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Response of Sorghum (*Sorghum bicolor* (L.) Munch) and Chemical Characteristics of Soil to Organic and Inorganic Fertilizers on Kenyan Lower Midlands Acid Soil

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Authors' contributions

This work was carried out in collaboration among all authors. Author POK designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Author PAO managed the analyses of the study. Author SOG managed the literature searches and revised the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Soil acidity, low level of nitrogen (N), phosphorus (P) and soil organic matter are major constraints to sorghum production in Kenya. We investigated the effect of farmyard manure (FYM) and combined application of inorganic nitrogen and phosphate fertilizers applied as calcium ammonium nitrate and triple superphosphate respectively, on soil pH, available P, total N, organic carbon and sorghum grain yield, on a smallholder farm in Siaya County, Kenya. The experiment was a randomized complete block design consisting of four treatments i.e., FYM applied at 0 and 4 t ha^{-1} in a factorial arrangement with inorganic fertilizers applied to provide 0 and 26 kg P ha^{-1} + 75 kg N ha^{-1}, replicated three times. The study was conducted during the long rains of March to June and short rains September to December, 2017. Farmyard manure was applied only during the long rains season of 2017, while P and N fertilizers were applied in both cropping seasons. Soil

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sampling was done before treatment applications and at harvest time. Soil analysis revealed that the soil was acidic (pH = 4.9) with low available P (5.3 mg kg^{-1} and N (0.08%) but moderate amounts of C (2.0%) and Ca (3.4 cmol kg^{-1}). The effect of sole application of FYM on soil P, N and grain yield were lower than those of the inorganic fertilizers. Farmyard manure increased soil pH because of its alkalinity (pH = 7.1) while triple superphosphate reduced it due to release of phosphoric acid into the soil. The mean annual (average of two seasons) grain yield increments, above the control with no nutrient inputs, due to 4.0 t FYM, 26 kg P ha^{-1} + 75 kg N ha^{-1} and 4.0 FYM + 26 kg P ha^{-1} + 75 kg N ha^{-1} were 64, 191 and 259%, respectively. Therefore combined applications of FYM and N and P fertilizers have the potential to increase sorghum grain yield on Kenyan acid soils.

Keywords: Sorghum; acid soils; response; farmyard manure; nitrogen; phosphorus fertilizers.

1. INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Munch] is an indigenous crop to Africa and remains a basic staple food for many rural communities especially in lower midland sub-humid and semi-arid climates [1]. In Kenya, sorghum is grown in many regions including western, northern Rift Valley, eastern and some parts of central. It is used both as human food and feed for livestock. Its grain is used for porridge, 'ugali', the local staple food and brewing while its stover is used for feeding livestock. Therefore, it plays a very important role in the Kenyan economy. Despite its importance, sorghum grain yields in Kenya have remained very low, ranging from 0.5 – 1.5 t ha^{-1}, compared to a potential of 3.0 t ha^{-1} under good crop husbandry [2]. The low sorghum grain yields are attributed to drought, pests, diseases, high temperatures, inappropriate agronomic practices and soil fertility depletion.

In the lower midland humid climates of Kenya, where sorghum is grown, major soil constraints limiting crop production include soil acidity, nutrient deficiencies, especially nitrogen (N) and phosphorus (P), and low soil organic matter (OM) [3-5]. The soil acidity is mainly due to leaching of base cations by high rainfall and their development from acid rocks [6,7]. Acid soils are associated with aluminium (Al), hydrogen (H), iron (Fe), and manganese (Mn) toxicities and deficiencies of P, molybdenum (Mo), calcium (Ca), magnesium (Mg) and potassium (K) [6]. Low available soil P levels are due to its fixation by Fe^{3+} and Al^{3+} ions in acid soils which is exacerbated by the fact that farmers in this region do not apply adequate amounts of P fertilizers to soil to replenish the P removed through crop harvests [8-10]. The low N and organic matter levels in most of these soils are caused by inadequate replenishment by farmers, leaching of soil N by high rainfall and high rate of organic matter decomposition due to high rainfall and temperatures [6,10]. Inorganic nitrogenous and phosphate fertilizers are generally used to ameliorate N and P deficiencies but their high cost makes them unaffordable to smallholder farmers. In addition, inorganic fertilizers do not supply organic C which can be used to build organic matter in these soils. There is therefore renewed interest in use of cheap locally available organic resources such as farmyard manure. In some cases, however, the organic inputs may not be available in adequate quantities and their integration with inorganic fertilizers, to serve the dual purpose of saving on the cost of buying inorganic fertilizer while ensuring that necessary nutrients are supplied in adequate amounts, is sometimes recommended. However, the effectiveness of this strategy in sorghum production in western Kenya has not been adequately been tested. The objective of this study was therefore, to determine the effect of farmyard manure and inorganic fertilizers, when applied alone and in combination, on selected soil chemical properties and sorghum grain yield in Siaya County, Kenya.

2. MATERIALS AND METHODS

2.1 Site Description

The study was conducted on a smallholder farmer's field (1°04'56.02" N and 34° 00'13.75"E) in Ugunja sub- county, Siaya County, Kenya. The site is 1446 m above sea level with mean temperature of 14-22°C and mean annual rainfall of 1300 mm. The rainfall is bimodal, with long rains occurring from March to June and short ones from September to December [6,11]. The soil at the study site is classified as chromic Ferralsols according to [12] soil classification.

2.2 Experimental Design

The experiment was a randomized complete block design consisting of two levels of FYM (0 and 4 tons ha^{-1}) in a factorial arrangement with two levels of inorganic fertilizers (0 and 26 kg P ha^{-1} + 75 kg N ha^{-1}), replicated three times. The recommended P and N rates for sorghum production in Kenya, 26 kg P ha^{-1} and 75 kg N ha^{-1} respectively [13] were used.

2.3 Agronomic Practices and Data Collection

After ploughing and harrowing, plots of 3.5 m by 3 m were demarcated and were separated from each other with guard rows of 1.0 m all round each plot. Farmyard manure was broadcast and thoroughly mixed with the soil in plots designated for its application. Triple superphosphate (TSP), the inorganic P fertilizer, was applied in the planting holes, in the appropriate plots and mixed with the soil. Three seeds of sorghum were then planted per hole at a spacing of 70 cm by 20 cm between and within rows, respectively. Sorghum accession Nyandundo–1, which is widely grown by farmers in this region was used. The seedlings were top-dressed with calcium ammonium nitrate (CAN) when the plants were at knee high.

Sorghum was harvested at physiological maturity from a net plot of 5.04 m^2. The guard rows in each plot were not harvested to avoid edge effects. Heads were separated from the stover and their fresh weight recorded. Eight representative heads were randomly taken per plot and their fresh weights recorded. The samples were air-dried to a constant weight, shelled and grain weight per plot determined. This was used for determination of grain yield per/ha.

2.4 Sampling of Soil and Farmyard Manure

Soil samples were taken from the top (0–30 cm) soil depth in a "W" transformation with a soil auger in March, 2017 before the applications of the organic and inorganic fertilizer materials. The soils thus collected were mixed thoroughly and about 1.0 kg composite sample packed in a paper bag, properly labeled and taken to the laboratory for physical and chemical analyses. Soil samples were also taken from each experimental plot before treatment application and during both long and short seasons harvesting period. They were analyzed for selected chemical properties to determine changes due to organic matter and inorganic fertilizers applications. A sample of completely decomposed manure was taken from a farmer's cattle yard and taken to the laboratory for analysis.

2.5 Laboratory Analyses

The soil samples were air-dried and the ones taken before treatment application were analyzed for texture, pH (1: 2.5; soil: water), bicarbonate extractable P, exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+), organic carbon (%C) and total N (%N). The samples taken after treatment applications were analyzed for pH, available P, %N and %C. The detailed laboratory procedures for these analyses are described by [14]. Farmyard manure was oven-dried at 70°C, ground to pass through a 0.5 mm sieve and then analyzed for nutrient content (total N, P, K, Ca, and Mg) and organic carbon (%C), lignin and polyphenols as described by [15].

2.6 Statistical Analysis of Data

The grain yield data was subjected to analysis of variance (ANOVA) using General Statistics [16]. Means were separated using pooled standard error of difference of means (S.E.D) whenever treatment effects were significant at $p \leq 0.05$.

3. RESULTS AND DISCUSSION

3.1 Quality of the Farmyard Manure

Chemical composition of the manure is shown in Table 1. The material had C: P and C: N ratios of 80 and 18, respectively with high lignin (> 15%) and low polyphenol (< 4%) levels. According to the criteria proposed by [17], the FYM is of good quality and is able to easily mineralize N and P into the soil for plants utilization.

3.2 Soil Chemical and Physical Characteristics

Table 2 shows the initial chemical and physical characteristics of the soil at the study site. The soil was acidic, deficient in N, P and Ca, and with low carbon levels. Acid soils deficient in N, P and

Table 1. Chemical composition of farmyard manure

MC (%)	% N	% P	% Ca	% Mg	% K	% C	pH	% Polyphenol	% Lignin
28	1.81	0.41	0.14	0.4	2.1	33	7.1	0.75	18

MC= Moisture Content

Ca with low carbon such as reported in this study are common in SSA agricultural lands [6,18]. The N deficiency are attributed to leaching by high rainfall, inadequate application of N fertilizers to replenish soil N removed through crop harvests and high rate of organic matter decomposition [6,10]. Phosphorus deficiency is likely in such an acid soil due to its fixation by Al and Fe ions, which is compounded by parent materials with low P, and inadequate P fertilizer replenishment by farmers [6,8,10]. The observed low soil C levels are due to high rate of organic matter decomposition and inadequate use of organic inputs in soil fertility management [19]. Low base cations levels in tropical soils are due to its leaching by high rainfall [6]. Such acidic and nutrient deficient soils cannot therefore, support healthy plant growth and often result in low yields.

The effect of the organic and inorganic materials applications on soil pH, available P, total N and organic carbon are shown on Table 3. Application of FYM alone gave the highest increase in soil pH in both seasons while inorganic fertilizers reduced it. Combined application of FYM with inorganic fertilizers gave a pH that was intermediate between the sole application of FYM and the inorganic fertilizers. Similar increase in soil pH due to application of organic materials and decrease due to inorganic fertilizer application has been reported by several researchers in acid soils such as in this study [20-22]. Increase in soil pH due to application of organic materials has been attributed to displacement of OH^- ions from soil adsorption sites by negatively charged substances contained in organic matter through ligand exchange [23]. The decrease in soil pH due to inorganic fertilizers applied alone, without FYM, is ascribed to release of phosphoric acid by TSP during its dissolution into the soil solution. The higher increase in soil available P due TSP fertilizer application compared to FYM is due to the greater amounts of P applied with TSP (26 kg P ha^{-1}) compared to only 16 kg P ha^{-1} supplied by the 4 tons of FYM. In addition, all the P in TSP is soluble and readily available while some of the P in the FYM is in organic forms and must first be mineralized before it becomes available. However, sole application of FYM did not significantly increase the available Soil P above the control with no nutrient inputs. This is likely due to uptake of the P that was mineralized from FYM. Soils were sampled after harvest, by which time most of the P could also have been fixed in these high P-fixing soils [24]. In fact, none of the treatments had available P levels greater than the critical 10 mg kg^{-1} that is considered adequate for most cereals in this region [14]. These low levels of P at the end of each season indicate that the residual effects on subsequent crops, due to application of these P inputs, may be limited and P nutrient inputs have to be applied seasonally. However, lower amounts may be applied where a combination of FYM and inorganic fertilizers were applied than with sole application of FYM or inorganic fertilizers at the P rates used in this study. Combined application of both P fertilizer and FYM had the highest increase in soil available P mainly because it had the highest total amount of P applied (42 kg P ha^{-1}) compared to FYM alone (16 kg P ha^{-1}) and inorganic fertilizers alone (26 kg P ha^{-1}). In addition, apart from providing small quantities of P to the soil, FYM likely reduced P sorption making both the native soil P and applied P fertilizer more available to plants [25]. Similar increase in soil P due to organic materials and P fertilizers applications have been reported on acid P deficient soils such as reported in this study [5,20,26]. The increase in soil N levels due to FYM was less than that of inorganic fertilizer because of its lower N content. Application of FYM significantly increased the organic C compared to treatments where it was not applied in both seasons. This is mainly due the C that was contained in the FYM (33%) which the fertilizers did not contain. Similar increases in organic C due to application of FYM have been reported [24,26,27]. However, the increase did not attain the critical level of 4%, and therefore there is need to continuously apply the organic materials to build up the organic matter levels in these soils.

3.3 Effect of Farmyard Manure and Inorganic Fertilizers on Sorghum Grain Yield

The effects of FYM and inorganic fertilizers on sorghum grain yield are shown in Fig. 1. The yields ranged from 0.83 to 3.04 t ha^{-1} in the long rains season (LR) and 0.74 to 2.58 t ha^{-1} in the short rains season (SR). The higher grain yield in the LR than the SR is attributed to the higher and better distribution of rainfall during the LR. Treatment effects on sorghum yield followed the incremental order of control < FYM < inorganic fertilizers < FYM + inorganic fertilizers in both seasons. All the treatments with fertilizer and FYM inputs significantly ($p \leq 0.05$) increased grain yield above the control in both seasons. The annual grain yield increments due to application of 4.0 t FYM, 26 kg P ha^{-1} + 75 kg N ha^{-1} (from TSP and CAN) and 4.0 FYM + 26 kg P ha^{-1} + 75 kg N ha^{-1} were 64, 191 and 259%, respectively. Although sole application of FYM supplied a similar amount of N (72 kg N ha^{-1}) as that of sole application of inorganic fertilizers (75 kg N ha^{-1}), it gave lower yields than the inorganic fertilizers mainly due to its low P content (16 kg P ha^{-1}) compared to inorganic fertilizers that provided 26 kg p ha^{-1}. Application of FYM alone, however gave significantly higher yields than the control due to its provision of N and P which were limiting in these soils. Organic materials are also known to confer other benefits such as improving water holding capacity, reducing Al toxicity, reducing P fixation and increasing

Table 2. Initial study soil chemical and physical properties (0-30 cm)

Soil pH	% N	Olsen P (mg P kg^{-1})	%C	Exchangeable bases ($cmol\ kg^{-1}$) Ca	Mg	K	Clay (%)	Silt (%)	Sand (%)	Textural class
≤5.5*	<0.25*	<10.0*	<4.0*	< 4.0*	<0.5*	<0.5*	32	16	52	Sandy clay loam
4.9	0.08	5.3	2.0	3.4	0.8	0.6				

** Indicates critical levels*

Table 3. Farmyard manure and inorganic fertilizer materials effects on some soil chemical characteristics

Treatment	Soil pH LR	Soil pH SR	Olsen P (mg kg^{-1}) LR	Olsen P (mg kg^{-1}) SR	% N LR	% N SR	% C LR	% C SR
1. Control	5.0	4.8	5.4	5.4	0.07	0.08	1.9	1.8
2. 4 tons FYM ha^{-1}	7.0	6.5	5.6	5.5	0.12	0.11	2.6	2.2
3. 26 kg P + 75 kg N ha^{-1}	4.8	4.7	6.7	6.5	0.13	0.14	1.8	1.8
4. 4 tons FYM + 26 kg P + 75 kg N ha^{-1}	6.8	6.3	7.0	6.9	0.17	0.16	2.5	2.3
S.e.d $_{(0.05)}$	0.3	0.3	1.4	1.2	0.04	0.03	0.2	0.4

LR = Long Rain, SR = Short Rain and FYM = Farmyard manure

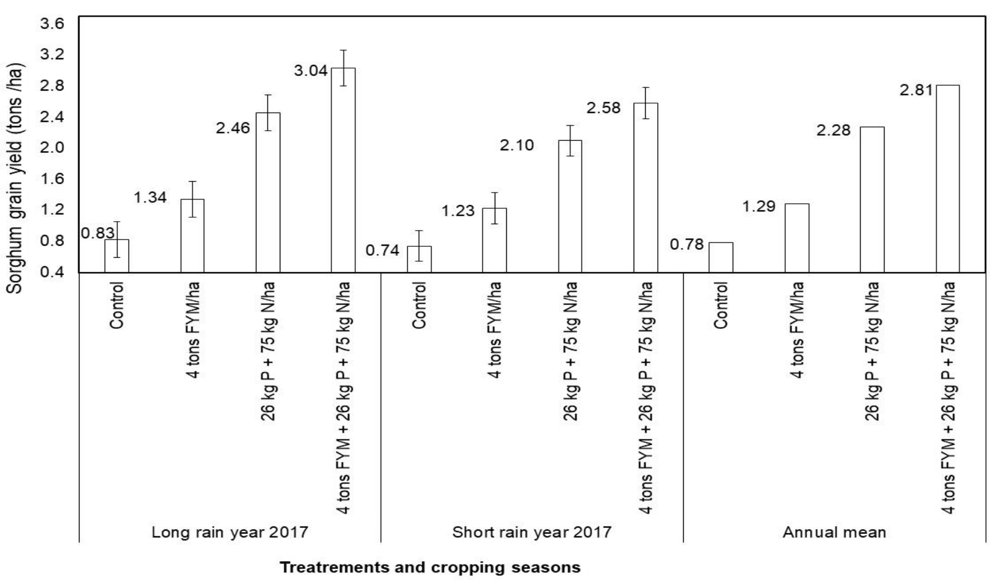

Fig. 1. Effect of farmyard manure and inorganic fertilizer material on sorghum grain yield
Error bars indicates s.e.d and FYM = farmyard manure

Table 4. Inorganic fertilizers and FYM effects on grain percent N and P contents

Treatment	% Grain N		% Grain P	
	Seasons			
	LR	SR	LR	SR
Control	0.91	0.81	0.16	0.14
4 tons FYM ha^{-1}	1.23	1.10	0.23	0.21
26 kg P + 75 kg N ha^{-1}	1.56	1.54	0.24	0.23
4 tons FYM + 26 kg P + 75 kg N ha^{-1}	1.70	1.66	0.27	0.25

Note: LR and SR are long rains and short rains seasons respectively

Table 5. Relationships soil pH, Olsen phosphorus, organic carbon and total nitrogen with maize grain yield

Parameter	R^2	Equation
Soil pH (1:5, Soil: water)	0.0632	y = 0.218 Soil pH + 0.537
Olsen Available P mg Kg^{-1}	0.9642	y = 1.1949 Olsen P - 5.5299
Total Nitrogen (% N)	0.8913	y = 23.157 Total N - 1.0481
Organic carbon (% C)	0.0865	y = 0.7697 Organic carbon + 0.1626

available soil P [19] and therefore impacting positively on crop growth. The higher yields from the combined application of organic and inorganic fertilizers, compared to sole application of FYM and inorganic fertilizers are mainly due to the higher amounts of both N and P they provided (147 kg N ha^{-1} and 42 kg P ha^{-1}). This also confirms that both N and P were deficient in these soils, an observation that has been reported by other studies in the area [8,10]. A response was therefore expected from N and P inputs irrespective of the source. Similar findings have been reported by [28,29].

3.4 Effect of Inorganic Fertilizers and FYM on Grain N and P Contents

Table 4 shows the effects of inorganic fertilizers and FYM on grain percent N and P contents. The mean annual % grain N contents were 0.86, 1.16, 1.55 and 1.68% due to control 4.0 tons FYM, 26 kg P ha^{-1} + 75 kg N (from TSP and CAN) and 4.0 FYM + 26 kg P ha^{-1} + 75 kg N ha^{-1}, respectively, while % grain P contents were 0.15, 0.22, 0.24 and 0.24% due to control, 4.0 t FYM, 26 kg P ha^{-1} + 75 kg N ha^{-1} and 4.0 FYM + 26 kg P ha^{-1} + 75 kg N ha^{-1}, respectively. There was a general higher % N and P grain contents where combined application of inorganic and FYM than either of them was applied alone. This is attributed to the synergistic effects that are often observed when organic and inorganic fertilizers are combined (19) and also the higher amounts of nutrient applied in this treatment compared to the others as already explained in section 3.3.

3.5 Relationships between Soil Chemical Properties and Sorghum Grain Yield

Correlations between soil pH, available P, organic carbon and total N with maize grain yield are show in Table 5. There were high correlations between soil available and grain yield (r = 0.98) and total N and grain yield (r = 0.94), but low between soil pH and grain yield (r = 0.25) and organic carbon and grain yield (r = 0.29). High correlation between soil available and total N with grain yield were because the two elements are essential for plant process. Phosphorus is important for good root development and growth, seed formation, faster grain maturity and strong straws in cereals. Nitrogen is important for vigorous vegetative growth and dark green colour in plants [30,31]. Therefore both N and P are important for high grain yields. High correlations between soil available P and grain yield and total N and grain yield are an indication that both nutrients can be used to predict maize grain yield. However, low correlations between soil pH and grain yield and organic carbon and grain yield is an indication that soil pH and organic carbon cannot solely be used to predict grain yield.

4. CONCLUSION

The effect of the FYM, and inorganic treatments on soil properties varied. FYM was basic in nature and hence increased the soil pH relative to the control with no nutrient inputs while TSP fertilizer reduced soil pH because of phosphoric acid released during its dissolution. The combined application of FYM and inorganic fertilizers gave the highest amounts of available soil P and total N, mainly due to the higher levels of N and P it supplied compared to the sole application of FYM or inorganic fertilizers. Organic C levels were also higher where FYM was applied, hence FYM can be used to build up organic matter in these soils. Sorghum grain yields generally increased with increase in rate of N and P inputs irrespective of sources. There were higher grain yields in the LR than the SR mainly due to the higher and better distribution of rainfall during the LR. The observed mean annual grain yield increments above the control due to 4.0 t FYM, 26 kg P ha^{-1} + 75 kg N ha^{-1} and 4.0 FYM + 26 kg P ha^{-1} + 75 kg N ha^{-1} were 64, 191 and 259%, respectively. Therefore combined applications of FYM and N and P fertilizers have the potential to increase sorghum grain yield on Kenyan acid soils. Economic analyses of the treatments would however need to be conducted to determine whether this combination is economically attractive before recommending its adoption to farmers in the region.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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