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Effect of *Mavuno* Phosphorus-Based Fertilizer and Manure Application on Maize Grain and Stover Yields in Western Kenya

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Abstract

Low crop productivity in western Kenya can be attributed to low soil fertility and limited use of organic and inorganic fertilizers. This is attributed to high costs of fertilizer, inconsistent application and duration of use. Efforts to improve and maintain soil productivity through use of manure and fertilizer among others has been ongoing in western Kenya for years. Despite these efforts low crop yield associated with limited use of common compound fertilizers is still prevalent. Remarkable increases in yield have been noted with compound fertilizers which offer additional benefits in terms of nutrient supply. *Mavuno* a locally blended fertilizer promoted in western Kenya offers such benefits. The objective of this study was to evaluate the effect of *mavuno* phosphorus-based fertilizer and manure on maize and stover yields in Nyalgunga, Nyabeda and Emusutwi sub-locations, western Kenya; where low soil fertility, coupled particularly with low available phosphorus has been pointed out as the major factor limiting crop productivity. The study was carried out on fields where *mavuno* fertilizer at 20kg P ha^{-1} and manure at 2t ha^{-1} has been applied for six years. A randomized block design was used and maize grain and stover yields calculated from the four treatment fields; control (no input), manure (2t ha^{-1}), *mavuno* (20kg P ha^{-1}) and manure (2t ha^{-1}) + *mavuno* (20kg P ha^{-1}). There was a remarkable increase in maize grain yield (control 904 kg ha $^{-1}$, manure+ *mavuno* 2238 kg ha $^{-1}$) a 148% increase in yield above control plot ($p=<0.001$) and stover yield (control 825 kg ha $^{-1}$, manure+*mavuno* 1381 kg ha $^{-1}$) a 67% increase above control plot ($p=<0.001$). *Mavuno* phosphorus-based fertilizer and manure have a positive effect on maize grain and stover yield and can sustain soil productivity under long term use, their application in soils improves availability of phosphorus to plants resulting in high yields and improved soil properties. Understanding the effect of continuous application of phosphorus-based fertilizers and manure is essential for sustaining soil productivity among small holder farms of western Kenya to meet the high food demand, which is currently forcing farmers to continuously grow maize on the same piece of land resulting to soil degradation.

Keywords: *Mavuno*, manure, Maize grain yield, Maize stover and Western Kenya

1. Introduction

Sub-Saharan Africa is faced with declining per capita food production mainly attributed to soil fertility depletion in small holder farms. An average of 660kg N ha^{-1}, 75kg P ha^{-1} and 450kg K ha^{-1} has been lost in the past 3 decades from about 200 million ha of cultivated land in 37 African countries; Kenya included (Hoeskstra and Corbert, 1995). Majority of rural households living in western Kenya are currently facing food insecurity caused mainly by declining production of maize and other food crops in the region. Farmers identify declining soil fertility and high fertilizer costs among others as the causal factors of low crop productivity, a fact supported by results of many studies conducted in the area (Smaling, 1997). Declining soil fertility and in particular low levels of soil phosphorus (P) and nitrogen (N) in western Kenya is largely attributed to the current land pressure resulting from increased human population that is forcing farmers to cultivate crops on the same piece of land continuously with little or no addition of inorganic and organic fertilizers. This is coupled with the removal of above ground crop residues subsequently used as cattle fodder, fencing material, or cooking fuel. This results in 100% removal of the P accumulated by crops for human nutrition (Vanlauwe, *et al*., 2004; Sanchez, 1976; Sanchez & Benites, 1987). According to Chien et al., (2011) Phosphorus, a major macronutrient, can limit normal plant growth if not applied at the proper time and right amount. It must be applied as either organic or inorganic forms for optimal crop production in deficit soils low in available P.

In most soils of western Kenya, P is one of the nutrients (after nitrogen) reported to limit crop production as its availability is very low. This is largely because soils in this region have naturally low P reserves and the little which is applied is easily fixed due to prevalence of higher levels of Aluminum (Al) and Iron (Fe) oxides that form complexes with P (Kifuko *et al.*, 2007). Most soils in the tropical region including western Kenya are acidic, predominantly ferralsols and acrisols. These soils have a greater ability to fix phosphate because of their characteristically high Fe and Al content, which causes considerable immobilization of any fertilizer P applied to these soils. Therefore, regular P fertilizer applications are required to maintain an adequate supply of plant-available P (Chien et al., 2011). Research with acrisols and ferralsols in western Kenya has shown that soil P replenishment using seasonal additions of small rates of P and organic manure could be attractive to small-scale farmers. For example, seasonal additions of P to the tune of 20-25 kg ha^{-1} increased maize grain yield to 1.5 t ha^{-1} compared to 0.7 t ha^{-1} that was obtained from unfertilized fields (Nemery and Gramier, 2007). Mavuno fertilizer (10%N, 26%P_2O_5, 10%K_2O, 4%S, 8%CaO, 4%MgO and traces of B, Zn, Mo, Cu and Mn) is one of the P-based fertilizers currently gaining popularity in the region and can offset P deficiency and improve crop yield.

There is undisputable need to correct deficiency of soil P in Africa, yet many small holder farmers in western Kenya lack financial resources to purchase sufficient fertilizers to either correct inherent low levels of P or replace the P exported with harvested products (World Bank, 1994; Sanchez *et al.*, 1996, 1997). Numerous studies have shown that P fertilizers including phosphate rock (PR) and soluble sources such as triple super phosphate (TSP), single super phosphate (SSP) and ammonium phosphates can singly increase soil productivity (Wild, 1973; Le Mare, 1984; Sale & Mokwunye, 1993). Relative small seasonal application of soluble P fertilizer can mitigate P deficiency in soils with low to moderate P sorption capacity, but large rates of P soluble fertilizers are required for soils with higher P sorption capacity (Koech, 2008).

Field trials in Kirinyaga showed that *mavuno* fertilizer increased yields by 178% from 1.9 to 5.3 t ha^{-1} H513 and 51% from 3.5 to 5.3 t ha^{-1} for WS403 (Fips Africa, 2004). Relatively small rates of P fertilizer (10-25kg p ha^{-1}) particularly when mixed with soil in the planting hole can be financially attractive on moderate P-fixing soils (Jama *et al.*, 1997) in the highlands of East Africa.

Phosphorus availability to plants is controlled mainly by soil pH, soluble Al, Fe, Ca, and organic matter content (Chien et al., 2011). Organic manure can improve productivity of degraded soils in a number of ways; it increases Cation Exchange Capacity (CEC) especially of light textured soils, and water holding capacity. During its oxidation P among other nutrients are released and may become plant available (Giller and Wilson, 1991). Organic materials have the potential to increase the availability of P capital, application of 6t dry matter ha^{-1} of organic matter containing 3g P kg^{-1} can provide 18kg P ha^{-1} to sustain a 2 t ha^{-1} maize crop (Palm, 1995). According to Palm *et al., (*1997) organic materials are restricted by the limited supply at farming level, making gradual build up through small seasonal additions as the viable option. Sufficient quantities of P-rich organic materials to meet the P requirements are simply not available at the farm level under smallholder farms therefore integrated use of inorganic P fertilizer sources with available organic materials is required to arrest and correct the depletion of soil P fertility and SOC occurring in many soils of Africa (Palm *et al.*, 1997). According to Jama *et al.*, (1997) relatively small rates of P fertilizer (10 to 25kg P ha^{-1}) particularly when mixed with soils in the planting hole can increase crop yield and be financially attractive on moderately P fixing soils in the highlands of East Africa. Phosphorus (P) is crucial to life and is an essential major nutrient for plant growth and root development, because of its role in increasing yield and improving crop quality. The crop recovery of added P ranges from 10% to 40% (Aulakh *et al.*, 1991).

Seasonal applications of P for gradual correction of P deficiency on soils with low to moderate P-sorption capacity will eventually result in greater build up of capital P (Cox *et al.*, 1981), and greater crop yields than a large, one time application of P. Gradual build up of soil P capital, however, will provide less immediate and cumulative crop yields than a relatively large corrective P application with subsequent maintenance application of P on moderate and high P-fixing soils (Rajan *et al.*, 1996). Existing knowledge on immediate and residual effects of P fertilizer (Jama *et al.*, 1997) suggests that the gradual build up of soil P with seasonal applications of P can economically increase soil productivity with a large crop responses to relatively moderate P rates (10 to 20 kg P ha^{-1}). Despite knowledge on soil fertility depletion and the need for P fertilizers, many small holder farmers in Africa have not adopted seasonal applications of sufficient P for the mitigation of soil P depletion. Economic, policy, and infrastructural factors have constrained the use of all fertilizers, including P fertilizer. This study investigated if there is significant effect of *mavuno* phosphorus-based fertilizer and manure on maize yield on degraded soils of western Kenya with successive seasonal application.

2. Materials and methods

This study was conducted in western Kenya at Emusutswi in Vihiga County located between latitude N0^{o} 07' 39.1 and longitude E034^{o} 40' 17.2) and receives a bimodal rainfall of 1000 - 1800mm, and average altitude of 1500m.The annual average temperature is about 22.5°C a relatively high humidity. Population density is about 500 people per square km, with an average of 8.25 persons per household; the average land ownership stands at 0.19ha per household. In Siaya County the study was conducted at Nyabeda located between latitude N0$^{°}$ 04′50.1, and longitude E034$^{°}$ 18′21.8 and at Nyalgunga located between latitude N0$^{°}$ 08′01.2, and longitude E034$^{°}$ 24′17.5, Siaya receives a bimodal annual rainfall of 800 - 1600mm (Rao *et al.*, 1999). The soils are developed mostly on basic igneous rocks and granites (Sombroek *et al.*, 1982). The soils are deep, well drained clay loam to sandy texture with low levels of available Phosphorus, Nitrogen and soil carbon (Jaetzold and Schmidt, 1982, Rao *et al*., 1999). The annual average temperature is about 21.5°C. Population density is about 188 people per square km, with an average of 5.25 persons per household; the average land ownership stands at 0.39ha per household.

The study was carried on randomizely selected fields from three sub-locations of western Kenya on plots measuring 25m^2 each which had received *mavuno* fertilizer rate of 20kg P ha^{-1} (375g) per plot, and or organic manure applied at 2t ha^{-1} (10kg) dry manure per 25m^2 and a control plot which had not received any input to determine their effect on maize grain and stover yield. The study was replicated at sub-location level with four fields in Nyabeda, four in Emusutswi and three in Nyalgunga.

2.1 Study design

A randomized experimental design was used to study the effect of *mavuno* phosphorus based fertilizer and manure on maize and strover yield in western Kenya where low phosphorus has been pointed out as the major factor limiting crop productivity. The study investigated changes in maize yield following continuous application of *mavuno* phosphorus based fertilizer and manure by sampling and analyzing three season's maize yield data on plots measuring 25m2 each which had received *mavuno* phosphorus fertilizer rate of 20kg P ha^{-1} (375g) per plot banded in planting furrows at 10 cm depth, and/or organic manure applied at 2t ha^{-1} (10kg) dry manure per 25m^2 plots in planting furrows.

2.2 Experimental treatments

Mavuno planting fertilizer is phosphorus based compound fertilizer blended by Athi-River Mining Cooperation to enhance plant growth and comprises (10%N, 26%P2O5, 10%K2O, 4%S, 8%CaO, 4%MgO and traces of B, Zn, Mo, Cu, Mn) while IR maize is a herbicide coated maize to combat parasitic cereal weed *Striga hermonthica*, suitable in striga prone areas of western Kenya. Four treatment plots comprising control, manure, manure+*mavuno* and *mavuno* all planted with herbicide coated maize (IR maize) were considered in this study to assess the effect on maize grain and stover yield.

2.3 Maize yields assessment

Maize grain and stover yield data for three seasons, harvested from net plots of 7.08m^2 calculated by leaving out the outer rows and end plants of each row of a 12.5m^2 plot were used to calculate biomass and grain yield to get an indication of P on maize productivity. The treatments were randomized within the field and replicated at household level and maize harvested at physiological maturity and grain yield calculated at 12% moisture content. Plants from the effective area were counted and cob removed from the husks in the standing plants. The cobs were counted and put in labeled bags and their fresh weight taken. Six cobs were sub-sampled and their fresh weights taken. The maize stover was then harvested at ground level from each plot, their fresh weights taken with a weighing scale to 1 decimal place. Four maize stems were randomly selected and chopped into small pieces. The maize stover sub-samples were oven-dried at 70^{0}C for 48 hours and dry weights taken. The difference between the dry weights and fresh weights was used as a conversion factor for determining the dry grain and stover yields on a hectare basis.

2.4 Statistical data analysis

Data was analyzed using the Statistical Analysis Systems (SAS) package. One way Analysis of variance (ANOVA) was performed to test for significant difference in maize grain and stover yield among different experimental treatments. The statistical analysis was based on maize yield data collected at physiological maturity in Emusutswi, Nyabeda and Nyalgunga. Treatments means were compared between sites and within treatments. Mean separation was done using Duncan Multiple Range Test (DMRT) to determine treatment differences (Mead and Curnow, 1983; Gomez and Gomez, 1984). Using SAS at 95% confidence interval (P=0.05) and means separated by DMRT, mean maize and stover yield (Kg ha^{-1}) data for the three sites were also analyzed and tested for significance to evaluate if they are influenced by *mavuno* phosphorus-based fertilizer and manure application. .

3. Results

Maize grain and stover yield was significantly increased by more than 100% following application of *mavuno* phosphorus-based fertilizer and manure ($P \leq 0.01$).

3.1 Effect of treatments on maize grain yield

The mean maize grain yield data for the three sites are given in Table 1. Control plot had a mean maize grain yield of 903.7±745.9 Kg ha^{-1} with Nyalgunga having the highest mean grain yield of 1168.5±903.7 Kg ha^{-1}

followed by Nyabeda 1113.5±702.4 Kg ha^{-1} and Emusutswi the lowest mean maize grain yield of 344.9±411.5 Kg ha^{-1}. Manure plot (2t ha^{-1}) had a mean grain yield of 1710.3±1189.7 Kg ha^{-1} with Nyabeda having the highest mean maize grain yield of 1998.7±958.1 Kg ha^{-1} followed by Nyalgunga 1940.2±1634.4 Kg ha^{-1} and Emusutswi the lowest yield of 1249.6±944.0 Kg ha^{-1}. Manure+*mavuno* plot (manure 2t ha^{-1} + *mavuno* 20Kg P ha^{-1}) had a mean maize grain yield of 2238.2±1348.3 Kg ha^{-1} with Nyalgunga having the highest mean grain yield of 2758.2±1736.7 Kg ha^{-1} followed by Nyabeda 2092.7±940.8 Kg ha^{-1} and Emusutswi the lowest yield of 1993.7±1378.5 Kg ha^{-1}. While, *mavuno* plot (20Kg P ha^{-1}) had a mean maize grain yield of 2162.0±1209.4 Kg ha^{-1} with Nyalgunga having the highest mean grain yield of 3006.4±949.1 Kg ha^{-1} followed by Nyabeda 2287.2±1132.5 Kg ha^{-1} and Emusutswi the lowest yield of 1223.2±1023.4 Kg ha^{-1}.

Considering mean maize grain yield for each sub location separately, in Emusutswi control plot had the lowest grain yield of 344.9±411.5 Kg ha^{-1} while manure+*mavuno* plot (manure 2t ha^{-1} + *mavuno* 20Kg P ha^{-1}) gave the highest yield of 1993.7±1378.5 Kg ha^{-1}. Manure and *mavuno* plots gave grain yields of 1249.6±944.0 Kg ha^{-1} and 1223.2±1023.4 Kg ha^{-1} respectively. There was a significant difference between treatments in Emusutswi (One-Way ANOVA, $F_{(3,47)} = 5.54$, P=0.0028), with Duncan Multiple Range Test (DMRT) further showing that the control plot was significantly different from the rest of the treatments. In Nyabeda control plot had the lowest mean grain yield of 1113.5±702.4 Kg ha^{-1} while *mavuno* plot (20Kg P ha^{-1}) had the the highest mean grain yield of 2287.2±1132.5 Kg ha^{-1}. Manure (2t ha^{-1}) and manure+*mavuno* plots (manure 2t ha^{-1} + *mavuno* 20Kg P ha^{-1}) gave grain yields of 1998.7±958.1 Kg ha^{-1} and 2092.7±940.8 Kg ha^{-1} respectively. There was a significant difference between treatments in Nyabeda (One-Way ANOVA, $F_{(3,47)} = 3.63$, P= 0.019), with Duncan Multiple Range Test (DMRT) further showing that the control plot differed significantly from the rest of the treatments.

In Nyalgunga sub location, where most farmers have not started using inorganic fertilizers, control plot had the lowest mean grain yield of 1168.5±903.7 Kg ha^{-1} while *mavuno* plot (20Kg P ha^{-1}) had the the highest mean grain yield of 3006.4±949.1 Kg ha^{-1}. Manure (2t ha^{-1}) and manure+*mavuno* plots (manure 2t ha^{-1} + *mavuno* 20Kg P ha^{-1}) gave grain yields of 1940.2±1634.4 Kg ha^{-1} and 2758.2±1736.7 Kg ha^{-1} respectively. There was a significant difference between treatments in Nyalgunga (One-Way ANOVA, $F_{(3,\ 35)} = 3.39$, P =0.029), with Duncan Multiple Range Test (DMRT) further showing that the control plot differed significantly from manure+mavuno and mavuno but not manure treatments, while manure plot did not significantly differ from manure+*mavuno* and *mavuno* treated plots.

A combination of manure (2t ha^{-1}) and *mavuno* (20Kg P ha^{-1}) raised maize grain yields by 1334.5 kg ha^{-1} a 147.7% increase compared to 903.75±754.9Kg ha^{-1} recorded at the control plots across all the three sub-locations combined.

Table 1. Effect of treatments on maize grain yield (Kg ha^{-1})

	Maize grain yield (Mean±SD) Kg ha^{-1}			
	Emusutswi N=48	Nyabeda N= 48	Nyalgunga N=36	Mean
Control	344.9±411.5^{B}	1113,5±702.4^{B}	1168.5±903.7^{B}	903.7±754.9 ^{B}
Manure	1249.6±944^{A}	1998.7±958.1^{A}	1940.2±1634.4^{AB}	1710.3±1189.7 ^{A}
Manure + Mavuno	1993.7±1378.5^{A}	2092.7±940.8^{A}	2758.2±1736.7^{A}	2238.2±1348.3 ^{A}
Mavuno	1223.2±1023.4^{A}	2287.2±1132.5^{A}	3006.4±949.1^{A}	2162.0±1209.4 ^{A}
Mean	1283.0±1126.4^{B}	1873.0±1022.3^{A}	2318.3±1493.5^{A}	

Means with the same superscript within the column are not significantly different (DMRT)

There were significant differences in mean maize grain yield for all sub-locations (One-Way ANOVA, $F_{(3,129)} =$ 8.92, P< 0.0001), with control plot recording the lowest maize grain yield (903.8±754.9 Kg ha^{-1}), while manure+ *mavuno* plot recording the highest yield (2238.2±1348 Kg ha^{-1}). DMRT further established that maize grain yield in the control plot differed significantly from other treatments. The study further showed that there was significant difference in mean maize grain yield between sub-locations (One-Way ANOVA, $F_{(2,131)} = 5.88$, P= 0.0042), with DMRT further showing that Emusutswi was significantly different from Nyabeda and Nyalgunga sub-locations. Emusutswi had the lowest mean grain yield of 1283.0±1126.4 Kg ha^{-1} while Nyalgunga the highest 2318.3±1493.5 Kg ha^{-1} and Nyabeda mean maize grain yield of 1873.0±1022.3 Kg ha^{-1}.

3.2 Effect of treatments on maize stover yield

The mean maize stover yield data for the three sites are given in Table 2. Control plot had a mean maize stover yield of 825.7±544.4 Kg ha^{-1} with Nyalgunga control plot having the highest mean stover yield of 997.5±619.7 Kg ha^{-1} followed by Nyabeda 985.8±432.7 Kg ha^{-1} and Emusutswi the lowest mean stover yield of 536.7±502.5 Kg ha^{-1}. Manure plot (2t ha^{-1}) had a mean stover yield of 1020.2±608.5 Kg ha^{-1} with Nyabeda having the highest mean stover yield of 1154.8±560.4 Kg ha^{-1} followed by Nyalgunga 1140.2±810.9 Kg ha^{-1} and Emusutswi the lowest stover yield of 790.6±445.3 Kg ha^{-1}. Manure+*mavuno* plot (manure 2t ha^{-1} + *mavuno* 20Kg P ha^{-1}) had a mean stover yield of 1381.0±728.4 Kg ha^{-1} with Nyalgunga having the highest mean stover yield of 1544.8±1096.5 Kg ha^{-1} followed by Nyabeda 1299.3±448.7 Kg ha^{-1} and Emusutswi the lowest stover yield of 1339.8±660.7 Kg ha^{-1}. While, *mavuno* applied plot (20Kg P ha^{-1}) had a mean stover yield of 1181.7±574.1 Kg ha^{-1} with Nyabeda having the highest mean stover yield of 1431.3±561.9 Kg ha^{-1} followed by Nyalgunga 1281.7±688.9 Kg ha^{-1} and Emusutswi the lowest stover yield of 785.6±409.9 Kg ha^{-1}.

Looking at mean maize stover yield for each sub location separately, in Emusutswi control plot had the lowest stover yield of 536.7±502.5 Kg ha^{-1} while manure+*mavuno* plot (manure 2t ha^{-1} + *mavuno* 20Kg P ha^{-1}) had the highest stover yield of 1339.8±660.7 Kg ha^{-1}. Manure and *mavuno* plots had stover yields of 795.6±445.3 Kg ha^{-1} and 785.6±409.9 Kg ha^{-1} respectively. There was a significant difference between treatments in Emusutswi (One-Way ANOVA, $F_{(3,47)}$ = 5.22, P= 0.036), with Duncan Multiple Range Test (DMRT) further showing that manure+*mavuno* plot differed significantly from the rest of the treatments and giving the highest stover yield.

In Nyabeda control plot had the lowest mean stover yield of 985.8±432.7 Kg ha^{-1} while *mavuno* plot (20Kg P ha^{-1}) had the the highest mean stover yield of 1431.3±561.9 Kg ha^{-1}. Manure (2t ha^{-1}) and manure+*mavuno* plots (manure 2t ha^{-1} + *mavuno* 20Kg P ha^{-1}) had stover yields of 1154.8±560.4 Kg ha^{-1} and 1299.3±448.7 Kg ha^{-1} respectively, however there was no significant difference between treatments in Nyabeda (P=0.175). While in Nyalgunga sub location, control plot had the lowest mean stover yield of 997.4±619.7 Kg ha^{-1} and manure+*mavuno* plot(manure 2t ha^{-1} + *mavuno* 20Kg P ha^{-1}) had the the highest mean stover yield of 1544.8±1096.5 Kg ha^{-1}. Manure (2t ha^{-1}) and *mavuno* plots (20Kg P ha^{-1}) had mean stover yields of 1140.2±810.9 Kg ha^{-1} and 1281.7±688.9 Kg ha^{-1} respectively, and just like in Nyabeda there was no significant difference between treatments in Nyalgunga sub location (P=0.5467).

Table 2. Effect of treatments on maize stover yield

Treatments	**Stover Yield (Kg/ha)** (Mean±SD)			
	Emusutswi N = 48	**Nyabeda N = 48**	**Nyalgunga N = 36**	**Mean**
Control	536.7±502.5^{B}	985.8±432.7^{A}	997.5±619.7^{A}	825.7±544.4^{C}
Manure	795.6±445.3^{B}	1154.8±560.4^{A}	1140.2±810.8^{A}	1020.2±608.5^{BC}
Manure + Mavuno	1339.8±660.7^{A}	1299.3±448.7^{A}	1544.8±1096.5^{A}	1381.0±728.4^{A}
Mavuno	785.6±409.9^{B}	1431.3±561.8^{A}	1281.7±688.9^{A}	1181.7±574.1^{AB}
Mean	882.4±564.5^{B}	1217.8±516.1^{A}	1241.0±814.5^{A}	

Means with the same superscript within the column are not significantly different (DMRT)

There was significant difference in mean maize stover yield between all treatments (One-Way ANOVA, $F_{(3,131)=}$ 4.28, P=0.0033), with control plot recording the lowest mean stover yield (825.7±544.4 Kg ha^{-1}) and manure+ *mavuno* plot recording the highest mean stover yield (1381.0±728.4 Kg ha^{-1}). The manure and *mavuno* treatment plots recorded 1020.2±608.5 Kg ha^{-1} and 1181.7± 574.1 Kg ha^{-1} of maize stover yield respectively. DMRT further established that maize stover yield in the control and manure plots differed significantly from stover yield *mavuno* and manure+*mavuno* plots. However there were no significant differences between control and manure plots, and also between *mavuno* and manure+*mavuno* plots. In addition, maize stover yield showed significant differences among sub-locations (One-Way ANOVA, $F_{(2,131)}$ = 4.65, P=0.0112), with DMRT further confirming that Emusutswi sub-location had significanlty lower (822.4±564.5 Kg ha^{-1}) maize stover yields than Nyabeda (1217.8±516.1 Kg ha^{-1}) and Nyalgunga (1241.1±814.5 Kg ha^{-1}).

4. Discussion

4.1 Effect of treatments on maize grain yield

Emusutswi exhibited the lowest yield compared to other sites under study.The low yields exhibited in Emusutswi can be linked to small land sizes which do not alow for crop rotation as maize is the preffered crop or natural regeneration through fallowing. Control plot had the lowest yield 344.9±411.5Kg ha $^{-1}$, while a combination of organic manure (2t ha^{-1}) + *mavuno* planting fertilizer (20Kg P ha^{-1}) gave the highest yield of 1993.7±1378.5Kg ha^{-1}, while manure and *mavuno* plots gave yields of 1259.6±944 Kg ha^{-1} and 1223.2±1023 Kg ha^{-1} respectively. This clearly indicates that application of manure and *mavuno* can greatly improve maize yield in Emusutswi. Manure and *mavuno* besides the direct benefit of nutrient supply, have an effect on soil properties which influence nutrient acquisition and plant growth (Palm *et al.*, 1997;). Poor maize growth was observed on control treament compared to treatment with both manure and *mavuno* treatments, which translated into low yield of control plot. Manure and the micronutrients in *mavuno* increseas P availability and use eefficiency (Nziguheba *et al.*, 1998; Ikerra *et al.*, 2006; Gachengo *et al.*, 1999).

In Nyabeda where land pressure is not yet high control plot yielded 1113.5±702.4kg ha^{-1}, manure plot 1998.7±958.1Kg ha^{-1} while *mavuno* and combined manure+*mavuno* yielded more than double control plot yield of 2287.2±1132.5 Kg ha^{-1} and 2092.7±940.8 Kg ha^{-1} respectively, an indication that P was limiting maize productivity. While in Nyalgunga where most farmers have not started using inorganic fertilizers, response to treatments were highest with control plot yielding 1168.5±903.7 Kg ha^{-1} which is more than double control yield in Emusutswi where land pressure and poulation is high, manure plot yielded 1940.2±1634.4 Kg ha^{-1}, combined manure and *mavuno* fertilizer yielded 2758.2±1736.7 Kg ha^{-1} and *mavuno* plot 3006.4±949.1 Kg ha^{-1}.

The high significant differences for all treatment across all sites ($p<0.001$) for mean grain yield is in agreement with a study by Qureshi (1991) which reported that organic and inorganic fertilizers when combined give maize grain yields above 4000 kg ha^{-1} with good crop husbandry whereas control plot gave only 462 kg ha^{-1}. 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. Farmyard manure (FYM) is a useful source of N, P, and K (Ghosh *et al.,* 2004: Sarwer *et al*., 2008). It normally contains all the trace elements needed by plants for growth. Manure at the rate of 2 t ha^{-1} significantly increased the average maize grain yields to 1249.6±944 Kg ha^{-1} compared to control 344.9±411.5 Kg ha^{-1} at Emusutswi. In Nyalgunga the increase was 772 kg ha^{-1} above control 1168.5±903.7 Kg ha^{-1} and Nyabeda 885 kg ha^{-1} above control 1113.5±702.4 Kg ha^{-1}. A cross all study sites addition of *mavuno* phosphorus based fertilizers resulted to doubling of maize grain yield compared to control plots. This was also observed by Qureshi, (1991) and Swift *et al*., (1994) in their previous studies. In Emusutswi application of *mavuno* resulted in a yield increase of 255% above control (control=344.9±411.5 Kg ha^{-1}, *mavuno*=1223.2±1023.4 Kg ha^{-1}); Nyabeda 105% above control (control=1113.5±702.4Kg ha^{-1}, *mavuno*=2287.2±1132.5 Kg ha^{-1}); and Nyalgunga 157% (control=1168.5±903.7 Kg ha^{-1}, *mavuno*=3006.4±949.1 Kg ha^{-1}). The ability of *mavuno* to improve soil properties like soil carbon, soil pH, soil bulk density among others contributes to a remarkable yield increase. Continuous croping without nutrient addition results in nutrient mining leading to low soil fertility as can be seen with control plots having the lowest mean grain yield across all sites studied.

4.2 Effect of treatments on maize stover yield

Just like maize grain yield, Emusutswi had low stover yield compared to other sites under study (control-536.7±502.5 Kg ha^{-1}, Manure-795.6±445.3 Kg ha^{-1}, *Mavuno*- 785.6±409.9 Kg ha^{-1} and combined manure and *mavuno*-1339.8±660.7 Kg ha^{-1}). This is attributed soil degradation common in small holder farms in the region caused by high population and limited land sizes prompting continuous farming on the same piece of land without fallow periods. Sanchez et al. (1997) reported soil fertility depleteion in small holder farms as the major cause of declining per-capita food production in Sub-Saharan Africa study area included. Work by Qureshi, (1987) also reported that in higly populated regions, maize yield can decline by about 30% in the absense of fertilizers and or manure application. This is consistent with the results in this study across all sites which shows low levels of maize stover (< 1t ha $^{-1}$) with significant treatment difference in Emusutwsi ($p=0.036$).

In Nyabeda site where land size is not limiting hence farmer are able to allow natural mineral accumulation through natural fallow and crop rotation, maize stover yield was relatively high, though not significant ($P=0.175$), (control- 985.8±432.7 Kg ha^{-1}, manure-1154.8±560.4 Kg ha^{-1}, *mavuno*- 1431.3±561.9 Kg ha^{-1} and manure+*mavuno*-1299.3±448.7 Kg ha^{-1}). The enhenced soil physical, chemical and biological properties following addition of *mavuno* phosphorus-based fertilizer and organic manure resulted into high stover yield in both *mavuno* and manure plots. Campbell *et al.* (1993) reported increased mineralization caused by addition of organic carbon to soil. While in Nyalgunga just like Emusutswi and Nyabeda using manure and *mavuno* resulted into high stover yield with a synergy when *mavuno* is applied in combination to manure due to increased nutrient availability and use efficiency (control – 997.5±619.7 Kg ha^{-1}, manure-1140.2±810.9 Kg ha^{-1} , *mavuno* 1281.7±688.9 Kg ha^{-1} and manure+ *mavuno* 1544.8±1096.5 Kg ha^{-1}). Stover yield at Nyalgunga were also not significantly different ($P=0.547$). However, the overall treatment effect across all study areas showed a high significant difference ($P<0.003$). The high significance for stover yield is in agreement with studies by Qureshi (1991) which reported that organic and inorganic fertilizers when combined improved maize growth, hence high stover and grain yield. Improved crop growth is essential for the build-up of soil organic carbon through organic residue turnover and is essential for maintaining soil productivity (Ghosh *et al.,* 2004: Sarwer *et al*., 2008).

The mean stover yield across all sites was lowest in control plot (825.7±544.4 Kg ha^{-1}) and highest in manure+*mavuno* plot (1381.0±728.4 Kg ha^{-1}), an indication that addition of manure and *mavuno* phosphorus based fertilizer increased maize growth and stover yield. A study by Gregorich *et al*., (1996) found a higher organic carbon in the top horizon in fertilized plots, and concluded that adequate fertilization increased biomass yield leading to greater carbon storage in the soils. This supports the need for integrated soil fertility management for enhanced farm productivity and reduction of environmental degradation. Chemical fertilizers combined with organic manure increased soil organic carbon content *in study by* Han *et al*. (2006) and Wang *et al.* (2006). Carbon build up is gradual according Giller *et al*., (1997), and primarily occurs in the top soil restoring fertility of degraded soils (Fisher *et al*., 1994; Sanchez, 1995). Increased C sequestration and decreased CO_2 emissions can be a positive environmental externality of replenishing soil fertility (Sanchez, 1995).This is especially important in western Kenya where farmers harvest above ground biomass for fuel and livestock feeding, Odell *et al*., (1982) reported that application of NPK fertilizers resulted in a significant increase in soil organic carbon over time.

Conclusions

Mavuno (20Kg P ha^{-1}) when applied alone or in combination with manure (2t ha^{-1}) was more effective in increasing maize grain and stover yields due to improved soil conditions compared to control plots in both Emusutswi, Nyabeda and Nyalgunga. Fertilization with manure and *mavuno* increased the mean maize yield significantly from < 1t ha $^{-1}$ in control plots to 3t ha $^{-1}$ when manure and *mavuno* are applied together. The use of manure and mavuno also resulted to doubling of mean stover yield through increased biomas production. *Mavuno* planting fertilizer has both *macro* and *micro* nutrients important for maize growth and improved soil conditions due to its Ca^{2+} and Mg^{2+} components, thus a synergy due to combined use of organic and inorganic fertilizers.

Recommendations

Integrated soil fertility management options which incorporate the use of organic and inorganic fertilizers and quality germplasm can help reduce food deficits in western Kenya through increased yield per unit area. Manure promotes phosphorus use efficiency among other soil properties like enhanced aeration, water holding capacity and mineralization of phosphorus increasing its availabitlity and uptake by plants, thus sustaining crop productivity, decreasing food insecurity and reversing soil degradation.

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