coefficient of variation (CV) of the soil sand (4.53%), silt (13.96%) and clay (7.93%) fractions or particles were low (<15%) i.e. soil PSD difference was low. The soil mean percentage gravel content ranged between 4.05 and 4.93%. Although, the soil mean percentage gravel contents were highly varied (>35%), this was due to wide difference between the minimum (1.01%) and maximum (10.36%), i.e. the range of obtained data. Soil bulk density (BD) ranged from 1.26 gcm^{-3} to 1.34 gcm^{-3} across the depths and the CV was low (6.29%).

Soil chemical properties

Soil chemical properties of CLU are presented in Table 2. The mean pH value of CLU was moderately acidic, ranging between 5.6 and 5.7. The CV of CLU (9.62%) soil pH was low (<15%). Across the four depths, soil organic carbon (SOC) ranged from 0.51-1.05% and the CV (64.51%) was high. The highest mean SOC was recorded at 0-15 cm depth and decreased down to 30-45 cm depth. Mean soil organic matter (SOM) across the CLU soil depth ranged between 0.86 and 1.80%. SOM followed same trend with SOC in CV, which was high (67.27%) and also, decreased down the depth, except at 45-60 cm depth. The highest SOM was observed at 0-15 cm depth. Mean total nitrogen (TN) content ranged from 0.12 to 0.57% across the four depths. The CV of TN was high (96.87%). Highest (7.05 mg kg^{-1}) and least (4.82 mg kg^{-1}) mean available phosphorus (AP) contents were recorded at 30-45 cm and 45-60 cm depths respectively. The % CV of AP showed a high variation (46.55 %).

Table 1: Physical properties of soil of citrus orchard land use

Depth	N	BD gcm^{-3}	Sand gkg^{-1}	Silt gkg^{-1}	Clay gkg^{-1}	Grav %	Textural class
0-15 cm	5	1.26	608.0	248.0	144.0	4.32	Sandy loam
15-30 cm	5	1.31	600.0	252.0	148.0	4.94	Sandy loam
30-45 cm	5	1.34	580.0	272.0	148.0	4.93	Sandy loam
45-60 cm	5	1.34	608.0	256.0	136.0	4.05	Sandy loam
SD		0.08	2.71	2.01	2.04	2.45	
MIN		1.18	54.80	12.00	23.20	1.01	
MAX		1.47	64.80	18.00	29.20	10.36	
%CV		6.29	4.53	13.96	7.93	53.64	
KURT		-0.87	0.06	-1.00	-1.16	1.15	
SKEW		0.28	0.38	0.25	0.10	1.01	
Median		1.29	59.80	14.00	25.20	4.21	

N = sample number; SD = Standard deviation; MIN = Minimum; MAX = Maximum; %CV = coefficient of variation; %CV ≤ 15% = low variation; %CV 15≤ 35% = moderate variation; %CV >35% = high variation; KURT = Kurtosis; SKEW = Skewness; BD = Bulk density; Grav = Gravel content

Mean exchangeable potassium (K) ranged from 0.19-0.39 cmol kg^{-1} and decreased with depth to 30-45 cm. Exchangeable K had a high variation (50.13 %). The CLU soil exchangeable sodium (Na) was high in variation, (40.02%) with average values ranging between 0.30 and 0.41 cmol kg^{-1}. Exchangeable Ca had highest mean values among the exchangeable cations. The mean exchangeable calcium (Ca) ranged from 2.50-3.76 cmol kg^{-1}, with the highest mean values recorded on 45-60 cm depth. The CV of exchangeable Ca was moderate (26.58%). Mean exchangeable magnesium (Mg) content ranged from 1.10-1.30 cmol kg^{-1} and varied moderately (27.07%). Mean Exchangeable Acidity (EA) across the four depths ranged from 0.69 to 1.50 cmol kg^{-1}. The EA increased with depth to 30-45 cm and had high variation (55.47%). Across the four depths, total exchangeable bases (TEB) decreased with depth to 30-45 cm and varied moderately (21.62%). The mean TEB ranged between 4.13 and 5.51 cmol kg^{-1}. Lowest and highest mean effective cation exchange capacity (ECEC) were 5.63 and 6.44 cmol kg^{-1} respectively across the depths. ECEC varied moderately (18.02%). Base saturation (BS) has low variation (9.95%). The mean BS ranged from 74.41-87.86% across the depths. Mean exchangeable sodium percentage (ESP) ranged between 5.54 to 8.53%. The CV of ESP values was high (39.67%).

Depth	N	pH	SOC %	SOM %	TN %	AP mg kg^{-1}	K cmol kg^{-1}	Na cmol kg^{-1}	Ca cmol kg^{-1}	Mg cmol kg^{-1}	EA cmol kg^{-1}	TEB cmol kg^{-1}	ECEC cmol kg^{-1}	BS %	ESP %
0-15 cm	5	5.7	1.05	1.80	0.57	6.94	0.39	0.35	3.12	1.24	0.69	5.10	5.79	87.86	7.18
15-30 cm	5	5.6	0.96	1.64	0.35	5.63	0.25	0.41	2.80	1.30	0.86	4.76	5.63	84.31	8.53
30-45 cm	5	5.7	0.59	0.86	0.12	7.05	0.19	0.34	2.50	1.10	1.50	4.13	5.63	74.41	8.45
45-60 cm	5	5.6	0.78	1.33	0.23	4.82	0.25	0.30	3.76	1.20	0.93	5.51	6.44	85.52	5.54
SD		0.54	0.54	0.95	0.31	2.84	0.14	0.14	0.81	0.33	0.55	1.05	1.06	8.26	2.95
MIN		4.91	0.27	0.46	0.04	3.50	0.09	0.24	2.00	0.70	0.48	3.48	4.13	54.49	4.39
MAX		7.12	2.36	4.06	0.88	14.31	0.62	0.88	4.90	2.00	3.04	6.96	7.76	90.93	15.69
%CV		9.62	64.51	67.27	96.87	46.55	50.13	40.02	26.58	27.07	55.47	21.62	18.02	9.95	39.67
KURT		1.34	1.58	1.61	-0.90	2.10	1.07	11.25	-0.12	1.35	10.36	-0.56	-0.75	7.08	1.98
SKEW		1.12	1.14	1.23	0.90	1.36	1.05	3.08	0.63	1.17	2.87	0.57	0.31	-2.26	1.53
Median		5.56	0.79	1.14	0.16	5.06	0.24	0.30	2.90	1.15	0.88	4.50	5.57	84.07	6.40

N = sample number; SD = Standard deviation; MIN = Minimum; MAX = Maximum; %CV = coefficient of variation; %CV ≤ 15% = low variation; %CV 15≤ 35% = moderate variation; %CV >35% = high variation; KURT = Kurtosis; SKEW = Skewness; SOC = Soil Organic carbon; SOM = Soil Organic Matter; TN = Total Nitrogen; AP = Available Phosphorus; K = Exchangeable Potassium; Na = Exchangeable Sodium; Ca = Exchangeable Calcium; Mg = Exchangeable Magnesium; EA = Exchangeable acidity; TEB = Total exchangeable bases; ECEC = Effective Cation Exchange Capacity; BS = Base Saturation; ESP = Exchangeable Sodium Percentage

Discussion

Soil texture serves an indicator to other properties such as aeration, organic content, and water holding capacity (Obreza and Morgan, 2008). In sandy loam soils, roots are not restricted, infiltration is moderate, plant water availability is moderate, but mechanical compaction can occur (Warren and Taylor, 2017). Consequently, the sandy loam texture of the CLU soil is suitable for citrus growth and yield (Agustí et al., 2014). The percentage of gravel was less than 10% (low), thus it would not affect the bulk density of the soil (Stockdale, 2022). When bulk density (BD) of soil is 1.7 gcm-3 in sandy-textured soil, natural root growth is limited (Mukhopadhyay et al., 2018). The CLU BD values are rated between good (1.3 gcm-3) and fair (1.3-1.55 gcm^{-3}) (Mukhopadhyay et al., 2018), which indicated that the soil was not compacted, but reducing frequency of practice of using tractor for slashing of bush is recommended to manage the soil against mechanical compaction.

Soil nutrients solubility and availability to plant are impacted by soil pH. For citrus, the pH of the soil should be between 6.0 and 6.5 (Obreza et al., 2020b), but pH range of 5-8 had been reported to yield appreciable citrus orchard output (Allotey et al., 2013). The moderately acidic (5.6-6.0) (FAO, 2004) condition of CLU soil implied that citrus yield will not be impacted negatively. Lime applications at a low dose rate will help keep the soil pH at its best level (Jones, 2012) and consequently prevent soil acidity induced deficiencies of micronutrients like molybdenum and copper (Allotey et al., 2013).

Soil organic matter is a source of soil organic carbon (SOC) as well as its sink (Frey et al., 2013). At 0-15 cm depth, SOC contents were highest due to crop residues returning to the topsoil, with high SOM contents (Kadiri et al., 2021). The SOC and SOM reduced with depth, due to high rainfall and leaching (Allotey et al., 2013) and the texture of CLU soil that was largely of sand proportion. The SOM was rated between low (<1.5%) and medium (1.5-2.5%), and was below critical level (2.0%) for Nigerian soils (Adepetu, 2000). The SOM management of CLU with the adequate quantity of organic matter is required (Allotey et al., 2013), to improve the soil structure, aeration, pH, nutrient, populations of earthworms and beneficial microorganisms (Obreza et al., 2020c).

Total nitrogen (TN) was high (>0.2%) (Adepetu, 2000), but decreased with depth; this could be due to high rainfall and leaching of basic cations of CLU location (Allotey et al., 2013) and its sandy loam texture. Meanwhile, the TN content of the CLU was within the recommended range (0.2-1.0 %) (Allotey et al., 2013) and it was sufficient for optimal growth of the vegetation, flowering, and fruit production (Allotey et al., 2013; Obreza et al., 2020b).

Available phosphorus (AP) values were below the fertility threshold (10.0 mg kg^{-1} (Bray P1)) for most Nigeria soils (Adepetu, 2000). Citrus thrives best in soils with AP levels between 40 and 60 mg kg^{-1} (Obreza and Morgan, 2008). The low content of AP (<8.0 mg kg^{-1}) (Adepetu, 2000) could be due to leaching of soluble phosphorus (P). Although it was anticipated that P would be more readily available in acidic soils. According to Allotey et al. (2013)

optimum performance of citrus requires P fertilization.

Exchangeable potassium (K) levels of CLU soil were low (<0.4 cmol kg^{-1}) (Horneck et al., 2011). This could be due to the high K demand of citrus crops, leaching and the sandy loam soil texture (Obreza and Morgan, 2008). As a result of low exchangeable K, potassium fertilization was recommended for CLU, since very low exchangeable K can retard vegetative growth and result in thinning of the topmost foliage. It also reduces fruit number and size, increases fruit wrinkles, plugging, and drops, and lowers citrus juice soluble solids, acids, and vitamin C content (Obreza et al., 2020b). However, to avoid imbalanced leaf calcium (Ca) and magnesium (Mg) which negatively impact fruit size, excess levels (>2.0 cmol kg^{-1}) should be avoided (Allotey et al., 2013).

The values of CLU exchangeable sodium (Na) were moderate (0.3-0.7 cmol kg^{-1}) (FAO, 2004). The exchangeable sodium percentage (ESP) was used to assess effect of Na levels in soil. The ESP is the proportion in percentage of the TEB occupied by exchangeable Na. Horneck et al. (2011) identified concerns with ESP values above 10%, while Adepetu (2000) defined critical values at 15% and above. The ESP of CLU soil was below critical level which would affect the growth of most crops, including citrus.

Exchangeable calcium (Ca) values were low (2–5 cmol kg^{-1}) (FAO, 2004) and this condition could be a result of leaching and acidic sandy soil texture (Jones, 2012). Liming to pH 6.5 is recommended to supply sufficient exchangeable Ca for citrus plant usage (Obreza et al., 2020d). Horneck et al. (2011) ranked exchangeable magnesium (Mg) levels of CLU soil as medium (0.5-2.5 cmol kg^{-1}) and an inadequate amount of this nutrient can lead to chlorotic patterns and premature defoliation (Obreza et al., 2020b). According to Horneck et al. (2011), the deficit in acidic soil can be rectified by liming with dolomitic lime (calcium magnesium carbonate [$CaCO_3$ -$MgCO_3$]).

The low values of exchangeable acidity from exchangeable hydrogen and aluminium ions (Epebinu, 2000), with low soil pH, indicated no aluminium toxicity threat, but should be prevented by adoption of better soil management practices (Allotey et al., 2013). The low (<6 cmol kg^{-1}) (FAO, 2004) and increase with depth of total exchangeable bases (TEB) values of CLU soil to 30-45 cm, but with highest mean value at 45-60 cm, could be connected to low SOM concentrations, leaching, and high sand percentage of CLU soil (Kadiri et al., 2021). Managing soil fertility by increasing organic matter input would improve the supply of TEB (Obreza and Morgan, 2008).

Effective cation exchange capacity (ECEC) is an indicator of soil ability to prevent leaching of positively charged nutrients (Obreza and Morgan, 2008; Allotey et al., 2013). ECEC values in CLU soil were below preferred 10 cmol kg^{-1} for plant production (Lines-Kelly, 1993), but base saturation (BS) values was very high (>80%) (FAO, 2004). This was due to high adsorbed bases by soil negative charges but with poor release, which inhibit growth and yield of the crop (Allotey et al., 2013).

Conclusion

This study on evaluation of soil properties of citrus orchard land use revealed that soil texture, pH, TN were within recommended range (sandy loam, 5-8, 0.2-1.0 % respectively) for vegetative growth and fruit yield. Exchangeable Na and exchangeable Mg were moderate while SOM, AP, exchangeable K, exchangeable Ca, EA, TEB, and ECEC were low. Soil management practices targeted toward optimum SOM level would improve soil structure, nutrient storage and supply providing sustainable, profitable and good quality citrus production.

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