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Effect of sugarcane bagasse ash and manure amendments on selected soil properties in Western Kenya

Tabere D. Taddeo Bidai*, Joyce J. Lelei and Josephine P. Ouma

Department of Crops, Horticulture and Soils, Faculty of Agriculture, Egerton University P. O. Box 536-20115, Egerton, Njoro, Kenya.

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This research determined the effects of incorporating sugarcane bagasse ash and cattle manure on soil pH, available P, and cation exchange capacity (CEC) during a 2 seasons' field experiment in Kakamega County of Western Kenya. The experiment used a Randomized Complete Block Design, 3 replications, and a 3 × 3 factorial arrangement of treatments. Sugarcane bagasse ash and cattle manure application showed highly significant effects on soil properties at P≤0.01. The combined application of 5 t ha^{-1} sugarcane bagasse ash with 5 t ha^{-1} cattle manure raised soil pH by 0.18, and with 10 t ha^{-1} manure by 0.17. These increments were higher than the positive control (2 t ha^{-1} lime alone), that raised soil pH by 0.03, while negative control (no amendment) decreased soil pH by 0.01 at the end of the 2nd season. Soil available P increased by 6 ppm due to 5 t ha^{-1} cattle manure and by 4 ppm due to 5 t ha^{-1} sugarcane bagasse ash. Soil CEC increased due to high application rates of cattle manure at the end of the second season. This study concluded that, the incorporation of sugarcane bagasse ash and cattle manure increased soil pH, available P and CEC.

Key words: Available P, bagasse ash, cation exchange capacity (CEC), cattle manure, soil pH, Western Kenya.

INTRODUCTION

Soils in Kakamega County, Western Kenya are predominantly Acrisols, Nitisols and Ferralsols (Jaetzold et al., 1982; NAAIAP, 2014). These soils are strongly weathered, with low pH, available P and cation exchange capacity (CEC) (IUSS Working Group WRB, 2015). The fixation of P in acid soils in the form of Al and Fe phosphates renders it unavailable for uptake by plants (Zhu et al., 2017). These conditions are further aggravated by continual cultivation in small holder farms without adequate replacement of nutrients. The use of inorganic fertilizers and lime to amend soil acidity and improve soil chemical properties is still low with about 7% of the farmers in Western Kenya applying lime (Kenya Markets Trust, 2019). Sugarcane bagasse ashes (SBA)

*Corresponding author. E-mail: fayatabaka@gmail.com. Tel: +254712014613.

Table 1. Basic soil characteristics (0-30 cm).

Soil property	Value
Soil texture	Clay loam
Sand (%)	42
Silt (%)	20
Clay (%)	38
Bulk density (gcm^{-3})	1.4
pH 1:2.5 (Soil water ratio)	5.39
Organic carbon (%)	1.93
Total N (%)	0.18
Available P (ppm)	25
CEC (meq 100 g^{-1})	20

from sugarcane mills in Western Kenya and decomposed cattle manure have the potential to improve soil properties. They are locally available and can provide an alternative for disposal of SBA in a useful way.

Bagasse ash contains micronutrients, secondary macronutrients (Mg and Ca) and primary macronutrients P and K (Khan and Qasim, 2008; Huotari et al., 2015; Benbi et al., 2017; Hale et al., 2020). The major role of Ca in soils and plants in addition to being an essential nutrient is to exclude or detoxify other elements such as Al and Mn present in acid soils (Fageria and Moreira, 2011). Application of manure can result to improved soil physical, chemical and biological properties (Thind et al., 2016). This study determined the effects of SBA and decomposed cattle manure on soil pH, available P, and CEC under field conditions.

MATERIALS AND METHODS

The study site

This research was conducted in Kakamega County of Western Kenya; 34° 36' E and 0° 15' N, altitude 1377 m above sea level (NAAIAP, 2014). The rainfall in this area ranges from 1280 to 2214 mm, and a temperature range of 18 to 29°C in a year (Jaetzold et al., 1982; NAAIAP, 2014). The major soils are Acrisols, Ferralsols and Nitisols, with soil pH ranging between 4.18 and 6.09 (Jaetzold et al., 1982; NAAIAP, 2014). This area has a relative humidity of 67% and undergoes intensive maize cultivation (NAAIAP, 2014). The field experiments included the cultivation of maize (*Zea mays* L.) during the short rain season; September to November, 2019 and long rain season; March to July of 2020.

Experimental design and field layout

The study used a randomized complete block design, with a 3 × 3 factorial arrangement of treatments, and 3 replications. It included 2 factors: cattle manure at the rates 0, 5, and 10 t ha^{-1} and soil conditioner at 0 and 5 t ha^{-1} sugarcane bagasse ash, and 2 t ha^{-1} lime. Plots that received 2 t ha^{-1} of lime were considered as positive controls, while plots that did not receive any amendment were negative controls. Plots of sizes 5 m × 4 m used during this field trials, received the treatments at random.

Soil and manure sampling

The sampling of soil, preparation of samples, and storage, for physical and chemical analyses followed procedures described by Anderson and Ingram (1993). Decomposed cattle manure was collected from Bukura Agricultural College in Western Kenya. The cattle manure was decomposed using composting method, and this followed procedures described by Rynk et al. (1992). The lime was sourced from Omya International AG Baslerstrasse, 42 4665 Oftringen Switzerland www.omya.com.

Analysis of soil physical and chemical properties

Soil texture was determined by Hydrometer method, and soil bulk density by coring method, as described by Okalebo et al. (2002). Soil pH (soil: water ratio of 1:2.5) was measured using a pH meter (Make: Jenway, UK; model: 3510 pH meter) (Mangale et al., 2016). The available soil P was determined by Mehlich Double Acid Method (Mangale et al., 2016); and soil CEC by the ammonium acetate method as described by Anderson and Ingram (1993).

Total nitrogen was determined by Kjeldahl method (Page et al., 1982) and total organic carbon, by Walkley-Black method, following the procedures of Anderson and Ingram (1993). The initial soil properties are presented in Table 1. The pH was low (medium acid) suggesting that H and Al ions toxicity were possible (FAO and ITPS, 2015; Jaiswal et al., 2018); and the soil deficient in nitrogen and P. Soil organic matter content required to be improved (Table 1).

Analysis of experimental soil amendments

The analysis of cattle manure and SBA for the chemical properties: pH, and total elements content, followed procedures and methods described by Okalebo et al. (2002) for plant tissue analysis. The characteristics of the amendments are shown in Table 2.

Land preparation and application of treatments

Land preparation was carried out in the short rain season using a tractor driven plough and harrow. In the long rain season land was prepared manually. The SBA was collected from West Kenya Sugar Company Limited. The bagasse ash was passed through a 2 mm sieve prior to its application in the field to enable a compatible mix with the soil particles. The bagasse ash, manure and lime were placed on top soil (15 cm depth) at planting according to treatments and mixed with soil thoroughly. The mixes were covered with light soil before placement of the seed to avoid seed burn. Maize was planted as a mono crop during the short and long rain seasons, at the spacing of 75 by 30 cm. Two seeds were planted per hill; later thinned to one seedling per hill two weeks after emergence, to give the recommended plant population of 44,444 plants per hectare.

Statistical analysis of data

Data were subjected to analysis of variance (ANOVA) using SAS software for windows 8.2 (TS2M0) 1999 – 2001 by SAS Institute Inc., Cary, NC, USA. Where the Fisher's protected F-test was significant, mean treatments were separated using Least significant difference (LSD) test at $P \leq 0.01$ level of significance. The statistical analyses and presentations for the data on soil parameters were done on the basis of the data collected for the two seasons.

Table 2. Characteristics of soil amendments (manure, bagasse ash and lime).

Sample description	Manure	Bagasse ash	Lime
pH-water	7.40	7.96	
N %	1.98	2.33	
P %	0.31	0.37	
K %	0.52	0.57	
Ca %	0.35	0.38	36
Mg %	0.23	0.25	0.6
Granulated Ca carbonate mm			2 - 6
Ca carbonate %			91
Mg carbonate %			2
Neutralizing value			52
Ca oxide %			51
Mg oxide %			0.9
H_2O %			< 2

Table 3. Interaction effect of manure and soil conditioner on soil pH during the short rain (2019) and long rain (2020) seasons at Kakamega, Western Kenya.

Treatment	Soil pH Season 1	Soil pH Season 2
0 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	5.38^{h}	5.38^{gh}
0 t ha^{-1} manure × 2 t ha^{-1} lime	5.41^{fg}	5.42^{f}
0 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	5.48^{e}	5.50^{de}
5 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	5.56^{c}	5.73^{b}
5 t ha^{-1} manure × 2 t ha^{-1} lime	5.73^{b}	5.85^{a}
5 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	5.54^{c}	5.56^{c}
10 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	5.41^{fgh}	5.42^{f}
10 t ha^{-1} manure × 2 t ha^{-1} lime	5.55^{c}	5.56^{c}
10 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	5.53^{cd}	5.55^{c}
Standard error	0.01	0.01

Means within a column or row followed by same letter are not significantly different at LSD P≤0.01 level of significance.

RESULTS AND DISCUSSION

Effect of SBA and decomposed cattle manure application levels on soil pH in the field

The objective of this study was to determine the effect of sugarcane bagasse ash and cattle manure amendments on soil pH. This was achieved by laboratory analysis of soil samples from the field under maize cultivation before the beginning of the field experiment, at the end of the first and second seasons, then subjecting the data to statistical analyses respectively. The results of the study revealed highly significant interactions among season, manure and conditioners (lime and bagasse ash) on soil pH at P≤0.01. Highly significant differences in pH values between seasons were observed with combinations of 5 t ha^{-1} decomposed cattle manure and 2 t ha^{-1} lime, and application of 5 t ha^{-1} manure with no soil conditioner (Table 3). In these treatments, the soil pH values at the end of the 2nd season were significantly higher than values obtained at the end of first season (Table 3). The interaction of 5 t ha^{-1} manure with 2 t ha^{-1} lime significantly yielded the highest pH values in both seasons.

Treatment 5 t ha^{-1} bagasse ash when incorporated with 5 t ha^{-1} manure gave pH values that were not significantly different in the two seasons but were significantly higher than treatments with no soil amendments in both seasons (Table 3). The results show that the interaction of manure at the rate 0 t ha^{-1} with bagasse ash caused a significant increase of pH compared to its interaction with lime at the end of seasons 1 and 2. However, high improvement of soil pH was observed mostly when lime interacted with either 5 or 10 t ha^{-1} manure unlike bagasse ash.

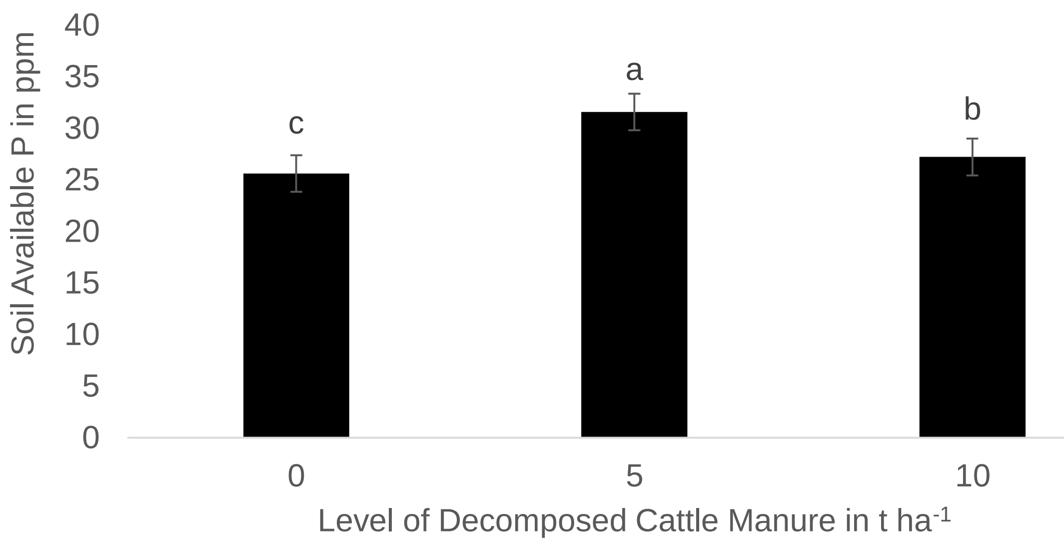

Figure 1. The main effects of manure application levels on soil available P in ppm during the short rain (2019) and long rain (2020) seasons at Kakamega, Western Kenya. The x-axis represents the treatments applied in the field under maize cultivation for 2 seasons. The 0 represents plots where 0 t ha^{-1} decomposed cattle manure was applied, 5 and 10 represent application of 5 t ha^{-1} and 10 t ha^{-1} decomposed cattle manure. The y-axis depicts mean values of available P in parts per million for the 2 seasons. The error bars represent the standard errors (SE). The letters a, b and c represent the means separation using the Least Significant Difference (LSD). Means represented by different letters are significantly different at P≤0.01. The available P in treatment 0 was 25 ppm; 5 t ha^{-1} 32 ppm and 10 t ha^{-1} 27 ppm at the end of the field experiments.

The initial soil pH value was 5.39, which was not conducive for crop growth due to toxicity of H^+ and Al^{3+} ions (Jaiswal et al., 2018). The application of manure combined with lime, manure only and manure combined with SBA significantly lowered soil acidity. The pH values of SBA and cattle manure were 7.96 and 7.40, respectively confirming their effects in raising soil pH. Liming in combination with farmyard manure is more efficient for acidity indicators than its application alone and reduces the amount of mobile Al to a level that is not toxic to plants (Karcauskiene et al., 2019). Lime (positive control) and manure contained 0.36% and 0.35% Ca and 0.6% and 0.25% Mg, respectively (Table 2). The reaction of lime with soil to release Ca and/or Mg ions into the soil solution leads to increase in soil pH and the reduction in exchangeable Al ions due to precipitation of H^+, Al^{3+}, Fe^{3+} and Mn^{4+} ions (Kisinyo et al., 2013). These amendments were reapplied in the second season, hence released bases over time. The results of this study concurs with research findings in the Nordic Countries where the application of ash at the rates 3 to 5 t ha^{-1} decreased soil acidity, increased base saturation and the total amount of nutrients (Huotari et al., 2015; Hale et al., 2020). Mineralization of manure over time also released basic elements into the soil. Manure used in the study contained 0.35% Ca and 0.23% Mg, respectively. The increase of soil pH in plots that received decomposed cattle manure after two seasons contrasts findings of a long-term field experiment where the stabilizing effect of farmyard manure (FYM) on soil pH was not proven. After 14 years of FYM application pH decreased at all the sites in the study (Vasak et al., 2015).

Effect of SBA and cattle manure on soil available P and soil CEC in the field

The objective of this study was to determine the effect of sugarcane bagasse ash and cattle manure amendments on soil available P and CEC in the field. The main effect of cattle manure on soil available P was highly significant at P≤0.01. Plots that received 5 t ha^{-1} manure gave the highest improvements followed by 10 t ha^{-1} while 0 t ha^{-1} remained significantly lower (Figure 1). The main effect of soil conditioner on soil available P was significant at P≤0.01. The application of bagasse ash and lime under field conditions resulted in significant changes of soil available P, at P≤0.01 level of significance. Treatments that received 5 t ha^{-1} of bagasse ash gave the highest values for soil available P, followed by 2 t ha^{-1} lime whereas 0 t ha^{-1} treatment rate remained significantly the lowest (Figure 2).

Significant increases in soil available P with sole application of decomposed cattle manure and SBA can be attributed partly to dissolution of the precipitated soil P with rise in soil pH. Huotari et al. (2015) reported that as the soil pH approaches 5.5 to near neutral, the precipitated P in soils occurring in pH below 5.5 is

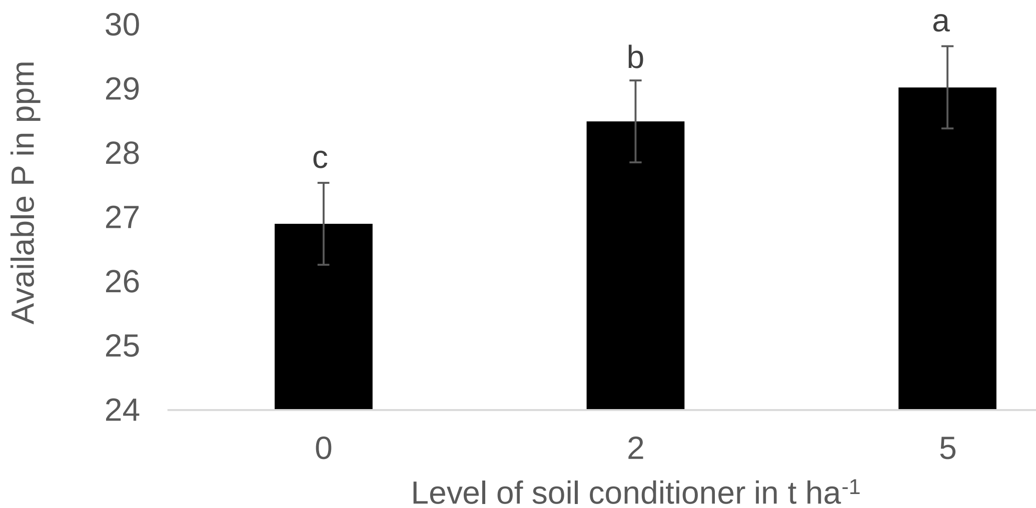

Figure 2. The main effects of soil conditioner application levels on soil available P in ppm during the short rain (2019) and long rain (2020) seasons at Kakamega, Western Kenya. The x-axis represents the treatments applied in the field under maize cultivation for 2 seasons. The 0 represents plots where 0 t ha^{-1} soil conditioner was applied, 2 represents 2 t ha^{-1} lime and 5 represents application of 5 t ha^{-1} sugarcane bagasse ash. The y-axis depicts mean values of available P in parts per million for the two seasons. The error bars represent the standard errors (SE). The letters a, b and c represent the means separations using the Least Significant Difference (LSD). Means represented by different letters are significantly different at P≤0.01. The available P in treatment 0 was 27 ppm; 2 t ha^{-1} lime was 28 ppm and 5 t ha^{-1} sugarcane bagasse ash was 29 ppm at the end of the field experiments.

released and hence becomes available. Additionally, both manure and SBA had adequate total P; 0.31 and 0.37%, respectively which improved the soil available P pool. This study found that application of manure at the rate 5 t ha^{-1} caused highest soil available P improvements followed by 10 t ha^{-1} and lastly no amendment. This could be possible because higher quantities of manure would require more time for mineralization to take place and nutrients to be released. This is in contrast with the findings of Lemanowicz et al. (2014) who found that the amount of available P in soil increased with increase in the amount of organic fertilizers (manure and slurry) applied. Bagasse ash significantly increased available P compared to liming and no amendment application. This agrees with findings by Hale et al. (2020) who reported that ash increased soil available P more than biochar, inorganic fertilizers and treatments with no amendment. Although the average available P was increased from 25 to 29 ppm, it is slightly above the adequate range. Results show that the main effect of season was significant at P≤0.01. The CEC was higher at the end of the 2nd season as shown in Figure 3.

The main effect of manure on soil cation exchange capacities was significant (P≤0.01). The CEC was highest at the highest rate of decomposed cattle manure applied. Treatments with no manure and 5 t ha^{-1} manure, had the lowest values (Figure 4). The main effect of soil conditioner on soil cation exchange capacities was significant (P≤0.01). Significantly higher CEC resulted from the application of bagasse ash. There was no significant difference in soil CEC values between the application of lime and nil application of any amendment (Figure 5).

The CEC of soil increased due to application of decomposed cattle manure at high rate (10 t ha^{-1}). Manure adds organic matter to soil and releases basic cations into the soil solution over time. Changes in CEC were not visible during the first season but increases were observed during the second season. The decomposed cattle manure and ash had been reapplied at the planting of second season. Despite CEC being an inherent soil property, it is highly influenced by the content of organic matter of a soil (FAO and ITP, 2015). This implies that soils with low organic matter content are likely to have low CEC as seen in the highly weathered soils like the Acrisols and Ferralsols and can be improved by increasing the organic matter content. Ingerslev et al. (2014) similarly reported that soil CEC and base saturation significantly increased in plots treated with ash, as a result of increase of magnesium and calcium ions at 10- 75 cm soil depth.

Conclusions

The application of amendments caused significant increases in soil pH, soil available P and CEC, at the end of the 2nd season. To raise soil pH to the optimum for

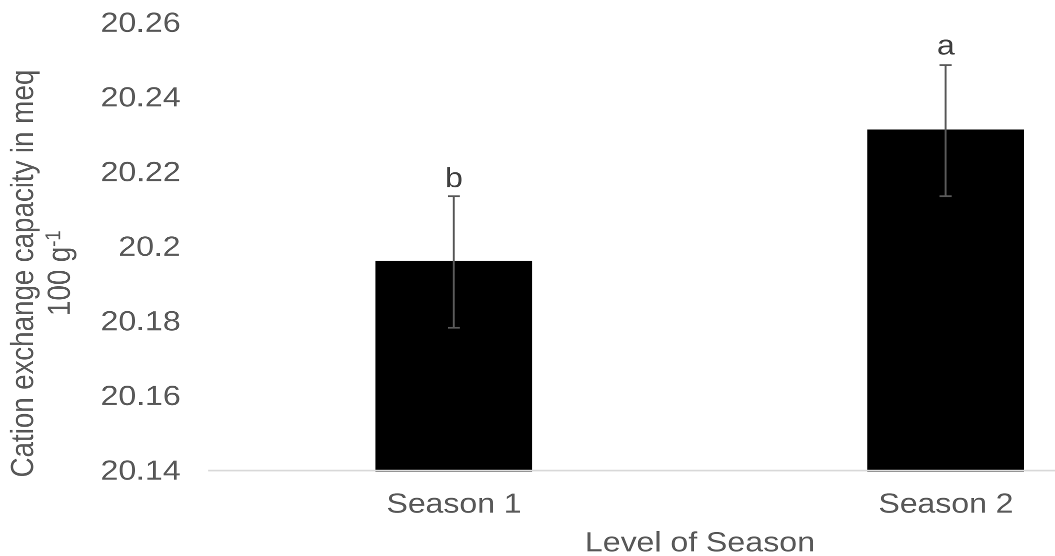

Figure 3. Main effect of season on soil CEC in meq 100g^{-1} during the short rain (2019) and long rain (2020) seasons at Kakamega, Western Kenya. The x-axis represents the levels of seasons. Season 1 represents the short rain season from September to December 2019 and season 2 represents the long rain season from March to July 2020. Treatments were applied in the field under maize cultivation for the 2 seasons. The y-axis depicts mean values of CEC for each of the two seasons. The error bars represent the standard errors (SE). The letters a, and b represent the means separations using the Least Significant Difference (LSD). Means represented by different letters are significantly different at P≤0.01. The mean CEC was 20.19 ppm at the end of season 1 and 20.23 at the end of season 2.

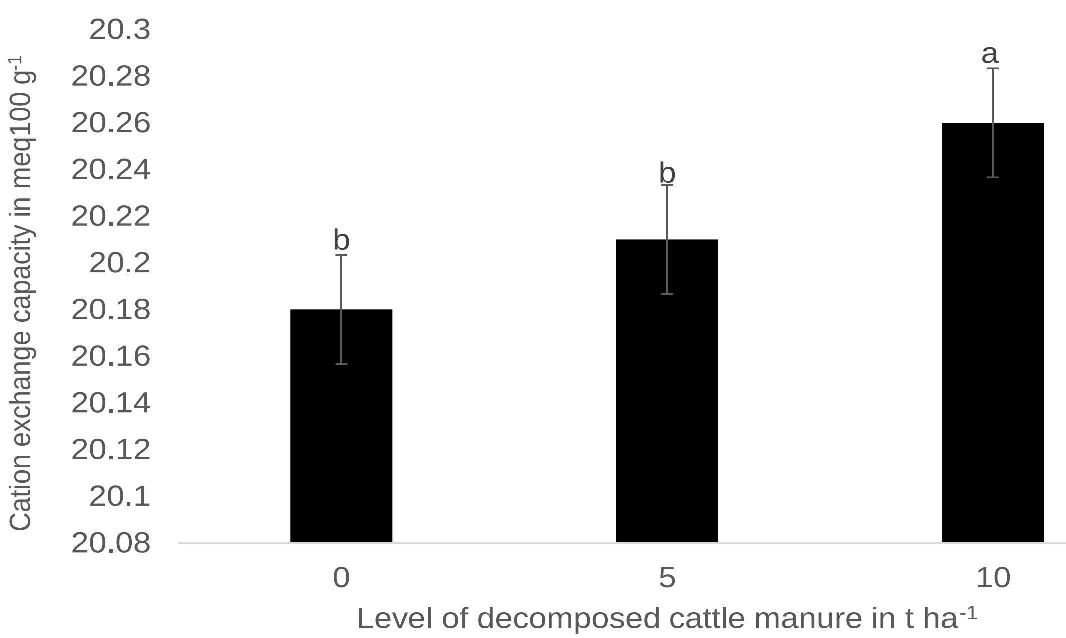

Figure 4. The main effects of manure application levels on soil CEC in meq 100g^{-1} during the short rain (2019) and long rain (2020) seasons at Kakamega, Western Kenya. The x-axis represents the treatments applied in the field under maize cultivation for 2 seasons. The 0 represents plots where 0 t ha^{-1} decomposed cattle manure was applied, 5 and 10 represent application of 5 t ha^{-1} and 10 t ha^{-1} decomposed cattle manure. The y-axis depicts mean values of CEC for the two seasons. The error bars represent the standard errors (SE). The letters a, and b represent the means separations using the Least Significant Difference (LSD). Means represented by different letters are significantly different at P≤0.01. The mean CEC value in treatment 0 was 20.18; 5 t ha^{-1} was 20.21 and 10 t ha^{-1} was 20.26 meq 100 g^{-1} at the end of the field experiments.

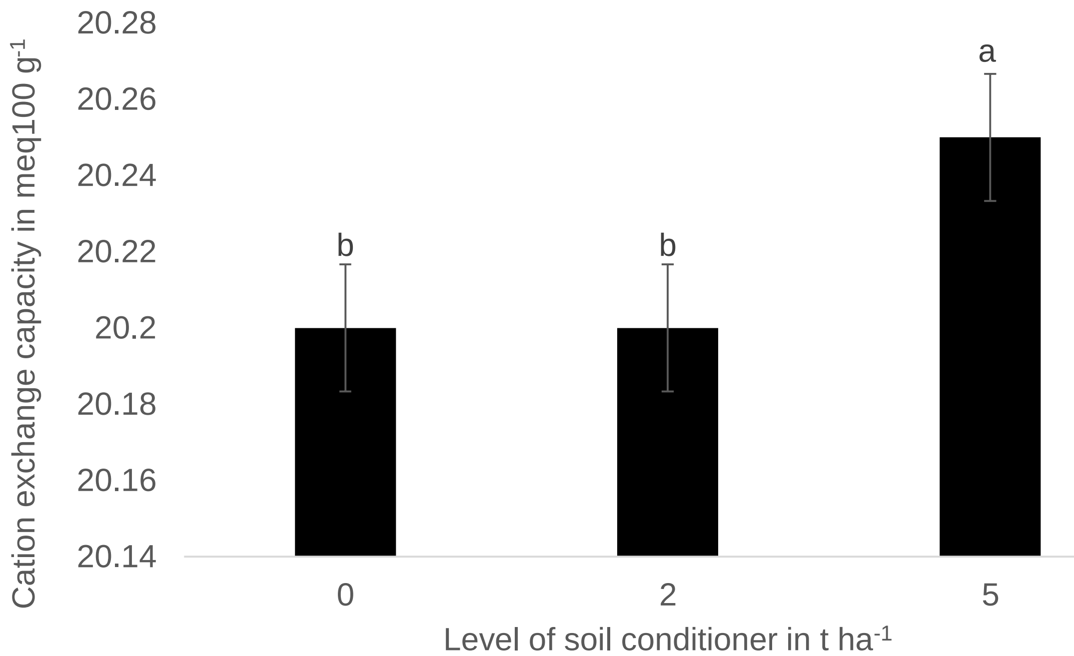

Figure 5. The main effects of soil conditioner application levels on soil CEC in meq $100g^{-1}$ during the short rain (2019) and long rain (2020) seasons at Kakamega, Western Kenya. The x-axis represents the treatments applied in the field under maize cultivation for 2 seasons. The 0 represents plots where 0 t ha^{-1} soil conditioner was applied, 2 represents 2 t ha^{-1} lime and 5 represents application of 5 t ha^{-1} sugarcane bagasse ash. The y-axis depicts mean values of CEC for the two seasons. The error bars represent the standard errors (SE). The letters a, and b represent the means separations using the Least Significant Difference (LSD). Means represented by different letters are significantly different at P≤0.01. The CEC in treatments 0 was 20.2; 2 t ha^{-1} lime was 20.2 and 5 t ha^{-1} sugarcane bagasse ash was 20.25 meq 100 g^{-1} at the end of the field experiments.

crop production, a combined application of decomposed cattle manure and lime at the rates 5 t ha^{-1} manure and 2 t ha^{-1} should be the first choice. The 2^{nd} alternative should be the application of 5 t ha^{-1} decomposed cattle manure alone or in combination with 5 t ha^{-1} SBA. To improve soil available P, 5 t ha^{-1} SBA or 5 t ha^{-1} well decomposed cattle manure and lime at 2 t ha^{-1} should be the best choice. On the other hand application of manure at high rates such as 10 or 5 t ha^{-1} SBA is recommended if improvement of soil CEC is the main objective.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Anderson JM, Ingram JSI (1993). Tropical Soil Biology and Fertility: A reference of ways. 2nd Ed. Wallingford, Oxon, UK: C.A.B International pp. 1-221.

Benbi DK, Thind HS, Shivani S, Kiranvir B, Toor AS (2017). Pulp Ash Application Stimulates Agricultural Soil C Siquestrationn without inhibiting Soil Accelerator Activity, Communications in Soil Science and Plant Analysis 48(15):1822-1833.

Fageria NK, Moreira A (2011). The Role of Mineral Nutrition on Root Growth of Crop Plants. In. Donald LS. (Eds.), Advances in Scientific Agriculture. USA: Elsevier Opposition pp. 251-331.

FAO and ATPS (2015). Standing of the World's Soil Resources (SWSR)-Main Report. Food and Agriculture Organization of the Global Organization and Intergovernmental Technical Panel on Soils. Rome, Italy. Available at: http://www.fao.org/publications

Hale SE, Nurida NL, Jubaedah, Mulder J, Somo E, Silvani L, Abiven S, Joseph S, Taherymoosavi S, Cornelissen G (2020). The Result of Biochar, Lime Associate in Nursing Ash on Maize Yield in an exceedingly semipermanent Field Trial in an Ultisol within the Wet Tropics. Science of the Full Setting 719(2020):137455.

Huotari N, Tillman-Sutela E, Moilanen M, Laiho R (2015). Exercise of Ash-for the Great of the Setting. Forest Ecology and Management

348(2015):226-240.
Ingerslev M, Hansen M, Pedersen LB, Skov S (2014). Effects of Wood Chip Ash Fertilization on Soil Chemistry in an exceedingly Norway Spruce Plantation on a Nutrient Poor Soil. Forest Ecology and Management 334(2014):10-17.
IUSS Working Group WRB (2015). World Reference Base for Soil Resources 2014, Update 2015. International Soil Organization System for Naming Soils and Making Legends for Soil Maps. World Soil Resources Reports No. 106. FAO, Rome. Available at: http://www.fao.org
Jaetzold R, Schmidt H, Hornetz Barthold SC (1982). Farm Mangagement Handbook: Natural Conditions and Farm Management; Atlas of Agro-ecological Zones, Soils and Fertilizing, Kakamega and Vihiga County. 2nd Ed. Ministry of Agriculture/Germany Agency for Technical Cooperation. Kenya/Nairobi pp. 1-317.
Jaiswal SK, Naamala J, Dakora FD (2018). Nature and Mechanism of Metallic Element Toxicity, Tolerance and Melioration in Dependent Legumes and Rhizobia. Biology and Fertility of Soils 54(2018):309-318.
Karcauskiene D, Repsiene R, Ambrazaitiene D, Skuodiene R, Jokubauskaite I (2019). Management of Soil Hydrogen Ion Concentration, its Ecological Associate in Nursing Scientific Discipline Assessment in an Agroecosystem. In: Suarau O (Eds.), Soil Hydrogen Ion Concentration for Nutrient Convenience and Crop Performance. Nigeria: University of Ibadan press pp. 47-71.
Kenya Markets Trust (2019). Enhancing Market Access and use of Agricultral Lime amongst Husbandman Farmers in Western Republic of Kenya Region. Early Impact Assessment Report. Available at: https:// www.kenyamarkets.org
Khan MJ, Qasim M (2008). Integrated Use of Boiler Ash as Organic Plant Food and Soil Conditioner with NPK in Chalky Soil. Songklanakarin Journal of Science and Technology 30(3):281-289.
Kisinyo PO, Otieno CO, Gudu SO, Okalebo Jr, Opala PA, Ngetich WK, Nyambati RO, Ouma EO, Agalo JJ, Kebeney SJ, Too EJ, Kisinyo JA, Opile W R (2013). Immediate and Residual Effects of Lime and P Chemical on Soil Acidity and Maize Production in Western Republic of Kenya. Experimental Agriculture 50(1):128-143.
Lemanowicz J, Siwik-Ziomek A, Koper J (2014). Effects of Yard Manure and Gas Fertilizers on Quality of P and Sulphur in Wheat and Activity of Elect Hydrolasesin Soil. International Agrophysics 28(2014):49-55.
Mangale N, Uriuki A, Kathuku-Gitonga AN, Kibunja CN, Mutegi JK, Esilaba AO, Ayuke FO, Nguluu SN, Gikonyo EW (2016). Field and Laboratory Research Manual for Integrated Soil Fertility Management in Kenya. https://www.kalro.org/sites/default/files/KALRO-KSHC-Manual%20final%202016-080118.pdf
National Accelerated Agricultural Inputs Access Programme (NAAIAP) (2014). Soil Quality Evaluation for Maize Production in Republic of Kenya. A Report by National Accelerated Agricultural Inputs Access Programme (NAAIAP) together with Republic of Kenya Agricultural Analysis Institute (KARI) Department of Kenya Soil Survey. Available at: https:// www.naaiap.go.ke
Okalebo JR, Gathua KW, Woomer PL (2002). Laboratory Ways of Soil and Plant Analysis: An Operating Manual. 2nd Ed. Nairobi/Kenya: TSBF-CIAT and SACRED Continent pp. 1-127.
Page AL, Miller RH, Keeney DR (1982). Ways of Soil Analysis. Part 2. 2nd Ed.Amer. Soc. of Agron., Madison, Winconsin, USA. pp. 595-622.
Rynk R, Kamp van de M, Willson GB, Singley ME, Richard TL, Kolega JJ, Gouin FR, Lucien Laliberty Junior, Kay D, Murphy DW, Hoitink FJA, Anthropologist WF (1992). On-Farm Composting Reference. North East Regional Agricultural Engineering Service. Available at: https://www.researchgate.net/publication/238283750
Thind HS, Sharma S, Sran HS (2016). Integration of Chemical Gas, Yard Manure and Multi-strain Microorganisms for Property Production of Rice-Wheat System. Journal of the Indian Society of Soil Science 64(1):78-85.
Vasak F, Cerny J, Buranova S, Kulhanek M, Balik J (2016). Soil Hydrogen Ion Concentration Changes in Semipermanent Field Experiments with Completely Different Fertilizing Systems. Soil and Water Analysis 10(1):19-23.
Zhu J, Qu B, Li M (2017). P Mobilization within the Yeyahu Wetland: Phosphatase Enzyme Activities and Organic P Fractions in the Rhizosphere Soils. International Biodeterioration and Biodegradation 124(2017):304-313.