Improving Soil Fertility and Crops Yields through Organic and inorganic inputs in Smallholder Farmers' fields in Western Kenya

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***Abstract*: Organic (FYM) and inorganic (Mavuno) manure and their combination were evaluated on sorghum grain yields and some soil chemical characteristics in the 2016 SR and 2017 LR growing seasons FYM, Mavuno and or their combinations significantly ($p<0.05$) increased soil N, P and pH in the immediate and residual seasons. The sorghum grain yields trends for Busia site were such that: (FYM + *Mavuno) >FYM>Mavuno>Control* with (1.36, 1.29, 1.19 and 0.35) t ha^{-1} respectively in 2016 short rains season. The sorghum grain yield trends for 2017 long rains were as follows: (*Mavuno) >(FYM=Mavuno)with same yields>Control* giving (2.28, 2.17, 2.17 and 1.67) t ha^{-1} respectively. The grain yields for Teso site were: (FYM + *Mavuno) >FYM>Mavuno>Control* that resulted into (1.65, 1.49, 1.11 and 0.34) t ha^{-1} sorghum grain yields respectively in 2016 SR and (FYM+*Mavuno) >FYM>Mavuno>Control* giving (2.86, 2.79, 2.76 and 1.59) t ha^{-1} respectively for 2017 LR cropping seasons. All treatments resulted in significantly higher nutrient concentrations in the soil above the control with *FYM (5.32,Mavuno (5.31),FYM+Mavuno(5.20)* and Control (4.45) in 2016 SR and *FYM (5.15),Mavuno (5.20),FYM+Mavuno(5.23)* and Control (5.06) in 2017 LR for Busia. Teso had a similar trend with *FYM (5.55),Mavuno (5.21),FYM+Mavuno (5.28)* and Control (4.42) in 2016 SR and *FYM (5.64),Mavuno (5.65),FYM+Mavuno(5.55)* and Control (5.36) in 2017 LR .Soil pH, due to its effect on nutrient availability contributed to higher soil total N, P contents due to treatments application. Therefore, FYM, Mavuno and their combination can improve sorghum grain yield on nutrient deficient smallholder farms.**

***Keywords*: Fertilizer, Sorghum, soil fertility**

I. INTRODUCTION

Soil fertility management approaches play a leading role in providing essential nutrients required for crop growth and yields. However, in Sub Saharan African (SSA) soil fertility depletion is still a challenge when trying to improve crop yields, food security, and poverty alleviation among smallholder farmers (Sanginga and Woomer, 2009; Stewart,2020). Factors that include continuous cropping without adequate nutrient replenishment, soil loss through erosion, soil acidity and lack of appropriate knowledge on soil fertility management are the major cause of poor crop yields on small hold farms (Okalebo *et al*., 2006, Njeru, 2009; Wawire, 2021).The problem of low soil fertility and the need to improve the general low crop yields on small hold farms, has provoked the government of Kenya through, `The National Accelerated Agricultural Inputs Access Programme'' (NAAIAP) (GOK, 2014;Bjornlund, 2021) to introduce subsidized inorganic fertilizers. This was aimed at raising fertilizer use to optimal levels and increase crop productivity from increased input use thereby raising land and labour productivity and food security for small holder farmers who form majority of households in Western Kenya (Ochola, & Fengying, 2015;Mwaura,2021). While there is evidence to suggest that inorganic fertilizer use has increased in recent years (GOK,2014; Ricker-Gilbert;2020), low grain to fertilizer response rates caused by low soil fertility remains a challenge (Jayne and Rashid 2013; Sheahan and Barrett (2014), Druilhe, & Barreiro-Hurlé, (2012); Mairura, 2022). Besides that, these inorganic fertilizers alone do not address soil degradation, which is becoming an increased concern due to such factors as physical soil degradation, soil erosion and leaching (Jonas *et al.*, 2012;Mishra ,2022). In addition, use of inorganic fertilizers by resource poor farmers is constrained by profound lack of knowledge of application, high fertilizer cost, unavailability and access (Njira *et al.*, 2012; Mwaura, 2021). Use of inorganic fertilizers has also been reported to have negative effects on water quality, soil fauna and soil health (Schröder, 2014; Nana,2022). SSA has been identified as a hotspot for the depletion of SOM (Montanarella, 2016; Krause, 2018). The supply of manure to agricultural soils is an ancient practice and a well-tested strategy to increase SOM, replenish basic plant nutrients, improve yield response to fertilizers and to restore soil productivity in degraded areas (Bogaard *et al.*, 2013; Nezomba *et al.*, 2015; Bayu, 2020). Regular input of organic matter to agricultural soils is needed to restore soil organic matter (SOM) and maintain soil humus. Organic materials contribute directly to the deposition of soil organic matter (SOM) and is important in improving the physical, chemical and biological composition of the soil (Moyin-jesu, 2015; Usevičiūtė,2021). Moreover, existing organic materials tend to be characterized by comparatively low contents of phosphorus (P) Sanginga (2009). Organic inputs alone are often insufficient to maintain nutrient balances in resource poor farming systems, because of the limited availability of nutrient-rich organic matter (e.g., manures and compost) and overall lack of nutrients in the system. The combined application of organic inputs and mineral micronutrient fertilizers has the potential to alleviate overall micronutrient shortage. Besides, agronomic efficiency of mineral fertilizers is often increased when applied in combination with organic matter (Vanlauwe *et al.,* 2015; Hoque, 2022). Although present in small amounts, these nutrients are very important from the viewpoint of soil fertility management. Evidence shows that the use of organic fertilizers combined with inorganic sources enhances nutrient availability, optimizes the soil environment and improves crop productivity (Schoebitz and Vidal, 2016; Krasilnikov,2022). To this end, the appropriate combination of organic and inorganic fertilizers sources for the specific soil type is needed to improve the soil fertility and productivity of crops. The objective of this study was, therefore, to evaluate the effect of organic fertilizer (farm yard manure), inorganic phosphorus (Mavuno) and the combined use of the two inputs on soil chemical properties, on the yield of sorghum under variable climatic conditions and soil fertility conditions and to further evaluate the residual effect of the treatments on yield performance of a subsequent sorghum crop. Sorghum was purposely chosen as it is one of the few crops that grows well under local conditions such as Western Kenya because it is naturally drought- and heat-tolerant.

II. MATERIALS AND METHODS

Study areas

The study was conducted in 2 sub-counties in Western Kenya: Busia township and Teso south for two consecutive seasons, 2016 short rains (SR) and 2017 long rains (LR), Busia has an average temperature of 22.0°C with an average annual of rainfall 1743 mm. The average temperature in Teso south is 28.0°C with an average annual rainfall of 1790 mm. The rainfall at all these sites is distributed over two main cropping seasons, the long rainy season from March to July and the short rainy season from September to December. The soils in Busia are Orthic Ferralsols with a clay loam texture while those at Teso south are Gleyic Acrisol with a sandy loam texture. The sites were selected on the basis of having a soil pH of less than 5.5. Farming in the region is largely undertaken by smallholder farmers, practicing a mixture of cash crops and livestock enterprises. Maize and beans are the most common food crops grown in the area mainly as intercrops with little or no fertilizer inputs. Sorghum is a staple in a variety of nutritious traditional foods in many parts of Africa (Elkhalifa, 2012; Andiku, 2021). Nutritional benefits combined with tolerance to adverse weather conditions make sorghum promotion an essential component for increasing African agricultural productivity and household food security (Okeyo,2020; AGRA,2021), in the twenty-first century, especially in food insecure areas as well as western region of Kenya.

Experimental design

The experiment was laid in RCBD design in 3 replications in each site and season. The treatments comprised of the fertilizer materials i.e., Mavuno fertilizer, Manure, Mavuno fertilizer + Manure and the Control.

Treatment application

The treatments were applied once at the start of the, 2016 SR and 2017 LR in Busia and Teso at their recommended rates (26 kg P ha^{-1}) according to FURP (1994) band applied. The treatments were replicated three times for each site and applied in plots measuring 5x4.5 m giving plot area of 22.5m^2. The phosphorus contribution from each input treatment was maintained at 26kg P $ha^{-1}$for this study, this rate being the recommended P level for most of the cereal crops within the western Kenya region for their optimum performance.

Planting of field experiment

Field experiments commenced during the 2016 short rain season (SRs) (August to December 2016) and replicated during the 2017 long rains (LRs) (March to May 2017). Seredo Sorghum variety from Kenya Seed Company was drilled at seed rate of 3 kg ha^{-1}also at the pacing of 0.75 x 0.2 m. The crop management practices i.e., gapping, weed control and top dressing with nitrogenous fertilizer, were done accordingly.

Soil Sampling and preparation

Initial composite soil samples were collected from a depth of 0–20 cm before planting the

Test crop in 2016 short rains. Soil samples were also taken from each plot at planting and at crop harvesting to assess the changes in soil fertility status due to integrated application of organic and inorganic fertilizers. Soil pH was measured using Glass electrode method (H_2O) meter. The Walkley–Black method was followed for the determination of soil organic carbon (%OC), whereas the cation exchange capacity (CEC), in centimole (cmolkg^{-1}) was analyzed using ammonium acetate. Total nitrogen (%N) and available phosphorus (mg kg^{-1} soil) were analyzed by the Kjeldahl and the Olsen methods, respectively. The procedures for the methods used are outlined in Okalebo *et al.*,2002. The result of initial soil analysis showed that the pH was in the strongly acidic range as per the standard classification procedure by Motsara and Roy (2008). Total nitrogen of the sites was highly variable and found in the low to moderate range. The available phosphorus content of the soil was categorized under very low range for both sites. Soil nitrogen and the organic carbon content varied in each site, though it was in the medium range for both sites

Table 1: Physical and chemical properties of soil at 0-20 cm depth.

		(MG KG^{-1})	(%)			($CMOLKG^{-1}$)					(%)				
SITE	pH	P.	N	OC	C:N	Ca	Mg	K	Na	$Al^{3+}+H^{+}$	Sand	Silt	Clay	Text class	Order
BUSIA	4.85	1.82	0.21	1.50	7:01	0.90	0.35	0.37	0.96	1.95	55	24	21	Loam	Orthic Ferralsols
TESO	5.13	1.85	0.17	1.54	9:01	0.97	0.46	1.02	0.97	1.86	78	10	12	Sandy Loam	Gleyic Acrisols

At agronomic maturity, sorghum crop was harvested from the net plot areas of 4.5 m x 5 m by excluding the border rows. The grain yield of sorghum was measured using electronic balances. Finally, soil and yield data for sorghum crop were subjected to analysis of variance using the GenStat-15 software. Means were separated using least significant value at the $p < 0.05$ probability level. Sigma plot Version 10 was used to sketch bar graphs.

Table 2: Quality of the organic material used in field trials.

PARAMETER	**O.M**	**Total N**	**Total P**	**Total K**	OC	Mg	Ca
	(%)					**(cmolkg^{-1})**	
	30.1	0.8	0.4	1.1	17.5	0.79	0.85

Table 3: Nutrient Content of Mavuno Fertilizer used in field trials

PARAMETER	**N**	**P_2O_5**	**K_2O**	MgO	CaO	**S**	Micronutrients (Traces)
	(%)						
	10	26	10	4	8	4	B, Zn, Mo, Cu and Mn

Source: (Abuom, Nyambega, & Ouma, 2014)

III. RESULTS AND DISCUSSION

Initial soil properties

The initial soil properties at the study sites are shown in Table 1. The soil pH ranged from 4.85 (Busia) to 5.13 (Teso) and would be rated as moderately acidic and therefore likely to encounter challenges associated with acidic soils such as Al toxicity, deficiencies of bases and available P, which are prevalent at soil pH <5.5. However, all the sites were low in exchangeable acidity

Suggesting that Al toxicity may not be a serious problem. The soil available P at all the sites was <10 ppm, which is considered the critical value of available P for cereal using the Olsen method that was used in this study (Okalebo, 2002). Hence, P deficiency is likely to limit Sorghum yields at these sites. In addition, N was almost deficient at all the sites (<0.2%). The low levels of soil N and available P. at these sites is consistent with other reported studies in the area and is partly attributed to mining of soil P and N through crop harvest on smallholder farms where the recommended N and P fertilizer rates to replenish the removed nutrients through crop harvests are rarely applied (Okalebo *et al.*,2006; Smaling *et al.*, 1993 Ndambi; 2019). The sites were low in organic Carbon (C) (<2%) indicating low levels of organic matter (Okalebo, 2002).Exchangeable bases (Ca, Mg and K) were also generally low as would be expected of acid soils due to leaching effects on these soils (Obiri-Nyarko, 2012; Gisaw,2021).

Effect of soil fertility improvement material on soil pH and available Olsen P (mg kg^{-1}).

All the treatments applied significantly ($p<0.05$) contributed to higher pH levels above the control. The increase in soil pH due to treatment application is attributed to the liming (Ca) contribution from the *Mavuno* fertilizer (Table 4).The high soil pH from FYM or their mix with Mavuno fertilizer might be due to buffering capacity of the organic material by releasing some organic compounds and liming (Ca) (Table 2) that fix or chelate H^{+}, Al^{3+} and other cations (Palm *et al.*,1997). Soils with high organic matter contents from additions of organic materials have high cation exchange capacity and buffering capacity that stabilize soil pH (Abera *et al.*, 2015). The soil pH however fluctuated over the cropping seasons in Busia site across all the treatments applied, this could be due to leaching or release of acidic organic compounds from organic matter decomposition. The higher soil pH realized in Teso could be due to the newly opened land that had remained fallow for several years, a fact that could have contributed to rejuvenation of the inherent soil nutrient content through organic material litter accumulation and mineralization and release of the soil nutrients including the basic cations that contribute to high soil pH levels observed in this study. The same scenario was observed in the control plots which could also explain the high soil nutrient content in this field accrued from the accumulated organic matter during the fallowing period. The pH levels however increased over time as indicated by the high soil pH values that were observed in subsequent sampling after the first planting of the experiment. Another reason for high soil pH levels could probably be related to organic acids formation during organic matter decomposition that release organic acids in the soil that facilitate mineralization of materials to release some plant nutrients including the basic cations that cause increases in soil pH levels. Variations in soil pH during cropping season also depend on crop uptake of the basic cations which can either, reduce or increase the soil pH accordingly (Tisdale *et al.,* 1985). Land Cultivation operations and overall soil amendments can also contribute to increase or decrease in soil pH over time (Brady and Weil, 2008).

Table 4: Effect of soil fertility improvement material on soil pH and available Olsen P (mg kg^{-1})

TREATMENT	**BUSIA**		**TESO**		**BUSIA**		**TESO**	
	TN (%)				**OC (%)**			
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
CONTROL	0.24a	0.25a	0.21a	0.15a	1.4a	1.9a	1.9a	1.6a
FYM	0.34b	0.29b	0.26b	0.30b	1.6a	2.0ab	2.1a	1.7a
MAVUNO	0.30ab	0.28ab	0.22a	0.22ab	1.6a	2.0ab	1.8a	1.5a
MAV+FYM	0.28ab	0.29b	0.24ab	0.22ab	1.6a	2.0ab	1.9a	1.6a
Mean	0.29	0.28	0.23	0.22	1.5	1.9	**1.9**	1.6
LSD$_{(0.05)}$	0.07	0.03	0.11	0.10	ns	0.15	ns	ns
CV	11.2	5.1	5.3	21.8	10.7	3.8	7.1	10.3

Table 5: Effect of treatments on soil %Nitrogen and % OC

TREATMENTS	**BUSIA**		**TESO**		**BUSIA**		**TESO**	
	pH (H_2O)				**Olsen P**			
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
CONTROL	4.45a	5.06a	4.42a	5.36a	1.55a	12.99a	1.60a	13.39a
FYM	5.32b	5.15ab	5.55c	5.64b	10.0b	35.10b	13.4b	48.21c
MAVUNO	5.31b	5.20ab	5.21b	5.65b	8.46c	34.43b	9.71b	43.63c
MAV+FYM	5.20b	5.23b	5.28b	5.55b	10.9bc	33.70b	10.35b	37.43b
Mean	**5.073**	5.16	**5.12**	5.55	8.76	**29.1**	8.76	**35.66**
LSD$_{(0.05)}$	0.21	0.15	0.18	0.15	0.974	14.23	1.8	6.16
CV	2.1	1.5	12.2	1.4	17.2	24.5	25.2	8.6

Means followed by the same letter within the column are not significantly different at 0.05 level of significance.

Significant (*p<0.05*) differences among the treatments were observed in soil available P. by all the treatments applied contributing to higher P. levels that were above the control levels in both Busia and Teso sites across the two cropping seasons. General increases in available P levels were also observed in subsequent soil sampling during the 2017 LR for both Busia and Teso sites across all treatments including the control plots (Table 4). Plots with FYM and (FYM+Mavuno) treatments maintained high levels of soil available P all of which were above the control. Generally, Teso site however recorded higher P values when compared with Busia site at the end of the study period in 2017 LR cropping season. The soil P. levels on the other hand dwindled greatly in control plots remaining low in relation to all the treatments. All the soil available p values in 2017 LR were higher than the values obtained in (2016 SR). The significant (*p.<0.05*) differences in available P could be attributed to positive response of the soil to the applied P sources since the soils were initially moderately acidic and low in available P (Table 1). Effectiveness of phosphorus fertilizer material when applied to the soil is determined by the properties of the source materials, soil being applied to, soil reaction and climatic factors such as temperature and soil moisture content (Havlin *et al.*, 2005; Bindraban, 2020).Thus the low soil pH and sufficient moisture during the season could also have contributed to dissolution of both *Mavuno* and FYM applied either in pure or combined forms thereby contributing to the increased P levels that were observed in this study. *Mavuno* planting fertilizer and FYM treatments applied either singly or the two materials combined gave higher P values above the control (Table 4). Nutrient mineralization of organic material with moderate amounts of available phosphorus such as farm yard manure and readily available phosphorus source materials such as *Mavuno* planting fertilizer, being a rich source of plant nutrients (Table 2) may have been mobilized overtime to release phosphorus in synchrony with the plant's growth needs. Another contributing factor to higher P levels realized could emanate from mineralization of the portion of soil organic phosphorus contained within the applied FYM (Table 3) that readily release the contained nutrient into the soil. In addition, P may also be immobilized through soil microbial activity following material application (Jama *et al.,*1997; Ducousso-Détrez,2022), the same nutrient may be released depending on the prevailing environmental conditions. However, the quantity of P released will depend on the quality or the nutrient content of the applied material. Hence in the two seasons, plots receiving FYM, Mavun*o* alone or the two (FYM+Mavuno) nutrient sources combined had relatively higher levels of phosphorus than control explaining the possible nutrient mineralization of the input materials to release the nutrient P available therein. The combination of *Mavuno* inorganic fertilizer and FYM together is known to enhance the decomposition of the latter and hence leading to subsequent increase in available phosphorus and plant uptake (Xin *et al.*, 2016; Wali,2022;). Supporting the findings in this study, other findings indicated that organic manure, besides being a plant nutrients source, also reduces moisture evaporation from the soil, supplies nutrients (Zerihun, Sharma, Nigussie, & Fred, 2013) in addition to improving soil moisture which enhances soil nutrients including P availability through organic matter mineralization. Given the initial low soil P nutrient status in the study sites. Integrated soil fertility management approaches, such as those undertaken in this study if well-articulated could offer a long-lasting solution in alleviating the soil constraints associated with low soil fertility in western Kenya soils to ensure their productivity and hence high crop yields in this region.

Effect of treatments on soil %Nitrogen and % OC.

Soil %N and % OC as affected by the treatment inputs are presented in Table 5. Application of FYM, *Mavuno* fertilizer or the (FYM +Mavuno) combination at the initiation of the study in (2016 SR) significantly ($p \leq 0.05$), increased soil % N at the Busia and Teso site above the control plots at both sites in both seasons. The %N contribution from FYM and the (FYM+*Mavuno*) combination of the two remained higher compared to *Mavuno* and control plots in both sites during soil samplings in both sites, thereby contributing to higher soil N levels in these treatments applied plots at the end of 2017 LR season (Table 5). The Busia site generally recorded higher soil %N content when compared with Teso site. The higher %N in Busia can perhaps be attributed to long cropping years, continuous fertilizer applications. In addition to that, the organic matter accumulation from long time cropping of the Busia site, could also explain the higher % N levels in these soils from organic matter decomposition and mineralization. The heavy textural nature (Table 2) of the soils in Busia site can also have a bearing on soil N nutrient retention in these soils. On the other hand, the sandy nature of the soils in Teso site could partly contribute to the soil N nutrient mobility given their large pore spaces in the sandy soils that easily losses the nutrients and specifically N through leaching beyond the root zone. The soils in Teso site, having been subjected to cropping and hence fertilizer inputs and organic matter buildup for a short duration could also explain the low nutrient N levels in these soils. In all, the study indicates the need for different and site-specific soil fertility management strategies for Busia and Teso sites to ensure sustainable productivity for each site.

Effect of Treatments on Soil Organic Carbon.

In the present study, soil organic carbon contents did not change significantly due to treatments applied within the growing season. The values showed little variation but as per classification, these values were found to be under moderate ranges (Okalebo *et al*., 2002). These findings are in agreement with other workers (Okalebo *et al*., 1997) who observed minimal changes in soil organic carbon after several years of cropping under various cropping systems. However, a general decrease in soil organic carbon in Busia and Teso sites observed during the first cropping season may be attributed to general decrease in residue inputs to the soil. The soil organic carbon contents however increased in the 2017 LR cropping season where the highest levels were observed at the end of this season. Minimum changes in soil organic carbon have been observed in other studies. (Nandwa,2003; Lembaid,2022) reported minimum changes in soil organic carbon in long term soil fertility experiment at NARL, Central Kenya, in clay Nitisols. Soils high in clay and silt content such as those in Busia have generally high levels of organic carbon compared to sandy soils such as those in Teso experimental site. The micropore spaces in this soil restrict water and air movements within the soil mass hence reducing the rate of organic matter decomposition (Brady and Weil, 2008). Another contributing factor to high accumulation of organic matter in fine textured soils could be due to formation of humus-clay complexes that protect the organic matter from rapid decomposition. (However due to high temperatures and moisture levels at the study sites, (Havlin *et al.,* 2005; Kome, 2019), the accumulated organic matter in the soil undergoes rapid decomposition into simpler nutrients ready for losses or plant uptake. Another contribution to low organic matter contents in Busia and Teso sites could be due to the presence of termites in these sites that quickly feed on the crop residues, thus leading to low organic matter contents in the soil. Increases in the soil organic carbon enhance soil quality, reduces degradation and erosion, improves surface water quality, and generally increase soil productivity. Maintenance of high soil organic carbon in agricultural soils through proper soil organic matter management such as soil organic manure additions allows carbon sequestration that provides a multitude of environmental benefits including contribution to high crop yields on low soil fertility soils such as those of Busia and Teso sites.

Treatment effects on yields of the sorghum crop during the 2016 SR and 2017 LR Cropping season.

The sorghum grain yields varied across sites and seasons. The yields in long rains season were generally higher than those in the short rains season (Fig.1). The treatments sorghum grain yield responses for Busia were as follows: (FYM+*Mavuno) >FYM>Mavuno>Control* giving (1.36, 1.29, 1.19 and 0.35) t ha^{-1} respectively for 2016 SR cropping seasons. The sorghum grain yield responses to the applied fertilizer materials for Teso site were as follows: (FYM+*Mavuno) >FYM>Mavuno>Control* that resulted into (1.65, 1.49, 1.11 and 0.34) t ha^{-1} respectively for 2016 SR cropping season. FYM at the rate of 26kg P ha^{-1} significantly increased the average sorghum grain yields from 0.34t ha^{-1} in control plots to 1.29 t ha^{-1} (246%) in Busia site and from 0.35 t ha^{-1} to 1.50 t ha^{-1}in (328.57%) Teso site. *Mavuno* phosphatic fertilizer applications however contributed to lower sorghum grain yields as compared to FYM in both site, these were 1.19t ha^{-1} (246 %) 1.11t ha^{-1} (229 %) sorghum grain yields for Busia and Teso sites respectively. The lower sorghum grain yields from *Mavuno* treatment as compared to either FYM or the two materials combined could be due to its easy dissolution and losses through leaching and hence much of it not being taken up by the sorghum crop. A cross all study sites addition of *Mavuno* phosphatic based fertilizers in combination with FYM resulted to raising the sorghum grain yield almost four (294 %) times above the control in Busia site and almost (392 %) increase in Teso site. The increase was from 0.35t ha^{-1} in control plots to 1.36 t ha^{-1} sorghum grains in treated plots in Busia site and from 0.34 t ha^{-1} to 1.65 t ha^{-1} in Teso site as indicated in Figure 1.

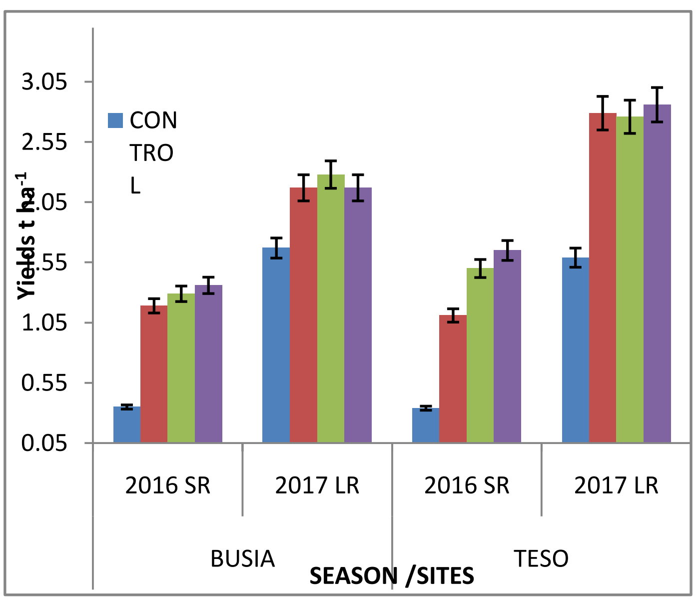

Figure 1: Sorghum grain yield in t ha^{-1}

There were general increases in sorghum grain yields across all the treatments due to residual effects in both Busia and Teso sites. The general yield trend for Busia was (FYM+Mavuno) >Mavuno>FYM= (FYM+Mavuno)>control with (2.28, 2.17, 2.17 and 1.67) t ha^{-1} of sorghum grains for Busia site. The sorghum yields trend for Teso was (FYM+Mavuno)>FYM>Mavuno >control with (2.86, 2.79, 2.76 and 1.59) t ha^{-1} of sorghum grains for Teso site. All the yields from the residual (2017 LR) from all the treatments were higher than for the first (2016 SR) season as observed in the Figure 1.

The response observed with application of the fertilizers (FYM, Mavuno or their combination confirms that both N and P are limiting at these sites and fall under the category of responsive soils (Kihara *et al.*, 2016). Similar responses of maize to N and P fertilizers have been reported by several studies in the region (Okalebo *et al.*, 2006; Ademba *et al.*, 2015; Nziguheba *et al*., 2016; Kihara *et al.*, 2016) Fertilizers containing these nutrients must therefore be applied. The application of soil fertility materials, irrespective of the type, contributed to yields that were significantly different from those of the control plots (Busia and Teso) in both seasons. However, in both sites and seasons application of FYM together with Mavuno fertilizer gave sorghum yields that significantly exceeded those FYM and Mavuno fertilizer applied individually (Figure 1).

The results are in conformity with the findings of Devi *et al.*, (2014; Urmi, 2022). Which clearly indicates the need of combining organic manures with inorganic fertilizers which ensure immediate and within season nutrient supply to the crop for a longer time in the available forms. The available nutrients translate to proper nutrient utilization by the crop, growth and development. Improved crop growth is essential for the build-up of soil organic carbon necessary for maintenance of soil structure and water holding capacity of soil. Farm yard manure (FYM) is an important source of the major crop nutrients N, P, and K (Nesomba *et al.*, 2015; Bhanwaria, 2022), besides being a rich source of all the trace elements useful for plants growth. The ability of phosphatic fertilizer to enhance soil properties like soil carbon, soil % N, soil nutrient availability and other favourable soil attributes contributes to a tremendous yield increase. Continuous cropping on the other hand without nutrient addition results in nutrient depletion leading to low soil fertility as can be seen with control plots having the lowest mean grain yield across all study sites in all the cropping seasons. Manure and *Mavuno* fertilizers on the other hand, besides offering the direct benefit of nutrient supply to the soil, they also have an effect on soil properties which influence plant nutrient acquisition by the plant roots besides enhancing plant growth (Guo, *et al*., 2016;Thuita, 2018). Combination of organic manures and inorganic fertilizer in this study might have improved the nitrogen use efficiency, micro and macro nutrient supply and helped in solubilizing P and its uptake by the study crop and enhanced K availability that in turn translated to better growth and yield of sorghum grains. In other studies, increased organic matter due to application of organic manures improved crop performance and soil characteristics (Li *et al*., 2010; Gross, 2021). Therefore, combined application of organic and inorganic fertilizers may be a good option to enhance nutrient recovery, plant growth and ultimate crop yields on low nutrient soils such as those in Busia and Teso sites in western Kenya. Otherwise higher N and P application rates are required to attain better yield in cereal crops (Mubeen, *et al*., 2013; Rawal, 2022).This may be a greater challenger to small holder farmers who may not afford to purchase these inputs. Similar findings were found by Hassanpanah and Azimi,(2012) who noted that corn yield was increased by 35% when combined (inorganic and organic) nutrients were applied. Combined application of organic and inorganic nutrient sources enhanced synergism and synchronization between nutrient release and plant recovery thus resulting in better crop performance and yield. Poor crop performance (Huang, Weijian, Yu, & Huang, 2010; Hoque,2022) was however observed on control treatment compared to manure and *Mavuno* treated plots. This translated into low grain yields of control plot indicating low nutrient contents of these soils and the need for appropriate soil nutrient approaches to these soils in order to ensure their productivity. FYM being a balanced nutrient source and the micronutrients in *Mavuno* (Table 3) increases P availability and crop nutrient use efficiency (Nziguheba *et al*., 2016). Tiamiyu *et al.* (2012; Rawal,2022) reported that higher yield response of crops due to organic manure application could be attributed to improved physical and biological properties of the soil resulting in better supply of nutrients to the plants. Organic inputs alone are often insufficient to maintain nutrient balances in resource poor farming systems, because of the limited availability of nutrient-rich organic matter (e.g., manures and compost) and overall lack of nutrients in the system. The combined application of organic inputs and mineral micronutrient fertilizers has the potential to alleviate overall micronutrient shortage. Besides, agronomic efficiency of mineral fertilizers is often increased when applied in combination with organic matter (Vanlauwe *et al.*, 2015; Hijbeek,2021) Application of got manure to P-fixing soils in South Africa was reported to have reduced the sorption of added P and this effect was largely attributed to the liming potential of goat manure (Gichangi& Mnkeni, 2009; Johan, 2021).In their studies (Zhang *et al.*, 2016 & Schroder, 2014; Aryal, 2021), noted that inorganic fertilizers have negative environmental effect if not well managed. The use of inorganic fertilizers has been observed to cause the destruction of soil texture and structure, which often leads to soil erosion and acidity as a result of the leaching effect of nutrients. All these give rise to reduced crop yields as a result of soil degradation and nutrients imbalance (Zhang *et al.*, 2016, Mishra, 2022).These findings are in agreement with the reported results obtained in the present study which realized poor crop performance on Mavuno fertilizer alone as reflected on poor crop performance. The same harmful effect from Mavuno fertilizer applications alone on soil properties are reflected on the low levels of % soil organic carbon and low levels of % soil N (Table 5) for both Busia and Teso study sites. The negative effects from Mavuno fertilizer applied alone could have contributed to the low crop yield that were obtained from the treatment compared to other treatments in Busia and Teso study site in the present study. There were general increases in sorghum grain yields harvested in (2017 LR) across all the treatments applied during the first (2016 SR) cropping season in both Busia and Teso sites. The highest yields (2.28 t ha-^{1}) were observed from plots that received Mavuno fertilizer in Busia site. For Teso site the highest (2.86tha-^{1}) sorghum grain yields came from the plots applied with (FYM+Mavuno). These were followed by FYM and (FYM+Mavuno) with equal yields of 2.17 t ha^{-1} from each for Busia site. And for Teso site there was (2.79 and 2.76) tha-^{1} from FYM and Mavuno respectively. The least residual effects on sorghum yields came from the control plots with 1.89 and 1.65 t ha-^{1} from Busia and Teso sites, respectively. All the yields from the residual (2017 LR) from all the treatments were higher than the first (2016 SR) season as observed from Figure 1. The residual effect of 26 kg P ha^{-1}inorganic P in FYM resulted in a significantly higher grain yield of sorghum grain in 2017 LR. However, doses of organic amendments did not significantly increase yields with great margins in the same (2016SR) current season treatments of application. However, in 2017 LR, the residual effect of Mavuno, FYM and their combination application resulted in a tremendous yield increase of the subsequent sorghum crop. The combination of chemical and organic fertilizers allows for immediate and long-term nutrient availability that benefit the crop in the subsequent seasons. This was possibly due to continues supply of nitrogen, phosphorus and other nutrients (not reported in this study) to the crop at early stage and through organic manure (FYM) at later stages of growth as slow-release plant nutrients. Similar findings were reported by Sunil Kumar *et al.*, (2014). Interestingly, the sorghum crop without fertilizer application significantly increased the yield of crop on the control plots in 2017 LR. The sorghum yields showed that the yield of sorghum increased by 377.14, 82.4, 76.94, and 60% under control, Mavuno, FYM and Mavuno + FYM for Busia site respectively when harvested in 2017 LR following 2016 SR material applications. The sorghum yield increases were: 373.2, 152.0, 94.0, 84.74 and 72.67% under control, Mavuno, FYM and Mavuno+ FYM for Teso sites respectively.

IV. CONCLUSIONS

Low soil fertility is one of the main challenges affecting the efforts made toward achieving surplus food for an ever-escalating population, particularly in Kenya. Continuous cropping on the other hand with reliance on chemical fertilizer sources is among the causes of the gradual soil fertility depletion. However, the integrated use of organic and inorganic fertilizer sources could help to avert such soil fertility related problems and lead to soil fertility improvement. Furthermore, this can increase the production and productivity of continuously-grown crops and hence address the food security problem.

REFERENCES

[1] Abera, T., Semu, E., Debele, T., Wegary, D., & Kim, H. (2015). Nutrient Status of Soils from Farmers'Maize Fields in Mid Altitude Areas of Western Ethiopia. Agric. Sci. Soil SciMerit Res. J, 3, 113–121.

[2] Abuom, P., Nyambega, L., & Ouma, G. (2014). Effect of Mavuno Phosphorus-Based Fertilizer and Manure Application on Maize Grain and Stover Yields in Western Kenya. Journal of Environment and Earth Science.

[3] Ademba JS, Kwach, JK Esilaba AO and. Ngari SM (2015).The Effects of Phosphate Fertilizers and Manure on Maize Yields in SouthWestern Kenya. East African Agric.For. J. 81(1):1-11.

[4] AGRA. (2021). Africa Agriculture Status Report. A Decade of Action: Building Sustainable and Resilient Food Systems in Africa (Issue 9). Nairobi, Kenya: Alliance for a Green Revolution in Africa (AGRA).

[5] Andiku Charles, Hussein Shimelis, Mark Laing, Admire Isaac Tichafa Shayanowako, Michael Adrogu Ugen, Eric Manyasa & Chris Ojiewo (2021) Assessment of sorghum production constraints and farmer preferences for sorghum variety in Uganda: implications for nutritional quality breeding, Acta Agriculturae Scandinavica, Section B — Soil & Plant Science, 71:7, 620-632, DOI: 10.1080/09064710.2021.1944297.

[6] Aryal, J.P., Sapkota, T.B., Krupnik, T.J. *et al.(2021).* Factors affecting farmers' use of organic and inorganic fertilizers in South Asia. *Environ Sci Pollut Res* **28,** 51480–51496. https://doi.org/10.1007/s11356-021-13975-7

[7] Bayu, T.(2020). Review on contribution of integrated soil fertility management for climate change mitigation and agricultural sustainability. *Cogent Environmental Science* 6:1, 1823631. doi:10.1080/23311843.2020.1823631. [Taylor & Francis Online], [Web of Science ®], [Google Scholar]

[8] Bindraban, P.S., Dimkpa, C.O. & Pandey, R.(2020). Exploring phosphorus fertilizers and fertilization strategies for improved human and environmental health. *Biol Fertil Soils* **56,** 299–317. https://doi.org/10.1007/s00374-019-01430-2.

[9] Bjornlund, Henning, Andre van Rooyen, Jamie Pittock, Vibeke Bjornlund. (2021). Changing the development paradigm in African agricultural water management to resolve water and food challenges. Water International 0:0, pages 1-18.

[10] Bogaard, A.,Fraser,R., Heaton, T.H.E., Wallace, M., Vaiglova, P., Charles, M., Jones,G., Evershed, R.P.,Styring, A.K., Andersen, N.H., Arbogast, R.-M., Bartosiewicz,L., Gardeisen, A., Kanstrup, M., Maier, U., Marinova, E., Ninov, L., Schäfer, M. & Stephan, E.(2013).Crop manuring and intensive land management by Europe's first farmers.*Proceedings of the National Academy of Sciences*, 110(31): 12589–12594.

[11] Brady, N. C. and Weil, R. R. (2008). The Nature and Properties of Soils (14th ed) 992p. Prentice-Hall Inc. New Jersey, USA.

[12] Bhanwaria, Rajendra, Bikarma Singh, and Carmelo M. Musarella. (2022). "Effect of Organic Manure and Moisture Regimes on Soil Physiochemical Properties, Microbial Biomass Cmic:Nmic:Pmic Turnover and Yield of Mustard Grains in Arid Climate" Plants 11, no. 6:722. https://doi.org/10.3390/plants11060722

[13] Devi, K. N., Singh, T. B., Athokpam, H. S., Singh, N. B. and Shamurailatpam, D.(2013). Influence of inorganic, biological and organic manures on nodulation and yield of soybean (*Glycine max* Merril L.) and soil properties. *Austra. J. Crop Sci.*,7(9):1407- 1415.

[14] Ducousso-Détrez, A.; Fontaine, J.; Lounès-Hadj Sahraoui,A.; Hijri, M.(2022). Diversity of Phosphate Chemical Forms in Soils and Their Contributions on Soil Microbial Community Structure Changes. Microorganisms, 10, 609.https://doi.org/10.3390/ microorganisms10030609

[15] Elkhalifa AEO (2012). Fermented sorghum foods. In: Vázquez M, Ramírez de León JA (eds) Food energy source. Nova Science Publishers, pp 167–193

[16] Fertilizer Use Recommendation Project (FURP) (1997). Description of the first priority sites. Phase 1.Final report Annex iii.Ministry of Agriculture Kenya in co-operation the German Agency for International Co-operation.Nairobi, Kenya.

[17] Gichangi, E. M., & Mnkeni, P. N. S. (2009). Effects of Goat Manures and Lime Addition on Phosphate Sorption by Two Soils from Transkei region, South Africa Communications in Soil Science Plant Analysis, 40:3335-3347.

[18] Gizaw Desta, Tibebu Kassawmar, Matebu Tadesse, Gete Zeleke. (2021). Extent and distribution of surface soil acidity in the rainfed areas of Ethiopia. Land Degradation & Development 32:18,pages5348-5359. Crossref

[19] Government of Kenya (GoK) (2014). Soil suitability evaluation for maize production in Kenya. A report by National accelerated Agricultural Inputs Access Programme (NAAIAP) in collaboration with Kenya Agricultural Research Institute (KARI), Department of Kenya Soil Survey, February 2014. Available at: http://kenya.soilhealthconsortia.org/?wpfb_dl=3

[20] Gross, Arthur, Tobias Bromm, and Bruno Glaser. 2021. "Soil Organic Carbon Sequestration after Biochar Application: A Global Meta-Analysis" Agronomy 11, no. 12: 2474. https://doi.org/10.3390/agronomy11122474

[21] Guo L, Wu G, Li Y, Li C, Liu W, Meng J, Liu H, You X, Jiang G. (2016). Effects of cattle manure compost combined with chemical fertiliser on topsoil organic matter, bulk density and earthworm activity in a wheat-maize rotation system in Eastern China. Soil and Tillage Research 156: 140-147.

[22] Hijbeek R, van Loon MP, ten Berge HFM, Gram G, Vonk W, Waldow L, van Ittersum MK. (2021). Efficiency of mineral and organic fertilizers across two continents. CCAFS Working Paper no. 397. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

[23] Havlin, J. L., Beaton, J. D., Tisdale, S. L., & Nelson, W. L. (2005). Soil fertility and fertilizers. An introduction to nutrient management (7th ed.). Pearson Prentice Hall, Upper Saddle River, NJ.

[24] Hoque, T.S.; Hasan, A.K.;Hasan, M.A.; Nahar, N.; Dey, D.K.; Mia, S.; Solaiman, Z.M.; Kader, M.A.(2022). Nutrient Release from Vermicompost under Anaerobic Conditions in Two Contrasting Soils of Bangladesh and Its Effect on Wetland Rice Crop. Agriculture 2022, 12, 376. https:// doi.org/10.3390/agriculture12030376

[25] Huang, S., Weijian, Z. W., Yu, X., & Huang, Q. (2010). Effects of Long-Term Fertilization on Corn Productivity and Its Sustainability in an Ultisol of southern China. Agri.Ecosyst. Environ. . 138: 44–50.

[26] Jayne TS, Rashid S (2013) Input subsidy programs in sub-Saharan Africa: a synthesis of recent evidence. Agric Econ 44:547–562.

[27] Johan, Prisca D., Osumanu H. Ahmed, Latifah Omar, and Nur A. Hasbullah. (2021). "Phosphorus Transformation in Soils Following Co-Application of Charcoal and Wood Ash" Agronomy 11, no. 10: 2010. https://doi.org/10.3390/agronomy11102010

[28] Jones, B., & Ljung, K. (2012). Subterranean space exploration: The development of root system architecture.Current Opinion in Plant Biology, 15, 97-102. http://dx.doi.org/10.1016/j.pbi.2011.10.003

[29] Kihara, J. et al. (2017). Agronomy for Sustainable Development 37: 25.

[30] Kome, G. , Enang, R. , Tabi, F. and Yerima, B. (2019). Influence of Clay Minerals on Some Soil Fertility Attributes: A Review. Open Journal of Soil Science, 9, 155-188. doi: 10.4236/ojss.2019.99010.

[31] Krasilnikov, P.; Taboada, M.A.; Amanullah. Fertilizer Use, Soil Health and Agricultural Sustainability. Agriculture 2022, 12, 462. https://doi.org/10.3390/ agriculture12040462.

[32] Krause, A.; Rotter, V.S.(2017). Linking energy-sanitation-agriculture: Intersectional. resource management in smallholder households in Tanzania. Sci. Total Environ. 2017, 590, 514–530. [CrossRef] [PubMed].

[33] Lembaid, I.; Moussadek, R.;Mrabet, R.; Bouhaouss, A.(2022). Modeling Soil Organic Carbon Changes under Alternative Climatic Scenarios and Soil Properties Using DNDC Model at a Semi-Arid Mediterranean Environment. Climate 2022, 10, 23. https://doi.org/10.3390/ cli10020023

[34] Li HG, Shen JB, Zhang FS, Marschner P, Cawthray G and Rengel Z.(2010). Phosphorus uptake and rhizosphere properties of intercropped and monocropped maize, faba bean, and white lupine acidic soil. Biology and Fertility of Soils, 46: 79–91.

[35] MairuraFranklin S, Collins M. Musafiri, Milka N. Kiboi, Joseph M. Macharia, Onesmus K. Ng'etich, Chris A. Shisanya, Jeremiah M. Okeyo, Elizabeth A. Okwuosa, Felix K. Ngetich,(2022). Farm factors influencing soil fertility management patterns in Upper Eastern Kenya,Environmental Challenges,Volume 6,100409,ISSN2667-0100, https://doi.org/10.1016/j.envc.2021.100409.(https://www.sciencedirect.com/science/article/pii/S2667010021003838)

[36] Mishra, P.K.; Rai, A.; Abdelrahman, K.; Rai, S.C.; Tiwari, A.(2022).Land Degradation, Overland Flow,Soil Erosion, and Nutrient Loss in the Eastern Himalayas, India. Land 2022,11, 179. https://doi.org/10.3390/land1102017

[37] Montanarella, L.; Pennock, D.J.; McKenzie, N.; Badraoui, M.; Chude, V.; Baptista, I.; Vargas, R. (2016) World's soils are under threat. SOIL, 2, 79–82. [CrossRef]

[38] Motsara, M.L.; Roy, R.N.(2008). Guide to Laboratory Establishment for Plant and Nutrients Analysis; FAO Fertilizer and Plant Nutrition Bulletin 19; Food and Agriculture Organization of the United Nations: New Delhi, India,

[39] Moyin-jesu EI. (2015). Use of different organic fertilizers on soil fertility improvement, growth and head yield parameters of cabbage (Brassica oleraceae L). International Journal of Recycling of Organic Waste in Agriculture 4(4), 291-298.

[40] Mwaura George G., Kiboi Milka N., Bett Eric K., Mugwe Jayne N., Muriuki Anne, Nicolay Gian, Ngetich Felix K. (2021).Adoption Intensity of Selected Organic-Based Soil Fertility Management Technologies in the Central Highlands of Kenya.Frontiers in Sustainable Food Systems

[41] Nana, A.S.; Falkenberg, T.;Rechenburg, A.; Adong, A.; Ayo, A.; Nbendah, P.; Borgemeister, C.Farming Practices and Disease Prevalence among Urban Lowland Farmers in Cameroon, Central Africa. Agriculture 2022, 12, 230. https://doi.org/10.3390/agriculture1202023.

[42] Ndambi, D.E. Pelster, J.O. Owino (2019).Manure management practices and policies in sub-Saharan Africa : implications on manure quality as a fertilizerFront. Sustain. Food Syst., 3(2019), pp. 1-14.

[43] Nezomba, H., Mtambanengwe, F., Tittonell, P. & Mapfumo, P.(2015). Point of no return? Rehabilitating degraded soils for increased crop productivity on smallholder farms in eastern Zimbabwe. Geoderma, 239: 143–155.

[44] Njira K, Nalivata PC, Kanyama-phiri GY, Lowole MW. (2012). Biological nitrogen fixation in sole and doubled-up legume cropping systems on the sandy soils of Kasungu, Central Malawi. Journal of Soil Science and Environmental Management 3(9), 224-230 .

[45] Nziguheba, G.; Zingore, S.; Kihara, J.; Merckx, R.; Njoroge, S.; Vanlauwe,B.(2016). Phosphorus in smallholder farming systems of sub-Saharan Africa: Implications for agricultural intensification. Nutr. Cycl. Agroecosys., 104, 321–340. [CrossRef].

[46] Ochola, R. O., &Fengying, N. I. E. (2015). Evaluating the effects of fertilizer subsidy programmes on vulnerable farmers in Kenya. Journal of Agricultural Extension and Rural Development, 7(6), 192-201

[47] Ojiem JO, Palm CA, Okwosa EA, Mudeheri MA (2004). Effect of combining organic and inorganicP sources on maize grain yield in a humicnitisolinWestern Kenya. In A. Bationo (Ed.), Managing nutrientcycles to sustain soil fertility in sub-Saharan Africa. Academy Sciences Publishers, Nairobi, Kenya. pp. 346-356.

[48] Okalebo, J. R., Gathua, K. W. & Woomer, P. L. J. (2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual (2nd Edition). Nairobi, Kenya. Marvel EPZ K Ltd

[49] Okalebo, J. R., Othieno, C. O., Woomer, P. L., Karana, N. K., Semoka, J. R. M., Bekunda, M. A., et al. (2006). Available technologies to replenish soil fertility in East Africa. Nutrient Cycling in Agriecosystems, 76:153-170.

[50] Okeyo Samuel O. , Samuel N. Ndirangu, Hezron N. Isaboke, Lucy K. Njeru, Jane A. Omenda, (2020).Analysis of the determinants of farmer participation in sorghum farming among small-scale farmers in Siaya County, Kenya, Scientific African, Volume 10, e00559,ISSN 2468 2276,https://doi.org/10.1016/j.sciaf.2020.e00559. (https://www.sciencedirect.com/science/article/pii/S2468227620302970)

[51] Palm, C.A., R.J.K. Myers, and S.M. Nandwa. (1997). Combine use of organic and inorganic nutrients source forsoil fertility maintenance and replenishment. In: Buresh, R.J., P.A.Sanchez and F.

[52] Qureshi, J.N.,(1991). The cumulative effects of N±P fertilizers, manure and crop residues on maize and some soil chemical properties at Kabete. In: Recent Advances in KARI' ResearchProgrammes. Kenya Agricultural Research Institute, Nairobi, pp. 160±16.

[53] Rawal N, Pande KR, Shrestha R, Vista SP (2022).Nutrient use efficiency (NUE) of wheat (Triticum aestivum L.) as affected by NPK fertilization. PLoS ONE 17(1): e0262771. https://doi.org/10.1371/journal.pone.0262771.

[54] Ricker-Gilbert, J. (2020). Inorganic Fertiliser Use Among Smallholder Farmers in Sub-Saharan Africa: Implications for Input Subsidy Policies. In: Gomez y Paloma, S., Riesgo, L., Louhichi, K. (eds) The Role of Smallholder Farms in Food and Nutrition Security. Springer, Cham. https://doi.org/10.1007/978-3-030-42148-9_5.

[55] Schoebitz, M., Vidal G. (2016). Microbial consortiumand pig slurry to improve chemical properties of degraded soil and nutrient plant uptake. J. SoilSci. Plant Nutr. 16 (1), 226-236.

[56] Schröder JJ. (2014). The position of mineral nitrogen fertilizer in efficient use of nitrogen and land: a review. Natural resources 5(15), 936-948.

[57] Smaling EMA, Stoorvogel JJ Windmeijer PN (1993). Calculating soil nutrient balances in Africa in different scales: II. District scale. Fert. Res. 35:237-250.

[58] Stewart, Z.P., Pierzynski, G.M., Middendorf, B.J., Vara Prasad, P.V., (2020). Approaches to improve soil fertility in sub-Saharan Africa. J. Exp. Bot. 71, 632–641.

[59] Sunilkumar, K., Gowda, A., Nagaraj, R., Veeranagappa, P. Jayaprakash, R. and Patil, S. (2014). Influence of integrated nutrient management on growth, yield, nutrient uptake and economics of vegetable soybean. Intern. J. For. Crop Impro., 4(1): 24-27.

[60] Thuita, M., Vanlauwe, B., Mutegi, E., & Masso, C. (2018). Reducing spatial variability of soybean response to rhizobia inoculants in farms of variable soil fertility in Siaya County of western Kenya.Agriculture, ecosystems & environment, 261, 153–160. https://doi.org/10.1016/j.agee.2018.01.007.

[61] Tiamiyu, R.A., H.G. Ahmed, and A.S. Muhammad (2012). "Effect of Sources of Organic Manure on Growth and Yields of Okra (Abelmoschus esculentus L.) in Sokoto, Nigeria." Nigerian Journal of Basic and Applied Science 20 (3): 213-216.

[62] Useviˇci ̄ut ̇e , L.;Baltr ̇enait ̇e-Gedien ̇e , E.; Feizien ̇e , D.(2022).The Combined Effect of Biochar and Mineral Fertilizer on Triticale Yield, Soil Properties under Different Tillage Systems. Plants , 11, 111. https://doi.org/10.3390/plants11010111

[63] Vanlauwe B, Descheemaeker K, Giller KE, Huising J, Merckx R, Nziguheba G, Wendt J. (2015). Integrated soil fertility management in sub-Saharan Africa: unravelling local adaptation 491-508.

[64] Wali, F.; Sardar, S.; Naveed,M.; Asif, M.; Nezhad, M.T.K.; Baig, K.S.; Bashir, M.; Mustafa, A. (2022).Effect of Consecutive Application of Phosphorus-Enriched Biochar with Different Levels of P on Growth Performance of Maize for Two Successive

Growing Seasons. Sustainability 2022, 14, 1987. https://doi.org/10.3390/su14041987.

[65] Wawire, A.W., Csorba, A., Toth, J.A., Mich_eli, E.,(2020). Integration of manure and mineral fertilizers among smallholder farmers in Kenya: a pathway to sustainable soil fertility management and agricultural intensification. Int. J. Agric. Ext. Rural Dev.Stud. 7, 1–20.