Linkages between soil acidity, plant nutrients and current land use on Ferralsols of Central Uganda

Abstract

A study to examine the linkages between soil acidity, plant nutrients and current land use on Ferralsols of Central Uganda was carried out on smallholder farms in Central Uganda. The objective of this study was to assess the effect of soil pH on plant nutrient availability under the current land use in Central Uganda. The study was carried out in Mpigi, Masaka, Wakiso, Mukono and Mubende districts respectively. Soil samples were randomly collected from Coffee, Banana, soybean, common bean, maize and virgin/undisturbed fields in the five districts and the pH and nutrient concentration analyzed accordingly. Result from the study showed that current land use had no significant effect on soil pH. Analysis of variance (ANOVA) also revealed significant difference ($p<0.01$) for soil nitrogen, Calcium ($p< 0.05$) and Magnesium ($p< 0.05$). Locations in the study showed no significant difference on potassium. However, when treatment was assessed, the study showed significant difference ($p< 0.01$) for potassium. Besides, the study also showed high concentrations of Manganese (Mn) and Iron (Fe) in addition to very high sand and low silt and clay contents. The current land use for coffee production in Masaka district recorded the lowest soil pH (4.4) followed by annual fields (pH 4.60) in Mpigi. The highest soil pH (5.7) was recorded in banana fields in Mubende. The study also recorded very low to low N, P and K. Generally, the study observed rapid soil fertility decline in smallholder farms in the region.

Key words: Soil pH, soil acidity, Ferralsols, nutrient availability and current land use

Introduction

Ferralsols are the most dominant soils constituting 25% of the soil type in Uganda (Bamutaze, 2015). The soils are weathered and leached with strong acidity containing toxic levels of Al^{3+}, Fe^{2+}, Mn^{2+}, low available phosphorus and has a pH (5.2) below the critical soil pH of 5.5 (Jaetzold *et al.,* 2012, Drake et al., 2017). The capacity of these soils to supply plant nutrients and retain cation exchange capacity (CEC) are both low. Additionally, soil pH is the most important factor in evaluating plant nutritional status due to its close association with nutrient availability (Beheiry et al., 2023). The chemical and physical Characterization of soils' properties are key in effectively managing acid soils under different land use. In East Africa, research has indicated that N, P, Mg, Ca and soil acidity are the major constraints to crop production (Kyomuhendo et al., 2020). Besides, in central Uganda, years of continuous cropping, erosion and poor soil management have contributed to soil acidity limiting average farm sizes to about 0.8 to 1.2 hectares per household in many farming communities with subsistence farming being unavoidable (Bulyaba et al., 2020; FAO and ITPS, 2015).

Soil pH known as the negative logarithm of the active hydrogen (H+) or hydroxyl ion concentration (OH−) or simply, pH = − log [H+]; pOH = − log [OH−] (Zhang et al., 2019) is scaled from 0 to 14 thus describing its acidity and alkalinity. pH values less than 7 refer to acidic conditions, while those above 7 indicate an alkaline environment; however, a pH values of 7 is considered neutral (Jackson and Meetei, 2018). Soils found in tropical regions such as Uganda are commonly acidic due to heavy precipitation and leaching. Soil acidity can result into sequestration of certain nutrients like phosphorus (P), causing it to be insoluble through binding with cations (Sharma et al., 2013). The use of compost from organic agricultural wastes has been recognized generally as an effective means for buffering soil pH, improving soil fertility and enhancing the contribution of inorganic fertilizers to soil fertility maintenance (Iqbal et al., 2015).

Rainfall influenced the leaching or removal of basic cations (Ca^{2+}, K^+ and Mg^{2+}) thus replacing them with acidic cations (H^+ and Al^{3+}) over a long period of time (Desalegn et al., 2017) exacerbates soil acidity by leaving the toxic and insoluble compounds of Al^{3+} and Fe^{2+} remains in the soils (Goulding, 2016). As the soil gets gradually depleted of its exchangeable bases through constant leaching, it gets de-saturated and becomes increasingly acid (Lesch et al., 2012). In productive agricultural systems, the most important source of soil acidity is the application of chemical fertilizer based on ammonium N (Goulding, 2016). Added to soil, N-fertilizer is nitrified (Goulding, 2016), and if the resulting NO_3^- isn't taken up by the crops, it gets leached causing acidification (Goulding, 2016). Application of acidifying fertilizer such as diammonium phosphate, which is used to improve the deficiencies of phosphorous has become a noticeable cause to increase soil acidity (Mosissa, 2018).

Notably, agricultural food production is constrained by reduced soil fertility that threatens the livelihoods of most farmers in Uganda (Muzira et al., 2018). Accelerated soil fertility reduction under the current land use in Uganda contributes to many soil management problems, including soil acidity. Though there are currently a number of soil fertility strategies being promoted in Uganda, soil acidity management has not been given serious attention. Although the extent and distribution of soil acidity are not well documented, it seems to be wide spread in many smallholder farms in the country. Besides, limited or no research emphasis has been placed on the management of acid soils (mainly Acrisols and Ferralsols) to promote sustainable crop production in Uganda. The objective of this study was to assess soil pH effect on plant nutrient availability under the current land use on smallholder farms in Central Uganda. The study hypothesized that addition of different quantities of liming materials i.e., $CaCO_3$ and biochar to Ferralsols will increase soil acidity (soil pH). It is expected that the findings from this study will improve on the knowledge and practices of soil fertility management on farmers' fields in Central Uganda. More to that, this study will provide information that will help the Ugandan policy makers understand the ways to increase agricultural production and productivity in the country. Results from this study will also assist in the integration of soil acidity (soil pH) management science in current soil fertility and productivity assessment for sustainable agricultural land use planning and environmental conservation.

Materials and Methods

Study Location

The study was carried out in Central Uganda. Central Uganda has nineteen (19) districts, five (5) of which were randomly selected, namely Mpigi, Mubende, Wakiso, Mukono and Masaka. The Central part of Uganda is a plateau, surrounded by four main mountain ranges: Rwenzori, Elgon, Mufumbira, and Moroto; the tallest point is the peak of Mt. Rwenzori at 5,110 m. According to Drake et al. (2017), the soils in these areas are highly weathered, have strong acidity and low level of phosphorus.

Soil sampling and preparation

Soil samples were collected at a depth of 0-20cm with the use of an auger and thoroughly mixed to form composite samples. The samples were put in plastic bags, tagged and transported at Les Rams Consultant, Water Quality, Soil and Plant Analysis Laboratory situated in Kampala, Uganda, Apollo Kaggwa Road, Bwaise. The samples were later air dried and ground to pass through a 2 mm sieve for analysis of selected soil chemical and physical properties.

Soil physico-chemical analyses

Soil particle size distribution was analyzed using the Bouyoucos hydrometer method (Day, 1965). Soil pH was determined in 1:2.5 soil water ratio using a glass electrode attached to a digital pH meter as described by Okalebo et al. (2002) while soil organic carbon was determined by the dichromate oxidation method as described by Walkley and Black (1934). Total Nitrogen was determined by the micro-Kjedahl digestion method as described by Bremmer and Mulvaney (1982). Soil available phosphorus was determined based on the Mehlich 3 extraction procedure (Mehlich, 1984). Exchangeable potassium was determined by use of the ammonium acetate method (McLean and Watson, 1985). Exchangeable calcium was determined by the buffer method as described by Adams and Evans (1962). Copper was determined by the DTPA method as described by Lindsay and Norvell (1978). Zinc was determined by the zincon method as described by Miller (1979). Iron, Magnesium and Manganese were determined by the EDTA method as described by Schnug *et al.* (1996).

Data Analysis

All data collected were subjected to analysis of variance (ANOVA) using GENSTAT 16th edition and declared significant at $p < 0.05$ using the statistical model as described by Gomez and Gomez (1984). Mean separation was done using the Duncan's Multiple Range Test (DMRT) and conclusions made at $p < 0.01$ and 0.05 levels of significance.

RESULTS AND DISCUSSION

Soil acidity in Central Uganda

Location and treatment had no significant effect on soil pH under the current land use in the study area. Interaction effect of location and treatment also showed no significant difference (Table 1b). There was varying, but decreasing soil pH under the current land use. In terms of location and treatment application, coffee fields in Masaka showed the lowest soil pH (4.4) under the different land use followed by annual fields (soybean, common bean and maize) in Mpigi (pH 4.6) and virgin/undisturbed fields in Wakiso District (pH 4.8). In addition to the lowest soil pH observed under the current land use in Masaka, Mpigi and Wakiso districts, the study recorded deteriorating soil pH in all the study locations cultivating banana, coffee and annual crops (soybean, common bean and maize) (Table 1b). According to the rating by Horneck et al. (2011), the varying soil pH as recorded in the study showed strongly to very strongly acidic soils while a few soils are moderately acidic. In these acidic soil conditions, there is also a complex interaction of growth-limiting factors among which is declining plant nutrients availability. Plant growth may be restricted by one or more of the following: Al or Mn toxicity; Ca, Mg, P or Mo deficiency and reduced mineralization and nitrification (Dinkecha and Tsegaye, 2017).

Effect of soil pH on plant nutrients availability under the current land use on Farmers' fields in Central Uganda

Location showed significant differences for Nitrogen ($p < 0.01$). According to Karltun et al. (2014), nitrogen is rated as very low (< 0.10%), low (0.1-0.15%) and optimum (0.15-0.30%). Based on these ratings, the study area had low nitrogen content. However, when %N content was assessed in the different land use, it was observed that virgin/undisturbed fields located in

Mubende recorded optimum N (0.18%), followed by field cultivated with maize and soybean (0.15 %N) and banana (0.15 %N). Coffee fields located in Masaka showed low N (0.14%), followed by Mubende (0.14% N). Low N levels were also recorded in Wakiso District (0.05%) (Table 1b). The low soil N observed in the study area may probably be attributed to the low soil pH. Wairegi et al. (2014) reported that coffee grows well in moderate acid soils (pH>5) and banana performs better at high pH (pH above 5.5). Both crops grow best in soils with total N above 0.15%.

There were significant differences for Calcium ($p<0.05$) and Magnesium ($p<0.05$) in the study area. According to the rating by Dan et al. (2011), Calcium and Magnesium are all low as observed in the different study locations (Table 1b). The low levels of calcium and magnesium could be attributed to the leaching of these basic cations (Ca^{2+} and Mg^{2+}) thus resulting to an increase in H^+ that aggravates soil acidity i.e., lower soil pH. Takala et al. (2020) observed highest growth performance on coffee seedling as well as plant height, stem girth, leaf number and area, tap and lateral root length, lateral root number, root volume, stem, leaf and root dry matter when 4 tons of $CaCO_3$ and 12.5 tons of coffee husk biochar were applied. Low soil pH affects the availability of nutrients, and particularly that of phosphorus and other macronutrients; therefore, correction of the low pH through liming is critical for sustainable management of acid soils for increased crop production (Tigist et al., 2019). Bossolani et al. (2021) observed that liming lowers the soil pH by neutralizing the acidic cation (H^+ and Al^{3+}) hence increases basic cations (Ca^{2+} and Mg^{2+}). Ameliorating low pH soils with liming materials such as calcium, magnesium and/or biochar reduces the toxicity effects of Al^{3+} and Mn^{2+} associated with low pH and at the same time helps create an enabling soil environment for sustainable crop production.

Location in the study had no significant effect on potassium levels (Table 1b). There were no significant differences for all the plant available nutrients when treatment was assessed, with the exception of potassium which showed significant difference ($p<0.01$). Interaction of treatment and location showed no significant effect for all the soil physiochemical properties in the current land use. However, significant differences were noted on K^+ among the banana fields. According to the rating by

Horneck et al. (2011), K^+ in this study area is low to high across farmers' fields, with banana fields located in Masaka having the highest K^+ concentration (1.69 meq/100 g soil), followed by Coffee fields in Mubende (1.69 meq/100 g soil) (Table 1b). The lowest K^+ concentration was recorded in virgin/undisturbed fields located in Mpigi District (0.12 meq/100 g soil). The low to high K^+ concentration recorded in the study could be attributed to the decomposition and addition of plant litters to the soils. Li et al. (2020) reported large amounts of K^+ concentration present in cereal crops such as maize and wheat. It has been well documented that both crop yield and soil K^+ availability can be improved by long-term straw return (Tan et al., 2017). In China, crop straw return is widely practiced in agricultural production (Huang et al., 2012; Zhu et al., 2015). Relying only on the internal circulation of the soil-plant system is not sufficient to relieve the soil K^+ deficiency (Li et al., 2020). Plant biomass should be combined with other soil amendments such as limestone so as to improve K^+ cycling.

Results in Table 1b showed significant differences on soil organic carbon ($p<0.01$) and organic matter ($p<0.01$) in the study area. According to Dan et al. (2011), organic carbon and organic matter is optimum, ranging from 1-4% (Table 1b). The changing soil pH in the current land use suggests an influence on soil organic matter and organic carbon. Besides, the optimum range (1-4%) could be attributed to the recycling of crop residues, addition of cow manure, short fallow and biomass transfer in the different land use in the study area. Farmers in the study area carry out these practices with the hope of replacing lost nutrients and reversing soil acidity. However, the observed soil pH suggests the introduction and adoption of Integrated Soil Fertility Management (ISFM) approaches, with the use of liming materials that could alleviate the problem of soil degradation due to increasing soil acidity in the region. Soil organic matter in particular is very important because of its influence on a number of soil chemical, physical and biological properties (Dan et al., 2011). Several authors (Filipe et al., 2015; Ghimire et al., 2017 and; Neina, 2019) have reported the negative impacts of low pH on Soil Organic Matter (SOM). Solly et al. (2019) found that SOM content was lower in soils with pH < 5.5. However, Aye et al. (2016) found higher OC of an experimental soil after application of lime integrated with N and P fertilizers at Haryana Agricultural University in India.

The study locations showed significant differences on %sand ($p<0.01$) and %Clay ($p<0.05$) and not on %silt (Table 1b). Percentage sand, silt and clay also showed no significant differences when the different treatments were assessed. However, %clay and sand were optimum, though high in some areas and low in others. The highest sand content (63%) was observed in annual fields in Mpigi, followed by banana fields (56.67%) in Mubende and Coffee fields (56%) in Masaka. Percentage clay (48%) was observed to be equally distributed in Coffee and banana farming systems in Masaka and Mubende, followed by annual fields in Mukono (45.33%) and annual fields in Masaka (43%). Percent silt was observed to range from 10% in Coffee fields in Mpigi to 20% in virgin/undisturbed fields in Masaka (Table 1b). Zhang et al. (2017) also attributed macropores reduction and increase in water retention times and nitrogen supply for plant growth to the optimality of silt and clay particles. Furthermore, Chen et al. (2020) reported significant effects soil texture has on soil aeration, water-holding capacity, soil fertility, crop yield and the important role it plays in regulating the leaching of soil nitrogen.

Effect of soil pH on selected trace elements in smallholder farms in Central Uganda

Location showed significant effect on iron ($p<0.05$) and zinc ($p<0.001$) as observed in the study (Table 2b). For treatment application, different soil parameters showed no significant effect, with the exception of manganese ($p<0.1$). Interaction effect for treatment and location showed no significant difference on the different soil parameters as recorded in the study (Table 2b).

The rating by Landon (1991), and Lindsay and Norvell (1978) showed very high iron and manganese concentration in the current land use. Manganese concentration in the study ranges from 121.1 ppm in the virgin/undisturbed fields in Masaka to 139.3 ppm in Coffee fields in Masaka District (Table 2b). Iron was also highest (1271.4 ppm) in the virgin/undisturbed fields in Mpigi. The high Fe^{2+} and Mn^{2+} concentrations indicate soil acidity problem in the area. These findings are in agreement with those of Zama et al. (2022) who reported an increase in soil acidity due to the toxicity effects of Al, Mn and Fe; they concluded that soil pH has a significant effect on plant growth and agricultural productivity. Similarly, Tigist et al. (2019) attributed low soil pH effect to low plant nutrients availability, especially phosphorus and other macronutrients; hence, correction of soil pH through liming and/or application of organic materials is critical for sustainable soil management.

Conclusion

Soil fertility is fast declining in banana, coffee, and annual (soybean, common bean and maize) fields of Central Uganda due to soil acidity (soil pH). The low soil pH (4.4) recorded in banana fields of Masaka, followed by pH 4.7 recorded in coffee fields of Mpigi, pH 4.9 recorded in coffee fields of Mubende and pH 4.6 recorded in annual fields of Mpigi, coupled with the high Manganese (Mn) and Iron (Fe) contents in Ferralsols of the study area are significantly influencing the low availability of plant nutrients. Soil acidity due to low soil pH is fast spreading across the current land use in Central Uganda. The extent of declination tends to affect crop production, and hence reduces soil productivity.

Recommendations

Stakeholders, policy makers, researchers and academics are required to do more to address the problem of soil acidity in the study area. Liming practices should be adopted in the current land use of Central Uganda as a means of addressing the problem of soil degradation due to soil acidity.

References

Adams, F., and C.E. Evans. (1962). A rapid method for measuring the lime requirement of Red-Yellow Podzolic soils. Protection Soil Society of America: pp. 255-357.

Aye, N.S., Sale, P.W., Tang, C. (2016). The impact of long-term liming on soil organic carbon and aggregate stability in low input acid soils. Biology and Fertility of Soils,52(5), 697-7 09.

Bamutaze, Y. (2015) Geopedological and Landscape Dynamic Controls on Productivity Potentials and Constraints in Selected Spatial Entities in Sub-Saharan Africa. In: Lal, R., Singh, B., Mwaseba, D., Kraybill, D., Hansen, D. and Eik, L., Eds., Sustainable Intensification to Advance Food Security and Enhance Climate Resilience in Africa, Springer, Cham, 21-44.

Beheiry, H.R.; Awad, A.A.M.; Hussein, H.A.Z. Response of Multi-Stressed *Olea europaea* Trees to the Adjustment of Soil pH by Acidifying Agents (2023): Impacts on Nutrient Uptake and Productivity. Agronomy, 13, 539. https://doi.org/10.3390/agronomy13020539.

Bossolani J. W. Crusciol, C.A.C., Leite, M. F. A., Merloti, L. F., Moretti, L. G., Pascoaloto, I. M., et al. (2021). Modulation of the soil microbiome by long-term ca-based soil admendments boosts soil organic carbon and physicochemical quality in a tropical no till crop rotation system system. Soil Biol. Bioche, 156:108188. Doi: 10.1016/j.soilbio.108188.

Bremner, J. M. and Mulvaney C. S. (1982). Methods of Determining Total Nitrogen. (Edited by Page A. L.), Methods of Soil Analysis, 624pp.

Chen, L.F.; He, Z.B.; Zhao, W.Z (2020). Soil structure and nutrient supply drive changes in soil microbial communities during conversion of virgin desert soil to irrigated cropland. *Eur. J. Soil Sci.*, *71*, 768–781.

Dan M. Sullivan, Donald A. Horneck, Jim Owen and John M. Hart (2011). Soil Test Interpretation Guide. View online: https://extension.oregonstate.edu/pub/ec-1478.

Day, P. R. (1965). Hydrometer method of particle size analysis. Methods of soil analysis. Agronomy, (Vol. 9,).

Desalegn T, Alemu G, Adella A, Debele T. 2017. Effect of lime and phosphorus fertilizer on acid soils and barley (*Hordeum vulgare* L.) performance in the central highlands of Ethiopia. Exp Agric. 53:432–444.

Dinkecha K, Tsegaye D. (2017). Effects of Liming on Physicochemical properties and Nutrient Availability of Acidic Soils in Welmera Woreda, Central Highlands of Ethiopia. Biochem. Mol. Biol. 2:102-109.

Drake N. M., Jalia N. James L. Godfrey A. O., Joseph K. Milly N. William N. and Mark S. C., (2017): Conservation Farming and Changing Climate: More Beneficial than Conventional Methods for Degraded Ugandan Soils. Available at: www.mdpi.com/journal/sustainability (Accessed 4 March 2023).

Filipe k, T.; Badora, A.; Lipi ´nski, W.; Brodowska, M.S.; Doma ´nska, J.; Harasim, P.; Kozłowska-Strawska, J.; Skowron, P.; Skowro ´nska, M.; Tkaczyk, P. Acidification and Liming of Soils; FAPA: Warsaw, Poland, 2015; p. 236.

Ghimire, R.; Machado, S.; Bista, P (2017). Soil pH, soil organic matter, and crop yields in winter wheat-summer fallow systems. J. Agron., 109, 706–717.

Gomez, A. K., Gomez, A. A. (1984). Statistical Procedure for Agricultural Research. John Wiley and Sons, Inc., London. 1984;680.

Goulding K.W.T. (2016): Soil acidification and the importance of liming agricultural soils with particular reference to the United Kingdom Soil Use Management., 32 (2016), pp. 390-399.

Horneck DA, Sullivan DM, Owen JS, Hart JM. 2011. Soil test interpretation guide. Oregon State University Extension Service. https://catalog.extension.oregonstate.edu/ec1478.

Huang X, Li MM, Li JF, Song Y (2012). A high-resolution emission inventory of crop burning in fields in China based on MODIS Thermal Anomalies/Fire products. Atmospheric Environment. 2; 50: 9–15. 26.

Iqbal T, Jilani G, Rasheed M, Siddique MT, Hayat A (2015). Enrichment of municipal solid waste compost through rock phosphate and phosprus solubilizing bacteria and effect of its application on soil and maize growth. Soil Environment 34 (2): 119-125.

Jackson, K., Meetei, T.T (2018). influence of soil pH on nutrient availability: A review of J. Emerg. Technol. Res. 5: 707-713.

Jaetzold R, Schmidt H (2012). Farm management handbook of Kenya-natural conditions and farm management information-vol II/A, West Kenya.

Karltun, E., Mamo, B.T., Gameda, T.S., & Kidanu, S. (2014). Ethiopian soil information system towards improved fertilizer recommendations in Ethiopia. Nutrient Indices for Categorization Fertilizer Blends from Ethio SIS District Soil Inventory Data Discussion Paper.

Kyomuhendo, P., Tenywa, M. M., Semalulu, O., Lenssen, A., Yost, R., Mazur, R., & Kyebogola, S. (2020). Lime requirement for bean production on two contrasting soils of Lake Victoria Crescent agro-ecological zone. African Journal of Agricultural Research, 15 (4), 531-537.

Landon, J. R. (1991). Booker Tropical Soil Manual. A Handbook of Soil Survey and Agriculture Land Evaluation in Tropical and Subtropical. Longman Publishers, London. 474pp.

Lesch S, Wallender W, Tanji K (2012). Statistical models for the prediction of field-scale and spatial salinity patterns from soil conductivity survey data. Agric Salin Assess Manag.;461-482.

Li X, Li Y, Wu T, Qu C, Ning P, Shi J, et al. (2020) Potassium fertilization combined with crop straw incorporation alters soil potassium fractions and availability in northwest China: An incubation study. PLoS ONE 15(7): e0236634. https://doi.org/ 10.1371/journal.pone.0236634.

Lindsay, W. L. and Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron manganese and copper. Soil Science Society of America Journal 42: Pp.421 – 428.

Lindsay, W. L. and Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron manganese and copper. Soil Science Society of America Journal 42: Pp.421 – 428.

McLean, E. O. and Watson, M. E. (1985). Soil Measurements of plant available potassium. In: Potassium in Agriculture. (Edited by Munson, R.D.), ASA, CSSA, and SSSA, Madison. pp. 277 – 308.

Mehlich, A. (1984). Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Communications. Soil Science and Plant Analysis 15: 1409 - 141 6.

Miller, D. G. (1979). Colorimetric determination of zinc with zincon and cyclohexanone. Journal of Water Pollution Control Federation 51: 2402.

Mosissa F. (2018) Prospect and use of acid tolerant crops as an option for soil acidity management in Ethiopia. Rev Nessa J Agriculture Science and Research.

Muzira, R., Basamba, TA and Tenywa, JS (2018). Assessment of soil nutrients limiting sustainable potato production in the highlands of south-Western Uganda. Open Access Libr J. 5(3):1–8.

Neina, D. The role of soil pH in plant nutrition and soil remediation. Appl. Environ. Soil Sci. 2019, 2019, 5794869.

Okalebo et al., (2002). Laboratory Methods of soil and plant analysis: a work manual second edition.

Schnug, E., Fleckstein, J. and Hankelaus, S. (1996). The ubiquitous extractant for micronutrients in soil. Communications in Soil Science and Plant Analysis 27: 1721 – 1730.

Shareef, M.; Gui, D.W.; Zeng, F.J.; Waqas, M.; Ahmed, Z.; Zhang, B.; Iqbal, H.; Xue, J (2019). Nitrogen leaching, recovery efficiency, and cotton productivity assessments on desert-sandy soil under various application methods. *Agric. Water Manag.*, *223*, 105716–105724.

Sharma S.B., Sayyed R.Z., Trivedi M.H., Gobi T.A (2013). Phosphate solubilizing microbes: Sustainable approach for managing phosphorus deficiency in agriculture soils. Springer Plus. 2:587. doi: 10.1186/2193-1801-2-587.

Solly, E.F.; Weber, V.; Zimmermann, S.; Walthert, L.; Hagedorn, F.; Schmidt, M.W.I (2019). Is the content and potential preservation of soil organic carbon reflected by cation exchange capacity? A case study in Swiss forest soils. Biogeosciences Discuss, preprint.

Takala, B., Kufa, T. and Regassa, A. 2020. Effects of lime and coffee husk compost on growth of coffee seedlings on acidic soil of Haru in Western Ethiopia. J. Degrade. Min. Land Manage. 8(1): 2391-2400, DOI: 10.15243/jdmlm. 2020.081.2391.

Tan DS, Liu ZH, Jiang LH, Luo JF, Li J. Long-term potash application and wheat straw return reduced soil potassium fixation and affected crop yields in North China. Nutrient Cycling in Agroecosystems. 2017; 108: 121–133.

Tigist, A., Lemma, W. and Tesfaye, F. 2019. Soybean (Glycine max L.) response to lime and vermicompost amelioration of acidic Nitisols of Assosa, North Western Ethiopia. International Journal of Plant & Soil Science 27(2): 1-18.

Wairegi, L.W.I., van Asten, P.J.A., Giller, K.E. & Fairhurst, T. (2014) Banana–coffee system cropping guide. Africa Soil Health Consortium, Nairobi. Pp 1-112.

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil science, 37(1), 29-38. (n.d.).

Zama, N.; Kirkman, K.; Mkhize, N.; Tedder, M.; Magadlela, A (2022). Soil Acidification in Nutrient-Enriched Soils Reduces the Growth, Nutrient Concentrations, and Nitrogen-Use Efficiencies of Vachellia sieberiana (DC.) Kyal. & Boatwr Saplings. Plants, 11, 3564. https://doi.org/10.3390/ plants11243564.

Zhang, Y.-Y.; Wu, W.; Liu, H. (2019). Factors affecting variations of soil pH in different horizons in hilly regions. PLoS ONE, 14, e0218563.

Zhang, Y.Y.; Zhao, W.Z.; Fu, L (2017). Soil macropore characteristics following conversion of native desert soils to irrigated croplands in a desert-oasis ecotone, Northwest China. *Soil Tillage Res.*, *168*, 176–186.

Zhu LQ, Hu NJ, Zhang ZW, Xu JL, Tao BR, Meng YL (2015). Short-term responses of soil organic carbon and carbon pool management index to different annual straw return rates in a rice-wheat cropping system. Catena. 2015; 135: 283–289

Table 1a: Source of Variation for Soil Nutrients by Location and Treatment

Source of Variation	P.H	N	P	K	Ca	Mg	OC	OM	Sand	Clay	Silt
Location	0.5325ns	0.012***	4367ns	0.9924ns	10.133**	2.8762**	1.5346***	4.562***	404.11***	250.76**	19.25ns
Treatment	0.8715ns	0.003ns	5828ns	1.2402*	3.555ns	0.6303ns	0.0778ns	0.2312ns	103.5ns	112.19ns	0.71ns
Location x Treatment	0.1908ns	0.001ns	1268ns	0.2461ns	1.935ns	0.4941ns	0.087ns	0.2587ns	115.03ns	109.8ns	32.23ns
Residual	0.440	0.002	3020	0.5284	3.023	0.772	0.167	0.4965	69.86	72.41	30.14
LSD	1.225	0.0912	101.47	1.342	3.210	1.622	0.755	1.301	15.43	15.71	10.136
CV (%)	12.95	45.18	182.05	112.03	47.58	47.09	23.07	23.07	17.41	23.42	35.05
SE	0.663	0.049	54.95	0.727	1.739	0.8785	0.4087	0.7046	8.358	8.509	5.490

**Significant at 5%, *Significant at 10%, ns=non-significant

Table 1b: Soil physiochemical characteristics in the different land use types

		District				
Soil properties	**Farming System**	**Masaka**	**Mpigi**	**Mubende**	**Mukono**	**Wakiso**
pH	Annual	5.27^{a}	4.60^{b}	5.31^{a}	4.84^{b}	5.07^{a}
	Banana	5.56^{a}	4.85^{b}	5.70^{a}	5.60^{a}	5.56^{a}
	Coffee	4.42^{b}	4.70^{b}	4.94^{b}	5.16^{a}	5.22^{a}
	Virgin	5.16^{a}	4.81^{b}	5.27^{a}	5.38^{a}	4.80^{b}
Nitrogen (%N)	Annual	0.10^{a}	0.09^{a}	0.15^{a}	0.11^{a}	0.08^{a}
	Banana	0.11^{a}	0.09^{a}	0.15^{a}	0.08^{a}	0.05^{b}
	Coffee	0.14^{a}	0.10^{a}	0.14^{a}	0.06^{b}	0.09^{a}
	Virgin	0.13^{a}	0.09^{a}	0.18^{a}	0.13^{a}	0.11^{a}
Phosphorous (ppm)	Annual	24.53	2.08^{d}	39.55^{bc}	68.07^{b}	1.30^{d}
	Banana	89.35^{a}	15.00^{c}	33.47^{bc}	105.93^{a}	45.39^{ac}
	Coffee	6.29^{d}	4.83^{d}	18.28^{c}	50.06^{ac}	28.90^{bc}
	Virgin	4.90^{d}	2.37^{d}	3.54^{d}	15.91^{c}	34.57^{bc}
K (cmol (+)/kg soil)	Annual	0.30^{b}	0.25^{b}	0.72^{b}	0.41^{b}	0.30^{b}
	Banana	1.46^{a}	0.40^{b}	1.69^{a}	0.75^{b}	0.98^{a}
	Coffee	0.41^{b}	0.34^{b}	0.54^{b}	0.86^{b}	0.57^{b}

Soil properties	Farming System	District				
		Masaka	Mpigi	Mubende	Mukono	Wakiso
	Virgin	0.53^{b}	0.12^{b}	1.39^{a}	0.57^{b}	0.26^{b}
Ca (cmol (+)/kg soil)	Annual	4.89^{a}	1.47^{c}	5.60^{a}	3.39^{b}	3.59^{b}
	Banana	5.04^{a}	2.35^{c}	4.42^{b}	4.77^{a}	4.45^{a}
	Coffee	2.00^{c}	2.31^{c}	4.17^{b}	3.64^{b}	3.41^{b}
	Virgin	3.99^{b}	1.81^{c}	3.62^{b}	4.66^{a}	2.79^{c}
Mg (cmol (+)/kg soil)	Annual	2.58^{a}	0.81^{c}	2.43^{a}	1.69^{b}	1.69^{b}
	Banana	2.54^{a}	1.27^{b}	2.27^{a}	2.16^{a}	2.31^{a}
	Coffee	1.08^{b}	1.15^{b}	2.08^{a}	1.89^{b}	1.85^{b}
	Virgin	2.39^{a}	0.69^{c}	2.23^{a}	2.47^{a}	1.39^{b}
OC (mg/ha)	Annual	1.93^{b}	1.18^{b}	2.36^{a}	2.06^{a}	1.63^{b}
	Banana	1.84^{b}	1.33^{b}	2.16^{a}	1.68^{b}	1.74^{b}
	Coffee	1.63^{b}	1.29^{b}	2.16^{a}	1.73^{b}	1.54^{b}
	Virgin	2.28^{a}	1.03^{b}	2.11^{a}	1.89^{b}	1.71^{b}
OM (%)	Annual	3.32^{b}	2.03^{b}	4.07^{a}	3.55^{b}	2.80^{b}
	Banana	3.18^{b}	2.28^{b}	3.72^{b}	2.89^{b}	3.00^{b}
	Coffee	2.80^{b}	2.23^{b}	3.72^{b}	2.97^{b}	2.66^{b}
	Virgin	3.92^{a}	1.77^{c}	3.64^{b}	3.26^{b}	2.95^{b}
% Sand	Annual	38.67^{c}	63.00^{a}	44.67^{b}	40.67^{c}	46.67^{b}
	Banana	43.33^{c}	48.00^{c}	56.67^{b}	52.67^{b}	37.33^{c}
	Coffee	38.00^{c}	58.00^{b}	42.00^{c}	44.00^{c}	51.33^{b}
	Virgin	46.67^{c}	63.33^{a}	53.33^{b}	44.00^{c}	52.67^{b}
% Clay	Annual	43.33^{b}	26.00^{c}	36.67^{b}	45.33^{a}	39.33^{b}
	Banana	40.00^{b}	33.33^{c}	30.67^{c}	31.33^{c}	48.00^{a}
	Coffee	48.00^{a}	32.00^{c}	39.33^{b}	39.33^{b}	29.33^{c}
	Virgin	33.33^{c}	32.67^{c}	35.33^{b}	39.33^{b}	30.67^{c}
% Silt	Annual	18.00^{a}	11.00^{c}	18.67^{a}	14.00^{b}	14.00^{b}
	Banana	16.67^{b}	18.67^{a}	12.67^{c}	16.00^{b}	14.67^{b}
	Coffee	14.00^{b}	10.00^{c}	18.67^{a}	16.67^{b}	19.33^{a}
	Virgin	20.00^{a}	14.00^{b}	11.33^{c}	16.67^{b}	16.67^{b}

Note: a,b and c means sharing a letter in their superscript are not significantly different at the .05 level. However, a and b, b and c and c and a are significantly different at 0.05 level.

Table 2a: Source of Variation for selected trace elements by Location and Treatment

Source	dfs	Mn	Fe	Cu	Zn
Location	4	8.36ns	428421**	270.2ns	1055***
Treatment	3	55.26*	75985ns	137.8ns	409.3ns
Location x Treatment	12	24.2	79729ns	93.6ns	191.2ns
Residual	17	20.49	93957	124.9	227.7
LSD		13.5	914.6	33.34	45.03
CV (%)		3.37	40.3	76.99	84.15
SE		4.526	306.5	11.17	15.09

**Significant at 5%, *Significant at 10%, ns=non-significant, df=degrees of freedom

Table 2b: Effect of different land uses on selected trace elements types

		Districts				
Trace elements	**Farming System**	**Masaka**	**Mpigi**	**Mubende**	**Mukono**	**Wakiso**
Mn (ppm)	Annual	136.1^{a}	132.4^{b}	133.5^{b}	132.8^{b}	135.7^{a}
	Banana	134.3^{b}	138^{a}	135.7^{a}	136.8^{a}	134.6^{b}
	Coffee	137.1^{a}	138.5^{a}	132.1^{b}	139.3^{a}	134.2^{a}
	Virgin	121.1^{b}	126.7^{b}	134.7^{a}	135.1^{a}	135.3^{a}
Fe (ppm)	Annual	744.7^{b}	355.8^{c}	337.2^{c}	742.5^{b}	1084.4^{a}
	Banana	947.4^{b}	639.1^{d}	724.4^{c}	1163.8^{a}	799.1^{c}
	Coffee	467^{c}	684.4^{b}	606.7^{b}	1035.8^{a}	1006.9^{a}
	Virgin	1271.4^{a}	294.3^{d}	674.7^{c}	886.6^{b}	1194^{a}
Cu (mg kg^{-1})	Annual	14.49^{b}	7.34^{d}	0.8	10.56^{c}	20.43^{a}
	Banana	40.28^{a}	12.13^{c}	10.1^{c}	16.43^{b}	16.3^{b}
	Coffee	10.47^{b}	10.25^{b}	7.63^{c}	17.71^{a}	17.01^{a}
	Virgin	9.77^{c}	8.31^{c}	9.64^{c}	20.92^{b}	27.41^{a}
Zn (ppm)	Annual	14.58^{b}	5.47^{c}	0	5.43^{c}	29.38^{a}

Banana	29.6^{b}	17.86^{c}	14.78^{c}	44.68^{a}	24.35^{b}
Coffee	9.03^{c}	8.24^{c}	2.1^{d}	35.05^{a}	28.97^{b}
Virgin	0	2.5^{c}	0	36.91^{b}	44.17^{a}

Note: a, b and c means sharing a letter in their superscript are not significantly different at the .05 level. However, a and b, b and c and c and a are significantly different at 0.05 level