

Synthetic Lime and Manure-NPK Effects in Sandy-Loam Ultisols after Growing Sweet Potato in Successive Rainy and Dry Seasons

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Summary

Leaching and associated low soil fertility are among the most important agricultural problems of coarse-textured soils of the humid tropics. This study assessed the effects of synthetic lime and manure-fertilizer combination on soil physicochemical fertility of sandy-loam Ultisols in southeastern Nigeria after growing high-density coverage sweet potato in successive rainy and dry seasons. Treatments were application of CaO-88% at 10 t·ha⁻¹ (limed) and 0 t·ha⁻¹ (no-lime) in the rainy season, each with poultry droppings at 20 t·ha⁻¹ (PD₂₀), NPK 15-15-15 at 0.40 t·ha⁻¹ (NPK_{0.40}), complementary manure-NPK at half doses (PD₁₀+NPK_{0.20}) and no-fertilizer in the two seasons. Soil bulk density was unaffected. Soil pH was highest in limed/fertilizer-amended plots (7.1-7.2) and lowest in the control plots (5.6). Liming enhanced soil organic matter (SOM) in the dry season. In both cropping seasons, soil available P was higher in PD₂₀ and PD₁₀+NPK_{0.20} (36-56 mg·kg⁻¹) than NPK_{0.40} and no-fertilizer (7-11 56 mg·kg⁻¹), while Ca²⁺ was highest in limed/PD₂₀ (3.59-5.09 cmol·kg⁻¹) and lowest in no-lime/PD₁₀+NPK_{0.20} (0.89 cmol·kg⁻¹) both of which were among treatments that affected Mg²⁺ similarly. Apparent cation exchange capacity (CEC) was highest in the control. Overall, liming enhanced soil pH and SOM, manuring enhanced available P, while their combination enhanced Ca²⁺ and/or Mg²⁺. The data support adoption of synthetic liming and poultry-droppings manuring for improving SOM and P-availability, respectively, or both practices for raising soil pH toward enhanced cations exchangeability under cover crops in humid tropical environments. This treatment-induced influence of soil pH mostly on Ca²⁺ but also CEC could be undermined by excessive environmental humidity.

Key words

Well-drained humid tropical soils, soil fertility management, lime application, poultry droppings, mineral fertilizer, cover cropping

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Introduction

Persistent decline in soil fertility has been identified as a major constraint to agricultural production especially in sub-Saharan Africa (SSA). Like many other tropical countries, Nigeria is dominated by soil resources that are characterized by fragile thin-layered, coarse-textured topsoils with multiple nutrients deficiency problems (Ahn, 1993; Igwe and Obalum, 2023). There are also cases of unsustainable production practices such as continuous nutrient mining without replacement by way of adequate application of fertilizers (Sanchez et al., 2002). This is aggravated by the prevalence of high acidity of the soils (Okalebo et al., 2006), making the limited nutrients unavailable for plant uptake. Consequently, self-sufficiency in food production for its ever-rising population remains yet to be realized. To enhance the overall productivity of the soils, their fertility management must involve the use of amendments. In so doing, there is need to explore alternative soil amendments and production strategies which might have implications for both food and nutrition security. The use of suitable organic amendments can help overcome soil fertility-related constraints to crop growth and/or yield of vegetables (Nwite et al., 2012a; Nwite et al., 2013; Ebido et al., 2024).

Mineral fertilizers are scarce in many agronomic production systems, and this has limited their use by smallholder farmers (Tanimu et al., 2007). Many crops respond well to manures, so they could sustain yields in soils under continuous cropping unlike their mineral fertilizer equivalents. There is a huge potential in minimizing wastage of agro-wastes and converting them into organic amendments for soils to actualize the trending concept of circular economy in tropical Africa (Baiyeri et al., 2020; Ndzheshala et al., 2024). Poultry droppings are perhaps the most effective of all manures of animal origin; and they are not only rich in plant nutrients, but can also be combined with mineral fertilizers (Mitchell and Tyson, 2001). Increasing per capita crop production in agro-environments of low soil organic matter (SOM) and nutrient status requires viable soil-and-water management technologies. One such agricultural technology is the integrated soil fertility management (ISFM) that entails complementary soil application of nutrient-rich manures and mineral fertilizers combined with better crop management.

Sweet potato (*Ipomoea batatas* L.) is an important food security crop with the potential to improve the livelihood of rural dwellers. Many farmers often wrongly associate this root crop with poor soils because of its ability to thrive in such soils. However, resource-poor African farmers can use poultry droppings with conventional tillage to improve soil properties and sweet potato production (Agbede and Adekiya, 2011; Sowley et al., 2015). Complementary application of poultry droppings as manure and mineral fertilizers has proved to be effective in low-fertility soils of the Derived Savannah for producing not just cereal and other vegetable crops (Nwite et al., 2012b; Unagwu et al., 2013), but also sweet potato (Nnadi et al., 2020; Ogumba et al., 2020).

In acid humid tropical soils, the effects of poultry droppings and its complementation may be pronounced in the presence of lime due to its role in raising soil pH, supplying Ca and Mg and decreasing Fe-Al toxicity. These effects are also expected to manifest more clearly under crops that provide surface cover

against rapid mineralisation and nutrient losses to runoff such as sweet potato. Soil fertility trials with sweet potato in humid tropical environments have traditionally focused on the crop's response (Akpaninyang et al., 2015; Sowley et al., 2015; Nnadi et al., 2020); soil 'physical' and physicochemical fertility has been sparingly studied (Ossom and Rhykerd, 2008; Obalum et al., 2020). In this paper, therefore, we report the effects of synthetic lime and manure-NPK complementation on these soil properties for sandy-loam Ultisols of the humid tropics after sweet potato production in successive rainy and dry seasons.

Materials and Methods

Site Description

The research was carried out at the University of Nigeria (UNN) Teaching & Research Farm (06° 52'N, 07° 24'E; 447 m asl.) situated at Nsukka campus of the University. The climate is humid tropical with two distinct seasons (rainy and dry). Mean annual rainfall is about 1600 mm, while mean minimum and maximum daily temperatures are 21 and 31 °C, respectively. The area also records variable relative humidity (range, 55 - 90%) yearly. At the study site, the soil is deeply weathered, brownish red, coarse-textured (sandy loam) and hence well drained, with dominant minerals being quartz, hematite and kaolinite (Obalum et al., 2013). The prevailing vegetation depicts the area as being in the Derived Savannah in southeastern Nigeria. The key physicochemical properties of the topsoil (0-20 cm) around the study site have been presented elsewhere; sand, silt and clay contents of 750, 70 and 180 g·kg⁻¹, respectively, acidic soil pH in water of 4.8, soil organic carbon content of 17.88 g·kg⁻¹, total nitrogen of 0.56 g·kg⁻¹, and cation exchange capacity of 12.40 cmol·kg⁻¹ (Obalum et al., 2017).

Experimental Set-up

The field study involved two factors, namely lime status of the soil and fertilizer type used as soil amendment. Two lime statuses were involved: liming at 10 t·ha⁻¹ and no liming. Four fertilizer types were involved including sole use of poultry droppings at the rate of 20 t·ha⁻¹, designated PD₂₀; sole use of NPK 15-15-15 at 0.40 t·ha⁻¹, designated NPK_{0.40}; poultry droppings at 10 t·ha⁻¹ plus NPK 15-15-15 at 0.20 t·ha⁻¹, designated PD₁₀+NPK_{0.20}; no-fertilizer amendments. The sole application rate for poultry droppings (20 t·ha⁻¹) was as adopted for the study area for improving soil properties (Ogunezi et al., 2019) and sweet potato productivity (Nnadi et al., 2020), while that for NPK 15-15-15 was based on the recommended fertilizer rate for sweet potato (0.30-0.40 t·ha⁻¹) in southeastern Nigeria (Nwinyi et al., 1987).

The study was executed as a 2 × 4 factorial experiment laid out as split-plots replicated three times in a randomized complete block design (RCBD). The high-density coverage variety of sweet potato, UMUSPO-2, was sourced from the National Root Crop Research Institute, Umudike, Nigeria. Poultry droppings, sourced from the Poultry Unit of Animal Science Section of the UNN Teaching & Research Farm, had a pH of 8.2 and N, P, K, Ca, Mg and Na contents of 3.10%, 0.67%, 0.75%, 0.96%, 0.49% and 0.38%, respectively. The synthetic lime (CaO-88%) and NPK fertilizer were sourced from an agro-chemical dealer in Nsukka, Nigeria.

Field Procedure and Cultural Practices

The study site had been under fallow for more than three years. In the study area, the practice of vegetable crop production in both the prevailing rainy and dry seasons is not only increasingly popular among farmers, but also important for agricultural development of the region (Atugwu et al., 2023; Okorie et al., 2024). Because of this, and to allow more time for greater manifestation of treatment effects, the growing of high-density sweet potato with lime-manure/fertilizer treatments was done for two successive rainy and dry seasons, before assessing treatment effects on soil physicochemical properties. It was manually cleared and demarcated into plots for the treatments using bunds. The size of each plot was 1.5 m × 1.5 m (2.25 m²). Considering the creeping nature of sweet potato and to minimize interference among treatment plots, 0.75 m space was left between neighbouring plots in a block. The separation between blocks was 1.5 m. Topsoil (0-20 cm) samples were randomly collected and used to determine the soil pH and to calibrate the quantity of lime to be added. Lime was applied only once, i.e., in the rainy-season cropping. This was done by uniformly spreading it to plots meant to receive it at an equivalent rate of 10 t·ha⁻¹. The poultry droppings were cured by air-drying, homogenized, crushed and sieved using a 2-mm-mesh sieve to remove debris before use. The droppings were applied evenly also to the relevant plots on the same day as lime.

The plots were then tilled by hoeing to about 20 cm depth, incorporating the amendments into the soil and making flatbeds. Sweet potato vines were cut into 20-25 cm vines and planted to a 10-15 cm depth. A plant spacing of 75 cm × 37.5 cm was used, giving six plants per plot. The corresponding plant density was similar to the recommended 37,000 stands per hectare for sweet potato on sandy-loam soils of humid tropical environments (Adubasim et al., 2017). The planting was done three weeks after applying lime and poultry droppings. The application of NPK was by topdressing, whereby 90 and 45 g were applied to plots receiving 0.40 t·ha⁻¹ (full) and 0.20 t·ha⁻¹ (half), respectively. This N-containing fertilizer was applied by split application, as this approach may be better than single dosing of N-rich fertilizers in the study environment (Oko and Asiegbu, 2001), a notion also supported by Umezina et al. (2020). The NPK was applied by band placement at 1, 4 and 7 weeks after planting (WAP), applying one-third of the adopted rate at each of these three growth stages of the crop. Thus, each time of adding NPK, 30 and 15 g were added to plots for full and half doses, respectively. Routine cultural practices were manually carried in the plots, such as weeding by hand picking at two-week intervals and manual irrigation to field capacity at two- or three-day intervals during the dry season trial.

Soil Sampling and Laboratory Analyses

The plots were sampled at sweet potato maturity some 17 WAP in the two seasons of the study, corresponding to 20 weeks after soil application of lime and PD. Soil samples were collected from the 0-20 cm depth of three randomly selected spots in each sub-plot. Both soil cores and loose soil samples were collected. Soil cores were collected with 100-cm³ cylindrical samplers. The loose samples were bulked together per plot and air-dried till no further weight loss. They were then gently crushed and passed through a 2-mm-mesh sieve before being used for laboratory determinations of the soil physicochemical properties of the study.

Soil Bulk Density Assessment

Soil bulk density was determined by the core method (Blake and Hartge, 1986). In this method, the undisturbed samples were oven-dried at 105 °C for 24 h to obtain the dry mass of the soil.

Determination of Soil Physicochemical Properties

Soil pH was measured in a 1:2.5 soil-H₂O/KCl ratio with a combined glass electrode pH metre following the procedure described by McLean (1982). Soil organic carbon was determined by the modified Walkley-Black wet digestion-combustion method (Nelson and Sommers, 1996); this was multiplied by 1.724 to derive SOM. Available phosphorus was extracted with Bray-2 solution and determined using Olsen and Sommers' (1982) colour development method. Soil exchangeable bases/acidity and the apparent cation exchange capacity (CEC) were determined by the ammonium acetate extraction method (Hendershot et al., 1993), while effective CEC was obtained as the sum of the exchangeable bases and the exchangeable acidity.

Statistical Analysis

The GenStat Discovery Edition 4 was used to subject the data to two-way analysis of variance, by this software's procedure most appropriate for field experiments with split-plot design in RCBD. Where significantly different, treatment means were compared using the procedure of Fisher's least significant difference at the 5% level of probability (F-LSD_{0.05}).

Results and Discussion

Interaction Effects of Lime Status and Fertilizer Type on Soil Bulk Density of the Sandy-Loam Ultisols under High-Density Coverage Sweet Potato

Soil bulk density did not differ among treatments in both the rainy season (1.46-1.60 g·cm⁻³) and the dry season (1.36-1.82 g·cm⁻³) of the study, neither were the main effects of lime status and fertilizer type significant. The species of these soil amendments (organic or synthetic) may partly explain these results. In a similar environment, Okonkwo et al. (2008) and Mbah et al. (2010) reported decreases in soil bulk density of plots amended with natural limes of wood ash and burnt rice-husk ash. The non-significant effect of fertilizer type is despite the expected and increases in SOM and hence improvements in structure-related properties including hydraulic properties of the soil following organic amendment (Ogunezi et al., 2019; Obalum et al., 2020; Onah et al., 2023). In the dry season cropping, however, the main effects of treatment showed tendency for the lowest soil bulk density in PD₂₀ and PD₁₀+NPK_{0.20} treatment plots (1.49 g·cm⁻³) and the highest values in plots treated with NPK_{0.40} (1.74 g·cm⁻³).

Soil bulk density is an indicator of soil productivity. Low values imply greater permeability and encourage downward movement of water through old root channels (Uwah et al., 2012), and hence root penetration in sweet potato production. The seemingly lowest value of 1.36 g·cm⁻³ in the dry season was recorded in no-lime/PD plots. This value translates into total porosity of 48.70%, assuming a soil particle density of 2.65 g·cm⁻³. Soil total porosity

> 50% is many times considered unsuitable for sweet potato production as it may be too friable and may fail to provide the necessary anchorage support for the crop growth (Stathers et al., 2013). Moreover, such high soil total porosity values may lead to leaching of plant nutrients and migration of some toxic substances resulting in groundwater contamination.

Interaction Effects of Lime Status and Fertilizer Type on Soil Physicochemical Properties of the Sandy-Loam Ultisols under High-Density Coverage Sweet Potato

The interaction effects of lime status and fertilizer type used to grow sweet potato in sandy-loam Ultisols were not significant for most of the soil physicochemical properties considered in this study. The results for some of them showing significant differences among treatments in either or both cropping seasons (including soil pH, Ca²⁺, Na⁺ and CEC) are presented in Table 1.

For the rainy season cropping, treatment limed/PD₁₀+NPK_{0.20} gave the highest value of soil pH-KCl (6.7), while no-lime/no-fertilizer (control) gave the lowest value (4.3). A similar trend prevailed during the dry season cropping. These differences in pH-KCl were used to discriminate the tendency of limed/PD₁₀+NPK_{0.20} and the control plots to also show highest and lowest values, respectively in both seasons. These results are not only typical of lime effect in acid soils (Kanyanjua et al., 2002; Nekesa et al., 2005), but also support other studies that found combined application of lime with manure and/or P-fertilizers to increase soil pH (Svotwa et al., 2007; Ossom et al., 2008; Kisinyo et al., 2012). The optimum soil pH range for sweet potato is 5.5-6.5. Soils with pH < 5 often show high ionic concentrations of H and Al in their solution, and this impedes plant uptake of nutrients.

In the rainy season cropping, limed/PD₂₀ and no-lime/PD₁₀+NPK_{0.20} plots gave the highest and lowest values of soil Ca²⁺

Table 1. Interaction effects of lime status and fertilizer type used to grow sweet potato in sandy-loam Ultisols in successive rainy and dry seasons on soil physicochemical properties

Lime Status	Fertilizer type	pH-H ₂ O	pH-KCl	Ca ²⁺	Mg ²⁺	Na ⁺	CEC [†]
				(cmol/kg)			
Rainy Season							
Limed	PD ₂₀	7.1	6.4	5.09	5.23	ND	14.40
	NPK _{0.40}	7.2	6.4	3.83	5.97	ND	11.73
	PD ₁₀ +NPK _{0.20}	7.1	6.7	3.43	4.39	ND	10.53
	No-fertilizer	6.8	5.9	2.10	4.64	ND	8.27
No-Lime	PD ₂₀	6.5	5.9	1.40	3.17	ND	12.80
	NPK _{0.40}	6.4	5.8	2.29	2.15	ND	10.00
	PD ₁₀ +NPK _{0.20}	6.1	5.4	0.89	3.55	ND	8.67
	No-fertilizer (Control)	5.6	4.3	3.08	2.66	ND	15.47
	F-LSD _(0.05)	<i>ns</i>	<i>0.57</i>	<i>1.65</i>	<i>ns</i>		3.44
Dry Season							
Limed	PD ₂₀	7.1	6.4	3.59	2.15	0.07	7.53
	NPK _{0.40}	7.2	6.4	2.99	1.49	0.02	5.93
	PD ₁₀ +NPK _{0.20}	7.2	6.6	2.85	2.24	0.03	6.70
	No-fertilizer	6.8	5.9	2.52	1.59	0.03	6.45
No-Lime	PD ₂₀	7.1	5.6	2.15	2.24	0.04	6.46
	NPK _{0.40}	6.3	5.9	1.82	1.63	0.04	6.70
	PD ₁₀ +NPK _{0.20}	6.0	5.4	0.89	1.45	0.04	5.86
	No-fertilizer (Control)	5.6	4.3	1.21	1.82	0.05	5.45
	F-LSD _(0.05)	<i>ns</i>	<i>0.71[§]</i>	<i>ns</i>	<i>0.64[§]</i>	<i>0.02</i>	<i>ns</i>

Note: PD₂₀ - poultry droppings at 20 t·ha⁻¹, NPK_{0.40} - NPK 15-15-15 at 0.40 t·ha⁻¹; PD₁₀+NPK_{0.20} - poultry droppings at 10 t·ha⁻¹ + NPK 15-15-15 at 0.20 t·ha⁻¹; Ca²⁺ - exchangeable calcium, Na⁺ - exchangeable sodium, CEC cation exchange capacity; [†]apparent CEC (rainy season) and effective CEC (dry season); ND - not determined; [§]significant at 10% level of probability; ns - not significant

of 5.09 and 0.89 $\text{cmol}\cdot\text{kg}^{-1}$, respectively (Table 1), representing ca. 470% increase in the former over the latter! A similar trend prevailed in the dry season cropping when the differences were, however, not significant. For Mg^{2+} , these limed/ PD_{20} and no-lime/ $\text{PD}_{10}+\text{NPK}_{0.20}$ plots were among treatments showing the highest and lowest values, respectively. The results were such that limed treatments showed nominally higher Mg^{2+} compared to no-lime treatments in the rainy season, whereas limed/ PD_{20} , limed/ $\text{PD}_{10}+\text{NPK}_{0.20}$ and no-lime/ PD_{20} plots gave significantly ($P \leq 0.10$) higher values compared to limed/ $\text{NPK}_{0.40}$, limed/no-fertilizer and no-lime/ $\text{PD}_{10}+\text{NPK}_{0.20}$ plots in the dry season. These results just presented (for Ca^{2+} and Mg^{2+}) generally reflect the synergistic effect of synthetic lime and poultry droppings in the soil. Similar observations were reported by Samsunnahar et al. (2006) in a Bangladesh tropical environment and Gichangi et al. (2009) in Transkei region of South Africa.

Though the higher soil Ca^{2+} in the control than the no-lime/ $\text{PD}_{10}+\text{NPK}_{0.20}$ plots is difficult to explain, it may be inferred from the rainy season data that PD-bearing fertilizer amendments require lime to enhance soil Ca^{2+} . Organic fertilizers can promote release of plant nutrients up to the adequate levels required to support crop production (Farhad et al., 2009). The optimum agronomic rate of poultry droppings for the soil of the present study was reported to be 20 $\text{t}\cdot\text{ha}^{-1}$ (Ogunezi et al., 2019). The present data suggest that the effects of poultry-droppings manure can be pronounced in limed acid tropical soils where this manure is applied at the optimum agronomic rate.

Soil Na^+ differed amongst treatments during dry season cropping when it was determined (Table 1). Compared to the control, all amended plots showed significant increases in soil Na^+ , but with less difference within the treatments. The highest and lowest values of 0.07 and 0.02 $\text{cmol}\cdot\text{kg}^{-1}$ were found in limed/ PD_{20} and limed/ $\text{NPK}_{0.40}$ amended plots, respectively.

The interaction effects of lime status and fertilizer type on soil CEC were significant in the rainy but not the subsequent dry season of the study. The apparent CEC as determined after rainy season cropping recorded the highest values of 14.40 and 15.40 $\text{cmol}\cdot\text{kg}^{-1}$ in the limed/ PD and the control plots, respectively, while limed/no-fertilizer and no-lime/ $\text{PD}_{10}+\text{NPK}_{0.20}$ plots showed the lowest CEC (Table 1). The control plots showing the highest apparent CEC values may seem strange; however, this observation is attributed to their lowest soil pH. Because the soils are acid and kaolinitic and hence known for variable charge, their CEC is pH-dependent, such that the deprotonation (displacement of protons) up to pH-7 in the determination of apparent CEC raised this CEC most where the soil pH was lowest (Obalum et al., 2013).

Somewhat contrary to the results in the rainy season, the effective CEC determined after the rainy season cropping tended to be highest and lowest in the limed/ PD and the control plots, respectively, with no-lime/ $\text{PD}_{10}+\text{NPK}_{0.20}$ plots still being among the lowest (Table 1). Apparent CEC (rainy season) represents the potential rather than the actual cations fertility of soils; effective CEC (dry season) represents otherwise. From agronomic perspective, therefore, limed/ PD should be preferred to the control for improving these soils' CEC. The Ca^{2+} and CEC data checked together point to the no-lime/ $\text{PD}_{10}+\text{NPK}_{0.20}$ as undermining the cation exchange behaviour of the soil. This poor performance of the no-lime/ $\text{PD}_{10}+\text{NPK}_{0.20}$ is noteworthy.

Overall, the treatment affected Ca^{2+} and CEC rather differently in this study. This was probably due to the relative influence of soil pH on these two indices of cation exchange. In this regard, we found that soil pH had greater influence on Ca^{2+} than it did on the apparent or effective CEC (Figs. 1 and 2, respectively).

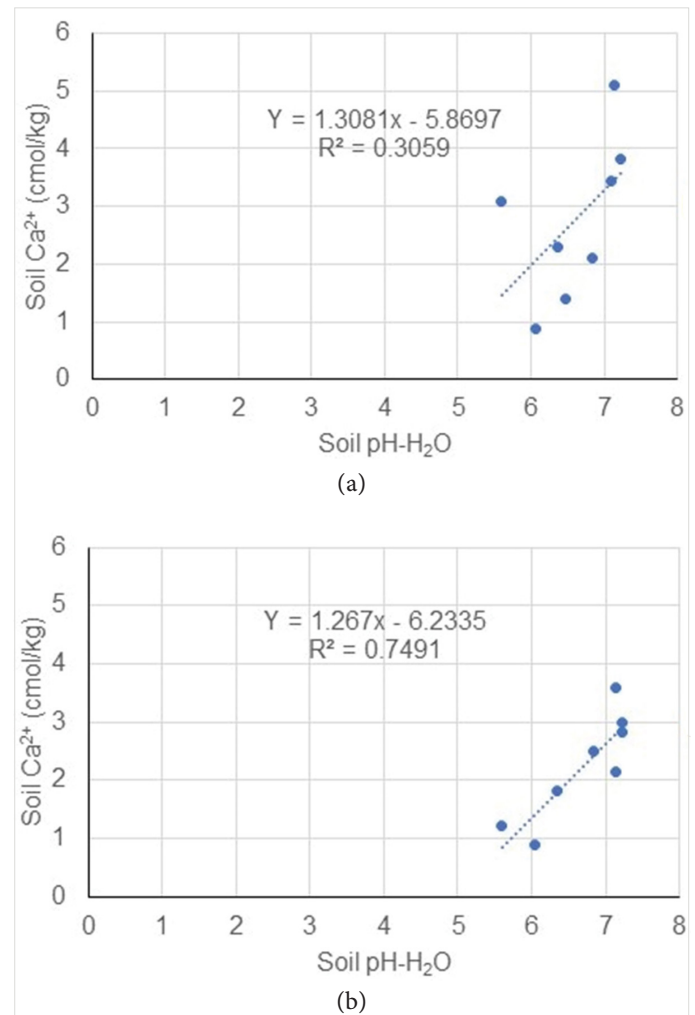


Figure 1. The relationship between soil pH and soil Ca^{2+} in the amended sandy-loam Ultisols after growing sweet potato in the (a) rainy season and (b) the successive dry season

Thus, increased soil pH can explain the highest Ca^{2+} in the limed/ PD plots. Weak relationships between soil pH and apparent CEC are a common situation in especially variable charge tropical soils (Obalum et al., 2013). The data presented show generally weaker relationships in the rainy than the dry season cropping, as well as the tendency for decreases in apparent CEC with increasing soil pH in the former. These observations, coupled with the lesser influence of soil pH on CEC, support the inference that the highest apparent CEC in the control plots in the rainy season was due to the lowest soil pH recorded in these plots and hence the aforementioned deprotonation in the determination of apparent CEC. Kabango et al. (2022) similarly reported an inverse relationship between soil pH and CEC following application of agricultural lime to Ferralsols at Uganda. Soil pH also influenced soil content of Mg^{2+} in the present study and the relationship was rather stronger in the rainy than the dry season ($R^2 = 0.65$ and 0.20, respectively; plotted data not shown).

In this study, lime was not re-applied before the second cropping in the dry season but it still had positive effect on the soil pH (see Table 2). The situation of soil pH-Ca²⁺ and soil pH-CEC relationships being weaker in the rainy than the dry season and vice versa for soil pH-Mg²⁺ suggests that the soil fertility benefits of lime-induced increases in soil pH can be greater or lesser beyond the season of application, depending on the soil fertility index considered. It can be deduced further from the relationships between soil pH and each of Ca²⁺, effective CEC and Mg²⁺ in the dry season that soil pH-induced variations in Ca²⁺ and Mg²⁺ contribute highly and lowly, respectively to the corresponding soil pH-induced variations in effective CEC of the soils.

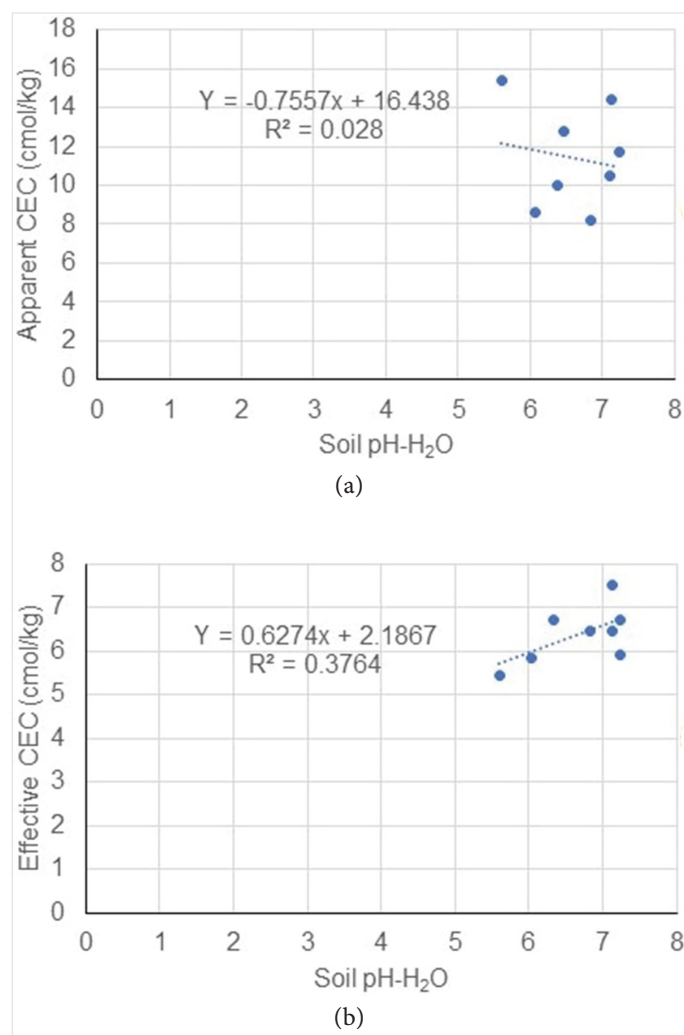


Figure 2. The relationship between soil pH and CEC of the amended sandy-loam Ultisols after growing sweet potato in the (a) rainy season when apparent CEC was determined and (b) the successive dry season when effective CEC was determined

Main Effects of Lime Status and Fertilizer Type on Soil pH, Organic Matter and Available P in the Sandy-Loam Ultisols under High-Density Coverage Sweet Potato

The main effects of lime status and fertilizer type on soil pH, SOM and available P content of the soil during rainy and dry seasons cropping are shown in Table 2. Soil pH was higher in limed than no-lime plots in both seasons. In each season, soil pH-H₂O and pH-KCl toed similar trends, thus lending support to the discrimination among the treatments in the former based on significant differences in the latter when examining the interaction effects. Liming could reduce soil acidity by displacing H⁺, Fe²⁺, Al³⁺ and Mn⁴⁺ (Kanyanjua et al., 2002; Khoi et al., 2010). Also, the anions CO³⁻ and OH⁻ in limes can neutralize the H⁺ released from the exchange complex and hydrolyze Al³⁺ in soil solution (Fageria et al., 2008). The effect of synthetic lime on soil pH in the present study is similar to that reported by other researchers (Omollo et al., 2016; Otieno et al., 2018). For fertilizer type effect, the highest and lowest values were recorded from PD-amended and no-fertilizer plots, respectively. This agrees with the commonly observed effectiveness of poultry manure in raising soil pH (Igwe et al., 2013; Ndzeshala et al., 2023).

The positive effect of liming on SOM was evident only in the dry season, while fertilizer types showed similar values in both seasons of the study (Table 2). Lime was applied before the rainy season cropping and was not re-applied before the dry season cropping, yet its positive effect on SOM was realized after the latter. This shows that the residual effect of liming could be to enhance SOM in the soil. The SOM often contributes to increasing soil aggregation in managed tropical agroecosystems (Igwe et al., 2013; Ogunezi et al., 2019); therefore, the ability of lime to increase SOM could be linked to its aggregation effect in the soil.

Of the no effects of fertilizer type on SOM, Ogunezi et al. (2019) reported increasing SOM with increasing poultry manure rates of 0, 10 and 20 t·ha⁻¹ after growing cucumber in the present location. That PD addition at 20 t·ha⁻¹ did not increase SOM in the present study was, therefore, surprising, especially with the expected impeded decomposition of SOM due to the high-density coverage by the sweet potato crop. In their study in this environment where the protective organic mulch over poultry-droppings amended plots was burnt to ash two months later, Onah et al. (2023) reported no differences in SOM content between plots amended at 25 t·ha⁻¹ and unamended ones five months after the amendment. Sampling the soil some 20 weeks (five months) after liming and manuring in the present study would, therefore, help to explain the similarity in SOM content of the PD₂₀-amended and no-fertilizer plots. Manure-based addition of organic matter was, after six months, similarly found not to improve SOM in sandy-loam soils under high-density coverage sweet potato elsewhere in the humid lowland tropics (Michael, 2020).

For available P, main effects of treatment were significant only for fertilizer type, whereby PD₂₀ and PD₁₀+NPK_{0,20} showed higher values than NPK_{0,40} and no-fertilizer, with the pattern of differences among the fertilizer types being the same in both cropping seasons (Table 2). The no effect of lime on available P is shown despite the former's positive effect on soil pH. Application of lime to acidic soils to raise their pH results in the release of Fe/Al-fixed phosphate ions into the soil solution (Kisinyo, 2016), and such increases in soil pH favour microbial activity and associated mineralization of soil organic P (Ameyu, 2019).

Table 2. Main effects of lime status and fertilizer type used to grow sweet potato in sandy-loam Ultisols in successive rainy and dry seasons on soil pH, soil organic matter and available P content of the soil

Treatments		pH-H ₂ O	pH-KCl	SOM (g/kg)	AvP (mg/kg)
Rainy Season					
Lime status	Limed	7.1	6.3	1.93	25.90
	No-lime	6.1	5.4	2.00	23.70
	F-LSD _(0.05)	0.54	0.63	ns	ns
Fertilizer type	PD ₂₀	6.8	6.2	2.15	45.70
	NPK _{0.40}	6.8	6.1	1.92	11.10
	PD ₁₀ +NPK _{0.20}	6.6	6.0	1.82	35.70
	No-fertilizer	6.2	5.1	1.97	6.90
	F-LSD _(0.05)	0.29	0.37	ns	21.70
Dry Season					
Lime status	Limed	7.1	6.3	1.95	31.20
	No-lime	6.2	5.3	1.60	29.00
	F-LSD _(0.05)	0.09	0.83	0.27	ns
Fertilizer type	PD ₂₀	7.1	6.0	1.95	55.90
	NPK _{0.40}	6.8	6.1	1.61	9.70
	PD ₁₀ +NPK _{0.20}	6.6	6.0	1.80	47.50
	No-fertilizer	6.2	5.1	1.74	7.40
	F-LSD _(0.05)	0.65	0.44	ns	21.00

Note: PD₂₀ - poultry droppings at 20 t·ha⁻¹, NPK_{0.40} - NPK 15-15-15 at 0.40 t·ha⁻¹; PD₁₀+NPK_{0.20} - poultry droppings at 10 t·ha⁻¹ + NPK 15-15-15 at 0.20 t·ha⁻¹; SOM - soil organic matter, AvP - available Phosphorus

The differences in available P due to the fertilizer types cannot be attributed to the decreases in soil acidity, as soil pH vs available P regressions showed R^2 values of 0.0597 and 0.0694 (plotted data not shown). Since the said P-fixation by Fe-Al oxides and hydroxides normally occurs at low soil pH values (Ameiyu, 2019), it could be that the soil pH values exceeded the critical values for this phenomenon. If that was the case, the inherent and the fertilizer-supplied P increased soil available P (Kisinyo et al., 2013). There have been similar reports of poultry-droppings application at 20 t·ha⁻¹ increasing available P under cucumber (Ogunezi et al., 2019) and sweet potato (Obalum et al., 2020). Similar results were obtained in other coarse-textured soils of the study area with 10 t·ha⁻¹ (Umeugokwe et al., 2021) and 25 t·ha⁻¹ (Onah et al., 2023). Relative to the no-fertilizer plots, soil available P increased in the PD-amended plots by about 562% and 655% in the rainy and dry seasons, respectively. These astronomical increases were because poultry droppings' effect in P release in these soils peak around 16 weeks after addition (Chukwuma et al., 2024), and the sampling was done 20 weeks after liming and manuring.

The main effects of lime status and fertilizer type on cation exchange indices in the soil are shown in Table 3. Of those determined among the base-forming cations (exchangeable bases), only Ca²⁺ was improved by liming in both seasons. Total exchangeable bases (TEB) measured only in the dry season followed suit. The increase in Ca²⁺ in limed plots is partly attributed to its release after lime dissociation and manure mineralization. The higher SOM due to liming in the dry season (see Table 2) might help to explain the concurrent increases in Ca²⁺ and TEB in limed relative to no-lime plots in the dry season (Obalum et al., 2012). For the fertilizer types, PD-amended plots generally showed higher values of exchangeable bases and their summation (TEB) than the rest in the dry season. Focusing on poultry droppings' effect in this and similar environments, the results for the exchangeable bases largely contrast with Ogunezi et al. (2019) in their application rate of 20 t·ha⁻¹. Also, they largely contrast with Umeugokwe et al. (2021) but not with Nnadi et al. (2021), where poultry droppings were applied at 10 t·ha⁻¹. Similar to our data, Awodun et al. (2007), Phengsouvana et al. (2009) and Odedina et al. (2011) found increases in soil Ca²⁺ with application of lime and manure or their combination.

Table 3. Main effects of lime status and fertilizer type used to grow sweet potato in sandy-loam Ultisols in successive rainy and dry seasons on cation exchange properties of the soil

Treatments		K ⁺	Ca ²⁺	Mg ²⁺	Na ⁺	TEB	CEC [†]
		(cmol/kg)					
Rainy Season							
Lime status	Limed	ND	3.61	5.06	ND	ND	11.23
	No-lime	ND	1.91	2.88	ND	ND	11.73
	F-LSD _(0.05)		1.55	<i>ns</i>			<i>ns</i>
Fertilizer type	PD ₂₀	ND	3.24	4.20	ND	ND	13.60
	NPK _{0.40}	ND	3.06	4.06	ND	ND	10.87
	PD ₁₀ +NPK _{0.20}	ND	2.16	3.97	ND	ND	9.60
	No-fertilizer	ND	2.59	3.65	ND	ND	11.87
	F-LSD _(0.05)		<i>ns</i>	<i>ns</i>			2.66
Dry Season							
Lime status	Limed	0.29	2.99	1.87	0.04	5.19	6.65
	No-lime	0.29	1.52	1.79	0.05	3.63	6.12
	F-LSD _(0.05)	<i>ns</i>	0.77	<i>ns</i>	<i>ns</i>	1.46	<i>ns</i>
Fertilizer type	PD ₂₀	0.48	2.87	2.19	0.06	5.60	7.00
	NPK _{0.40}	0.11	2.40	1.56	0.04	4.11	6.31
	PD ₁₀ +NPK _{0.20}	0.30	1.87	1.84	0.04	4.05	6.28
	No-fertilizer	0.27	1.87	1.70	0.04	3.88	5.95
	F-LSD _(0.05)	<i>ns</i>	0.60	0.42	0.01	0.80	<i>ns</i>

Note: PD₂₀ - poultry droppings at 20 t·ha⁻¹, NPK_{0.40} - NPK 15-15-15 at 0.40 t·ha⁻¹; PD₁₀+NPK_{0.20} - poultry droppings at 10 t·ha⁻¹ + NPK 15-15-15 at 0.20 t·ha⁻¹; K⁺ - exchangeable potassium, Ca²⁺ - exchangeable calcium; Mg²⁺ - exchangeable magnesium; Na⁺ - exchangeable sodium; CEC - cation exchange capacity; TEB - total exchangeable bases; †apparent CEC (rainy season) and effective CEC (dry season); ND - not determined; ns - not significant

Lime status had no effect on cation exchange capacity (CEC) of the soil in both cropping seasons. Fertilizer type affected apparent CEC determined in the rainy season, but not effective CEC determined in the dry season (Table 3). For the apparent CEC, values were higher in PD₂₀ than NPK_{0.40} and PD₁₀+NPK_{0.20} but not the no-fertilizer plots. The enhanced values in PD₂₀ could be due to improved soil conditions including favourable soil pH, increased Ca²⁺ release from lime dissolution and manure mineralization, and reduction of exchangeable acidity which in turn increased the exchange sites of the soil. The similarity between PD₂₀ and no-fertilizer plots may have to do with certain peculiarities of the study environment (Igwe et al., 2013). Under conditions of having protective organic mulch burnt to ash two months after applying poultry manure in this environment, CEC was found not to be improved with poultry manure at 25 t·ha⁻¹ but at rates ≥ 50 t·ha⁻¹ five months after the amendment (Onah et al., 2023). Dikinya et al. (2010), who added poultry manure to three soils at much higher rates, similarly reported increases in their CEC, attributing such

increases to the humus contained in the manure. In the present study, the highest apparent CEC due to PD₂₀ (13.60 cmol·kg⁻¹) was close to the threshold value of 15 cmol·kg⁻¹, understandably due to the corresponding high soil pH (6.8, see Table 2) which implied reduced deprotonation to raise the apparent CEC of this kaolinitic soil, but this PD₂₀ cannot be said to have adversely affected its cation exchange behaviour (Onah et al., 2023).

Conclusion

This study has demonstrated the importance of using synthetic lime and/or manure-NPK combination in soil fertility management of the dominant coarse-textured acid soils of the humid tropics across the prevailing rainy and dry seasons. The choice of use of synthetic lime and/or sole or complementary use of poultry-droppings and NPK fertilizer would depend on the soil physicochemical properties that the farmer targets to improve. Liming without adding any fertilizer should be adopted if the target

is to improve SOM, whereas poultry-droppings manuring should be adopted if the target is to improve P-availability in the soil. Either of these two practices can be used to ameliorate soil acidity; however, where both of them are applied, there might be not only amelioration of soil acidity as the enhanced soil pH could lead to improvements in 'actual' exchange and hence concentration of base-forming cations in these highly leached tropical soils. There were seemingly no clear-cut improvements in any of these indices of soil quality and fertility supporting the adoption of NPK or its complementation with poultry droppings, nor liming alongside either of these two fertilizer application options.

The observed influence of soil pH on cations exchange indices of the soil mostly Ca^{2+} and, to a lesser extent, CEC, was less pronounced in the rainy than the dry season, an indication that excessive environmental humidity could undermine such influence. The findings of this study are important for sustainable crop production on soils that share similar characteristics as the one investigated. Though these findings apply particularly to crops that provide adequate near-soil vegetative cover, they might also be applicable outside this category of crops.

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CRedit Authorship Contribution Statement

Prisca O. Ogumba: Provisioning of some of the experimental resources and manuscript writing. **Anulika I. Orah:** Provisioning of some of the experimental resources and editing of the manuscript. **Solange T. Ndzeshala:** Project management and manuscript editing. **Nancy E. Ebido:** Data analysis and manuscript editing. **Adaobi L. Nnadi:** Investigation, performance of some of the experiments and manuscript editing. **Kolawole E. Law-Ogbomo:** Project management and manuscript editing. **Sunday E. Obalum:** Project conceptualization and management, data analysis and manuscript editing. **Charles A. Igwe:** Overall project management and manuscript editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Adubasim C. V., Law-Ogbomo K. E., Obalum, S. E. (2017). Sweet Potato (*Ipomoea batatas*) Growth and Tuber Yield as Influenced by Plant Spacing on Sandy Loam in Humid Tropical Environment. *Agro-Science* 16 (3): 46-50.
- Agbede T. M., Adekiya, A. O. (2011). Evaluation of Sweet Potato (*Ipomoea batatas* L.) Performance and Soil Properties under Tillage Methods and Poultry Manure Levels. *Emir J Food Agric* 23 (2): 164-177.
- Ahn P. M. (1993). *West African Soils*. Oxford University Press, London, 33-36.
- Akpaninyang F., Okpara D. A., Njoku J. C., Ogbologwung P., Okpara B., Akpan A. E., Jan L. (2015). Combinations of Organic and Inorganic Fertilizers for Vine, Carotene and Root Yields of Orange-Fleshed Sweet Potato at Umudike, Southeastern Nigeria. *Niger Agric J* 46 (1): 87-94.
- Ameyu, T. (2019). A Review on the Potential Effect of Lime on Soil Properties and Crop Productivity Improvements. *J Environ Earth Sci* 9 (2): 17-23. doi: 10.7176/JEES/9-2-03
- Atugwu A. I., Imoh O. N., Nnadi A. L., Chukwudi U. P., Obalum S. E., Onyia V. N., Kato K. (2023). Comparative Assessment of Adaptability and Agronomic Traits of Seventeen Tomato Varieties on Coarse-Textured Soil in Tropical Dry and Rainy Seasons. *Agric Conspec Sci* 88 (3): 177-186
- Awodun M. A., Omonijo L. I., Ojeniyi S. O. (2007). Effects of Goat Dung and NPK Fertilizer on Soil and Leaf Nutrient Content, Growth and Yield of Pepper. *Int J Soil Sci* 2 (2): 142-147.
- Baiyeri P. K., Ugese F. D., Obalum S. E., Nwobodo C. E. (2020). Agricultural Waste Management for Horticulture Revolution in Sub-Saharan Africa. *CAB Reviews* 2020 15: No. 017. doi: 10.1079/PAVSNNR202015017
- Blake G. R., Hartge K. H. (1986). Bulk Density. In: A. Klute, ed. *Methods of Soil Analysis*, part 1 (2nd ed.). Agronomy Monograph No. 9. Madison Wisconsin: American Society of Agronomy, pp. 363-382.
- Chukwuma C. C., Oraegbunam C. J., Ndzeshala S. D., Uchida Y., Ugwu V. U., Obalum S. E., Igwe C. A. (2024). Phosphorus Mineralization in Two Lithologically Dissimilar Tropical Soils as Influenced by Animal Manure Type and Amendment-to-Sampling Time Interval. *Commun Soil Sci Plant Anal* 55 (5): 707-722. doi: 10.1080/00103624.2023.2276269
- Dikinya, O., Mufwanzala N. (2010). Chicken Manure-Enhanced Soil Fertility and Productivity: Effects of Application Rates. *J Soil Sci Environ Manage* 1: 46-54.
- Ebido N. E., Nnadi A. L., Adeoluwa O.O., Ndubuaku U. M., Obalum S. E., Ugwuju C. L., Ajoagu G. M., Baiyeri K. P. (2024). Influence of Brewery Waste and Animal Manure-Based Compost on the Growth of Green Amaranth in Sandy Tropical Soils. *Organic Farming* 10 (1): 69-79. doi: 10.56578/of100104
- Fageria N. K., Baligar V. C. (2008). Ameliorating Soil Acidity of Tropical Oxisols by Liming for Sustainable Crop Production. *Advances in Agronomy* 99: 345-399.
- Farhad W., Saleem M. F., Cheema M. A., Hammad H. M. (2009). Effect of Poultry Manure Levels on the Productivity of Spring Maize (*Zea mays* L.). *Anim Plant Sci J* 19 (3): 122-125.
- Gichangi E. M., Mkeni P. N. S. (2009). Effects of Goat Manures and Lime Addition on Phosphate Sorption by Two Soils from Transkei Region, South Africa. *Commun Soil Sci Plant Anal* 40: 1-13.
- Hendershot W. H., Lalonde H., Duquette M. (1993). Ion Exchange and Exchangeable Cations. In: M.R. Carter (ed.), *Soil Sampling and Methods of Analysis*, Lewis Publisher, pp. 167-174.
- Igwe C. A., Obalum S. E. (2023). Sustainable Agriculture in Fragile Ecosystems. In: Nnabude P.C., Onunwa A.O., Uko I., Okolie C.U. and Okpata P.N. (eds.), *Soil: The Indispensable Link*, Cadventures Press, Umunya, Anambra State, Nigeria, Chapter 2, pp. 32-51.
- Igwe C. A., Nwite J. C., Agharanya K. U., Watanabe Y., Obalum S. E., Okebalama C. B., Wakatsuki T. (2013). Aggregate Associated Soil Organic Carbon and Total Nitrogen Following Amendment of Puddled and Sawah-Managed Rice Soils in Southeastern Nigeria. *Arch Agron Soil Sci* 59 (6): 859-874. doi: 10.1080/03650340.2012.684877

- Kabango F., John B., Onesimus S., Lenssen A. W., Majaliwa M. J. G., Stewart K. (2022) Effect of Applying Low Rates of Agricultural Lime and Chicken Manure on Selected Soil Properties on Ferralsols of Lake Victoria Agro-Ecological Zone, Uganda. *J Agric Chem Environ* 11: 240-257. doi: 10.4236/jacen.2022.114017
- Kanyanjua S. M., Ireri L., Wambua S., Nandwa S. M. (2002). Acidic Soils in Kenya: Constraints and Remedial Options. KARI Technical Note No. 11. Nairobi, Kenya.
- Khoi C. M., Guong V. T., Trung P. N. M., Nilsson S. I. (2010). Effects of Compost and Lime Amendment on Soil Acidity and N Availability in Acid Sulfate Soil. *Proceedings of 19th World Congress of Soil Science, Soil Solutions for a Changing World, 1-6 August 2010, Brisbane, Australia*, pp 52-55.
- Kisinyo P. O. (2016). Long Time Effects of Lime and Phosphorus on Maize Productivity in an Acid Soil of Uasin Gishu Country, Kenya. *Sky Journal of Agricultural Research* 5 (3): 48-55.
- Kisinyo P. O., Gud S. O., Othieno, C. O., Okalebo J. R., Opala P. A., Maghanga J. K., Agalo J. J., Ng'etich W. K., Kisinyo J. A., Osiyo R. J., Nekesa A. O., Makatiani E. T., Odee D. W., Ogola B.O. (2012). Effects of Lime, Phosphorus and Rhizobia on Sesbania Sesban Performance in a Western Kenyan Acid Soil. *Afr J Agric Res* 7 (18): 2800-2809.
- Kisinyo P. O., Othieno C. O., Gudu S. O., Okalebo J. R., Opala P. A., Maghanga J. K., Ng'etich, W.K., Agalo J. J., Opile. R. W., Kisinyo J. A., Ogola B. O. (2013). Phosphorus Sorption and Lime Requirement of Maize Growing Acid Soils of Kenya. *Journal of Sustainable Agricultural Research* 2 (2): 116-123.
- Mbah C. H., Nwite J. N., Nweke I. A. (2010). Response of Maize (*Zea Mays* L.) to Different Rates of Wood Ash Application of an Acid Ultisol in Southeastern Nigeria. *Afr J Agric Res* 5 (7): 580-583.
- McLean E. O. (1982). Soil pH and Lime Requirement. In: Page A.L. (ed.). *Methods of Soil Analysis, Part 2: Chemical Methods*. Agronomy Monograph no. 9, American Society of Agronomy, Madison Wisconsin. pp. 199-224.
- Michael P. S. (2020). Soil Fertility Status and Sweet Potato Cultivation in Composted Mounds under Humid Lowland Tropical Climatic Conditions. *Sains Tanah Journal of Soil Science and Agroclimatology* 17 (2): 144-151. doi: 10.20961/stjssa.v17i2.43426
- Mitchell C. C., Tyson T. W. (2001). *Nutrient Management Planning for Small AFOs: Broilers Operations*, Alabama Cooperative Text Systems. ANR - 926.
- Ndzeshala S. T., Adubasim C. V., Joseph P. O., Ugwu V. U., Nnadi A. L., Sato S., Obalum S.E., Nzeadibe C. T., Dong Y., Soretire A. A., Rayns F., Igwe C. A. (2024). Converting Lignified Waste to Dignified Wealth: The Crucial Role of Microbial Biotechnology in Sustainable Agriculture and Environmental Management. *Environmental Engineering and Management Journal* (in press)
- Ndzeshala S. D., Obalum S. E., Igwe C. A. (2023). Some Utilization Options for Cattle Dung as Soil Amendment and Their Effects in Coarse-Textured Ultisols and Maize Growth. *Int J Recycl Org Waste Agricul* 12 (1): 123-139. doi: 10.30486/ijrowa.2022.1934239.1284
- Nekesa A. O., Okalebo J. R., Othieno C. O., Thuita M. N., Kipsat M., Bationo A., Sanginga N., Kimettu, J., Vanlauwe, B. (2005). The Potential of Minjingu Phosphate Rock from Tanzania as a Liming Material: Effect on Maize and Bean Intercrop on Acid Soils of Western Kenya. *African Crop Science Conference Proceedings* 2005 (7): 1121-1128.
- Nelson D. W., Sommers L.E. (1996). Total Carbon, Total Organic Carbon, and Organic Matter. In: Sparks, D.L. (ed.). *Methods of Soil Analysis, Part 3: Chemical Methods*. Agronomy Monograph no. 9, American Society of Agronomy, Madison Wisconsin. pp. 961-1010.
- Nnadi A. L., Nnanna P. I., Onyia V. N., Obalum S. E., Igwe C.A. (2020). Growth and Yield Responses of High-Density Coverage Sweet Potato to Liming and Fertilizer Combinations for Sandy-Loam Ultisols at Nsukka, Southeastern Nigeria. *Proceedings of the 44th Annual Conference of Soil Science Society of Nigeria (SSSN), 16-20 March 2020 [Colloquia SSSN 44]*, Enugu State University of Science and Technology (ESUT), Enugu, Enugu State, Nigeria, pp. 263-269.
- Nnadi A. L., Ugwu V. U., Nwite J. C., Obalum S. E., Igwe C. A., Wakatsuki T. (2021). Manurial Amendments and Source of Water for Supplemental Irrigation of Sawah-Rice System Influenced Soil Quality and Rice Yield. *Agro-Science* 20 (1): 95-102. doi: 10.4314/as.v20i1.15
- Nwinyi S. C. O. Odurukewe S. O., Emezier J. F. (1987). Studies on Optimum Fertilizer Requirement of Sweet Potato. *Proceeding of 15th Annual Conference. Soil Science of Nigeria. Kaduna, 20-24 October*, pp. 120-126.
- Nwite J. C., Ogbodo E. N., Obalum S. E., Igbo V. C., Igwe C. A. (2012a). Short-Term Response of Soil Physical Properties of an Ultisol, and Nutrient Composition of Fluted Pumpkin to Organic and Inorganic Fertilizer Mixtures. *Journal of Biology, Agriculture and Healthcare* 2 (10): 195-204.
- Nwite J. C., Keke C. I., Obalum S. E., Okolo C. C., Essien J. B., Anaele M. U., Igwe C. A. (2012b). Evaluation of Organo-Minerals and Inorganic Fertilizer Soles and Their Mixtures on Some Selected Soil Chemical Properties and Leaf Nutrient Composition of Fluted Pumpkin (*Telfairia occidentalis* Hook F.) in an Ultisol of Southeastern Nigeria. *Proceedings of International Agricultural Conference, Anambra State University, Igbariam Campus, Anambra State, Nigeria, 6th-9th May 2012*, pp. 494-503.
- Nwite J. C., Keke C. I., Obalum S. E., Essien J. B., Anaele M. U. and Igwe C. A. (2013). Organo-Mineral Amendment Options for Enhancing Soil Fertility and Nutrient Composition and Yield of Fluted Pumpkin. *Int J Veg Sci* 19 (2): 188-199. doi: 10.1080/19315260.2012.705233
- Obalum S. E., Watanabe Y., Igwe C. A., Obi M. E., Wakatsuki T. (2013). Improving on the Prediction of Cation Exchange Capacity for Highly Weathered and Structurally Contrasting Tropical Soils from Their Fine-Earth Fractions. *Commun Soil Sci Plant Anal* 44 (12): 1831-1848. doi: 10.1080/001036 24.2013.790401
- Obalum S. E., Edeh I. G., Imoh O. N., Njoku O. M., Uzoh I. M., Onyia V. N., Igwe C. A., Reichert J. M. (2017). Agronomic Evaluation of Seedbed and Mulching Alternatives with Plant Spacing for Dry-Season Fluted Pumpkin in Coarse- Textured Tropical Soil. *Food Energy Secur* 6 (3): 113-122.
- Obalum S. E., Nwite J. C., Watanabe Y., Igwe C. A., Wakatsuki T. (2012). Comparative Topsoil Characterization of *Sawah* Rice Fields in Selected Inland Valleys around Bida, North-Central Nigeria: Physicochemical Properties and Fertility Status. *Tropical Agriculture and Development*, 56 (2): 39-48. doi: 10.11248/jsta.56.39
- Obalum S. E., Ogumba P. O., Uzoh I. M. (2020). Influence of Tillage-Seedbed and Manure-NPK-Micronutrient Management Options on Selected Soil Properties of Sandy-Loam Ultisols Evaluated Using Sweet Potato. *Nigerian Journal of Soil Science* 30 (3): 117-125.
- Odedina J. N., Odedina S. A., Ojeniyi S. O. (2011). Effect of Types of Manure on Growth and Yield of Cassava (*Manihot esculenta* Crantz). *Researcher* 3 (5): 1-8.
- Ogumba P. O., Obalum S. E., Uzoh I. M. (2020). Soil Biochemical and Microbial Properties of Sandy Loam Ultisols as Affected by Some Tillage and Nutrient Management Practices. *International Journal of Agriculture and Rural Development* 23 (2): 5184-5195.
- Ogunezi K. C., Okebalama C. B., Obalum S. E. (2019). Optimum Poultry Droppings Rate for Coarse-Loamy Ultisols Based on Soil Macro-Aggregation and Fertility Indices and Evaluation Using Cucumber (*Cucumis sativus*). Presented under *Understanding Nigerian Soils for Sustainable Food & Nutrition Security and Healthy Environment*, the 43rd Annual Conference of Soil Science Society of Nigeria (SSSN), University of Agriculture, Makurdi, Benue State, Nigeria, 15th-19th July 2019
- Okalebo J. R., Othieno C. O., Woomer P. L., Karanja N. K., Semoka J. R. M., Bekunda M. A., Mugendi D. N., Muasya R. M., Bationo A., Mukhwana E. J. (2006). Available Technologies to Replenish Soil Fertility in East Africa. *Nutrient Cycling in Agroecosystem* 76: 153-170.
- Oko G.O., Asiegbu J. E. (2001). Evaluation of Varieties of Tomato for Yield, Quality and Optimum Time of Fertilizer Application for a Rainy Season Crop. *Proceedings of the 19th Annual Conference of Horticultural Society of Nigeria*, pp.126-129

- Okonkwo C. L., Mbagwu J. S. C., Nwoke F. N. (2008). Tillage Effect on Selected Properties of an Utitisol and Adaptability of Direct Seedbed Upland Rice in Abakaliki Nigeria. *International Journal of Tropical Agriculture and Food Systems* (2): 3-4.
- Okorie B. O., Obi J. O., Chioke G. U., Obalum S. E., Onah C. J., Nnadi A. L., Igwe C. A., Obi M. E. (2024). The Concept of Bio-Economic Mulching in Droughty Tropical Agroecosystems and Its Trans-Season Effects on Soil Hydro-Thermal Regime and Okra Performance. *SAINS TANAH - Journal of Soil Science and Agroclimatology* 21 (2):165-178. doi: <https://doi.org/10.20961/stjssa.v21i2.83285>
- Olsen S. R., Sommers L. E. (1982). Phosphorus. In: Page et al. (eds.), *Methods of Soil Analysis, Part 2 Agron.* Madison, WI: ASA, Soil Science Society of America, pp. 403-434.
- Omollo J. O., Semu E., Msaky J., Owuor P. (2016). Effects of Cropping Systems and Agricultural Lime on Soil Properties and Nutrient Content of Sugarcane on Acidified Soils of Kisumu Country, Kenya. *Am J Agric For* 4 (4): 97-111.
- Onah C. J., Nnadi A. L., Eyibio N. U., Obi J. O., Orah A. I., Amuji C. F., Obalum S.E. (2023). Off-Season Heavy Application of Poultry Manure to Droughty-Acid Soils under Heavily Protective Organic Mulch Later Burnt to Ash Improves Their Productivity. *West African Journal of Applied Ecology* 31 (1): 23-36.
- Ossom E. M., Rhykerd R.L. (2008). Effects of Lime on Soil and Tuber Chemical Properties and Yield of Sweet Potato (*Ipomoea batatas* L.) in Swaziland. *American-Eurasian Journal of Agronomy* 1 (1): 1-5.
- Otieno H. M. O., Chemining'wa G. N., Zingore S. (2018). Effects of Farmyard Manure, Lime and Inorganic Fertilizer Applications on Soil pH, Nutrients Uptake, Growth and Nodulation of Soybean in Acid Soils of Western Kenya. *J Agric Sci* 10 (4): 199-208.
- Phengsouvana V., Attanandana T., Yost R. S. (2009). Lime Application to Two Acidic Upland Soils for Soybean Production in Champasak Province, Lao PDR. *Kasetsart Journal of Natural Sciences* 43: 19-27.
- Sanchez P. A., Jama B. A. (2002). Soil Fertility Replenishment Takes off in East and Southern Africa. In: *Integrated Nutrient Management in Sub-Saharan Africa: From Concept to Practice*, (Vanlauwe B., Diels N., Sangina N., Merckx R.). Wallingford, UK: CABI, pp 23-46.
- Samsunnahar Nahar S., Baten M.A. (2006). Effect of Organic Farming on Soil Properties and Growth and Yield of Red Amaranth. *Bangladesh Journal of Environmental Sciences* 12 (2): 323-325.
- Stathers T., Bechoff A., Sindi K., Ndyetabula D. (2013). *Everything You ever Wanted to Know about Sweet Potato: Reaching Agents of Change Tot Manual*. (5): Harvesting and Postharvest Management, Processing and Utilization, Marketing and Entrepreneurship International Potato Centre, Nairobi, Kenya.
- Sowley E. N. K., Neindow M., Abubakari A. H. (2015). Effect of Poultry Manure and NPK on Yield and Storability of Orange-and White-Fleshed Sweet Potato [*Ipomoea batatas* (L.) Lam]. *ISABB-Journal of Food and Agriculture Science* 5 (1):1-6. doi: 10.5897/ISABB-JFAS2014.0005
- Svotwa E., Baipai R., Jiyane J. (2007). Organic Farming in the Small Holder Farming Sector of Zimbabwe. *Electronic Journal of Environmental, Agricultural and Food Chemistry* 6 (2): 1820 - 1827.
- Tanimu J. E. Iwuafor N. O. Oduze A. C., Tian G. (2007). Effect of Incorporation of Leguminous Cover Crops on Yield and Yield Components of Maize. *World Journal of Agricultural Sciences* 3 (2): 243-249.
- Umeugokwe C. P., Ugwu V. U., Umeugochukwu O. P., Uzoh I. M., Obalum S. E., Ddamulira G., Karwani G. M., Alenoma G. (2021). Soil Fertility Indices of Tropical Loamy Sand as Influenced by Bambara Groundnut Variety, Plant Spacing and Fertilizer Type. *Agro-Science* 20 (1): 65-71. doi: 10.4314/as.v20i1.11
- Umezina P. O., Nnadi A. L., Onyia V. N., Atugwu A. I., Obalum S. E. (2020). Evaluation of Eggplant Parental Varieties against Their Hybrid Progenies and Responses to N-fertilizer Doses and Dosing Options on Well-Drained Humid Tropical Soils. *Tropical Agriculture (Trinidad)* 97 (2): 94-103.
- Unagwu B. O., Asadu C. L. A., Obalum S. E. (2013). Maize Performance in a Sandy Loam Ultisol Amended with NPK 15-15-15 and Poultry Manure. *Proceedings of the 1st National Annual Conference of the Crop Science Society of Nigeria (CSSN)*, pp. 135-141.
- Uwah D. F., Ukoha G. O., Iyango J. (2012). Okra Performance and Soil and Water Conservation as Influenced by Poultry Manure and Organic Mulch Amendments. *J Food Agric Environ* 10 (1):748-754.