Organic Inputs on Maize (*Zea mays*) Yield and Chemical Properties of Two Ultisols

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Abstract

Effects of organic inputs (OIs) on maize grain yield and chemical properties of Ultisols were assessed at Msekera and Misamfu Agricultural Research Stations in the medium and high rainfall regions respectively of Zambia. The OIs included biomasses of the leguminous species *Cajanus cajan*, *Tephrosia vogelii*, and *Crotalaria juncea*, *in-situ* composted native grasses and shrubs called fundikila, modified fundikila using *Mucuna pruriens*, and composted cattle manure, with chemical fertilizer as a control. After two crop growing seasons, cattle manure significantly increased soil pH, while modified fundikila significantly increased levels of soil organic matter. At Msekera, OIs increased levels of total N by 300%. At Misamfu, fundikila and *Cajanas cajan* increased total N by 35%. The OIs did not significantly increase available P and K at both sites. In the first season at Msekera, OIs had a higher mean maize yield (6075±368 kg/ha) than chemical fertilizer (3567±715 kg/ha). Maize yields for OIs in the second season did not differ significantly from those of the first season. At Misamfu the leguminous OIs *Cajanas cajan* and *Tephrosia vogelii,* had a lower combined mean maize yield (5405±242 kg/ha) than chemical fertilizer (7426±430 kg/ha) in the first season. A 70% decline in maize yield occurred on plots with leguminous OIs in the second season compared to the first season. Leguminous OIs generally performed better at Msekera than at Misamfu. At both sites, the traditional OIs, cow manure at Msekera, and fundikila at Misamfu had higher maize yields than leguminous OIs. We concluded that effects of OIs on soil chemical properties and maize yield vary with soil and climatic conditions and that these need to be considered when selecting OIs for use by farmers.

Keywords: organic inputs, soil chemical properties, maize yield, leguminous organic inputs

1 Introduction

Small scale resource poor farmers are the major producers of maize, the staple cereal crop in Zambia (Zambia Development Agency, 2011). Most of them cultivate soils with inherently low nutrient and organic matter contents that rapidly lose their productivity following the removal of nutrients by crops and natural leaching with limited or no replacement of the nutrients lost. When the productivity of cultivated fields decline, some farmers in rural areas without high demand for land resort to shifting cultivation. The degraded fields are left fallow for a number of years, to allow the fertility of the soils to regenerate naturally, while new fields or formerly fallow fields are used to grow crops. However, with the increasing human population, shifting cultivation is unsustainable (Matthews, Holden, Volk, & Lungu, 1992).

To promote sustainable agriculture among resource poor farmers who are unable to afford expensive chemical fertilizers and other purchased external inputs required to produce adequate yields of maize and other crops, a number of soil management practices that do not require leaving land fallow have been developed or proposed (Ogunlana, Salokhe, & Lund, 2006; Subbian, Lal, & Subramanian, 2000). Most such practices involve the use of organic inputs to improve soil fertility and are reported to eliminate the need for fallow periods, increase productivity and maintain soil fertility. According to Ogoke et al. (2009) the use of organic inputs is usually the only viable options for small scale farmers without access to chemical fertilizers, which are also believed to contribute to the rapid degradation of the fertility of soils when used in large quantities.

The chemical condition of soils have a significant influence on their productivity. This is because it affects the bioavailability of plant nutrients, and the ability of roots to grow and take-up nutrients from the soil. Organic inputs are reported to increase the levels of soil organic matter (SOM) which has a significant influence on many soil properties (Ed-Haun, Chung, & Wang, 2008). According to Bot and Benites (2005), SOM affects the chemical and physical properties of soil and its overall health. The availability of nutrients, diversity and activity of soil organisms, the structure of the soil, porosity, and water infiltration rate and soil moisture retention are some of the important soils properties cited to be affected by SOM.

Although a number of organic inputs are widely used to enhance the productivity of soils for growing maize and other crops in Zambia, there is limited documented information on their effects on soil chemical properties and on maize grain yield. This study was undertaken to assess effects of selected organic inputs on maize grain yield, and on the pH, SOM content, and levels of total N, plant available P and exchangeable K on two acid soils in Kasama and Chipata districts of Zambia.

2. Materials and Methods

2.1 Description of Study Sites

Field trials were conducted at Misamfu Agricultural Research Station in Kasama district of the Northern Province of Zambia and at Msekera Agricultural Research Station in Chipata District of the Eastern Province of Zambia. Kasama is in Agro-ecological region III, or the high rainfall region of Zambia, and has a mean annual rainfall of 1304 mm. Chipata is in Agro-ecological zone II or the medium rainfall region, and has a mean annual rainfall of 1034 mm. Soils at Msekera are classified Paleustults while soils at Misamfu as Kandiustults according to the USDA Soil Taxonomy. Table 2 presents summary data of the geographic locations, climatic data and selected baseline properties of surface sample at the two research sites.

2.2 Characterization of Soils and Organic Materials Used as Inputs

Before establishing the crop trials at the two sites, surface soil samples (0-20 cm) from the field trial sites were collected to establish baseline values of soil properties. Simple random sampling using an auger was used to collect the samples which were then bulked to form composite samples. The composite samples were used to determine baseline values of soils at each site. The samples from the field were air-dried, disaggregated and passed through a 2 mm sieve. Sieved air-dry samples were used to determine the particle size distribution using Bouyoucos hydrometer method (Anderson & Ingram, 1993), pH in 0.01M $CaCl_2$ (McLean, 1982), exchangeable acidity (McLean, 1982), soil organic carbon by the Walkley and Black method (Nelson & Sommers, 1982). Total N contents of the soils were determined by the Kjeldah method (Bremner & Mulvaney, 1982), exchangeable bases were extracted with 1N ammonium acetate buffered at pH 7.0 (Doll & Lucas, 1975) and their concentrations in the extracts were read on a Perkin Elmer AAnalyst 400 Atomic Absorption Spectrometer (AAS). Plant available P was extracted using the Bray-1 method (Bray & Kurtz, 1945) and concentrations of P in the extracts were read on Ultraviolet/visible (UV/Vis) spectrophotometer at 882 nm wavelength after developing the molybdenum blue colour. The effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable bases and exchangeable acidity. The phosphate sorption properties of the two soils were determined using the six day incubation method described by Fox and Kamprath (1970). The amount of P adsorbed by the soil to give an equilibrium soil solution P concentration of 0.2 mg/L was taken to be the estimate of the amount of P needed to be added to the soils in the field to be able to supply adequate P in solution to meet the requirements of most crops.

The organic materials used as amendment were tested for their organic carbon contents using the Walkley and Black method (Nelson & Sommers, 1982), and for their total N by the Kjeldah method (Bremner & Mulvaney, 1982). The nutrients Ca, Mg, K, P and sulphur (S) were extracted by dry ashing and digestion in 1N nitric acid. Concentrations of Ca, K and Mg in the extracts were determined by AAS, while S and P were determined colorimetrically at wavelengths of 430 nm and 882 nm respectively.

Crop trials were established in the 2015/16 agricultural season, and laid out in a Randomized Complete Block Design (RCBD) with 5 treatments as summarized in Table 1. Blocking was made to take care of possible soil fertility gradients across the slope of the land at both sites.

2.3 Description of Treatments

Research plots at each site were 10 m × 10 m. The control plots consisted of plots tilled with a hand-hoe to the chemical fertilizers Compound D (10% N: 20% P_2O_5:10% K_2O) was applied at the time of planting maize followed by a top dressing of Urea (46:0:0) four weeks after planting. Both fertilizers were applied at the rate of 2 kg/plot corresponding to field application of 200 kg/ha. In the pigeon pea alley treatments, pigeon peas were

planted in rows 90 cm apart with intra low spacing of 10 cm in December. One kilogram of Compound D fertilizer was applied to pigeon pea planting stations per plot and maize was then planted in between the rows of pigeon pea on the same day. Pigeon pea trees were trimmed in December before planting the second maize crop. The trimmings were left on the soil surface to decompose. *Tephrosia vogelii* alley cropping treatments were prepared in the same manner as the pigeon pea alley cropping treatments. The summary description of the treatments are presented in Table 1.

Table 1. Summary descriptions of treatments used in field trials at the two study sites

Study Site	Treatment	Description of treatments
Misamfu	Chemical fertilizers	200 kg Comp D/ha + 200 kg Urea/ha (Full fertilizer rate)
	Pigeon pea	6121 kg Pigeon pea biomass/ha + ½ fertilizer rate
	Tephrosia vogelli	8014 kg *Tephrosia vogelii* biomass/ha + ½ fertilizer rate
	Fundikila	20,480 kg native grasses & shrubs /ha + Full fertilizer rate
	Modified Fundikila	10,328 kg velvet beans biomass /ha + no chemical fertilizer
Msekera	Chemical fertilizers	200 kg Comp D/ha + 200 kg Urea/ha (Full fertilizer rate)
	Pigeon pea	6121 kg Pigeon pea biomass/ha + ½ fertilizer rate
	Tephrosia vogelli	8014 kg *Tephrosia vogelii* biomass/ha + ½ fertilizer rate
	Sunn hemp	7812 kg Sunn hemp biomass /ha + ½ fertilizer rate
	Cow manure	20,000 kg composted cow manure/ha

In the fundikila treatments, native grass and shrubs were left to grow on plots from December to the end of March. Two kilograms of Compound D fertilizer were broadcast across each plot before the grass and shrubs were buried with topsoil to make ridges. Ridges were left undisturbed until December to allow plant residues to decompose. In December, ridges were opened and flattened in preparation for planting of maize. In modified fundikila treatments, velvet beans were planted on plots in January in the first season and allowed to grow with native grass and shrubs to the end of March. The velvet beans, native grasses and shrubs were then buried with topsoil to make ridges that were managed the same way as the fundikila plots. No chemical fertilizer was applied to plots under modified fundikila. In the cow manure treatments, 630 grams composted cow manure were applied to hand-hoe dug planting basins 30 cm long, 15 cm wide and 20 cm deep, in rows 90 cm apart with intra-row spacing's of 70 cm. For the Sunn hemp (*Crotalaria juncea*), treatments, maize was planted in December of the first season. A week after maize emerged, sunn hemp seeds were broadcast across the plots and the sunn hemp was left to grow with the maize until time of harvest.

The treatments were different at the two study sites, because the locations are in different Agro-ecological zones and treatments used were based on practices used by farmers in the respective locations. The farmers chose the inputs readily available in the area and which they thought would be likely adopted. The fundikila and cow manure treatments were referred to as traditional organic inputs because they are traditionally used by farmers in Kasama and Chipata respectively. The other treatments with the exception of chemical fertilizers were referred to as leguminous organic inputs because they use biomass from leguminous plants.

2.4 Management of Field Trials and Harvest of Maize

At Misamfu maize was planted on the 9th December 2015, while at Msekera it was planted on the 28th of December 2015. These dates coincided with onsets of the rainfed crop growing seasons at the two locations. Tillage operations were done manually using hand-hoes and weeding was also done using hand hoes.

Maize was harvested from sub-plots after removal of two border rows on all sides of the plot. Maize cobs from sub-plots were harvested, weighed and sun-dried separately in well labeled paper bags for about three weeks until the moisture content dropped to about 12.5%. The dried cobs were weighed and shelled. The weight of the shelled grain per plot was recorded. The grain yield from the subplots was used to calculate the estimate the grain yield per hectare.

2.5 Sampling of Soils

At the end of the second season in May, 2017, soil samples were collected from the topsoil (0-20cm depth) of each plot using the simple random sampling method. Four subsamples were collected per plot and mixed to

make a composite sample. The samples were collected in black polyethylene bags, labelled and transported to the laboratory for analysis.

2.6 Data Analysis

Analysis of Variance (ANOVA) was used determine there were significant differences in selected properties due to treatments. Duncan's Multiple Range Tests was used to separate treatment means. All statistical analyses were carried out using the SAS software version 9.0 for Windows.

3. Results

3.1 Properties of the Soils Used in the Study

Table 2 presents summary data on the location, climatic conditions and baseline properties of the soils at the two research sites. Soils from Msekera were very strongly acid, sandy clay loams, with moderate levels of SOM, low total N, and low levels of plant available P for maize production based on the 12 mg P/kg the critical value reported by (Mutsaers, Weber, Walker, & Fisher, 1997). The levels of exchangeable K in soils at Msekera were adequate for maize production. Soils at Misamfu were very strongly acid loamy sands, with moderate levels of SOM, low total N, adequate levels of plant available P and exchangeable K for maize production.

Table 2. Location, climatic conditions and baseline soil properties of the research sites

Site	Msekera	Misamfu
Location	13°38′42″S; 32°33′47″E	10°10′S; 31°26′E
Elevation (m)	1030	1384
Average annual rainfall (mm)	1034	1360
Average annual temperature (°C)	22.0	20.1
Soil classification (USDA)	Paleustult	Kandiustult
pH (0.01M CaCl$_2$)	4.38	4.29
SOM (%)	1.86	2.29
Total N (%)	0.03	0.10
Bray-1 P (mg/kg soil)	5.38	25.06
Exch K (cmol(+)/kg)	0.69	0.47
ECEC (cmol(+)/kg)	4.38	2.90
Standard P requirement (mg/kg)	185	323
Bulk density (Mg m^{-3})	1.48	1.38
Clay (%) (< 0.002 mm)	23.6	15.2
Silt (%) (0.002-0.05 mm)	21.6	3.6
Sand (%) (0.05-2.0 mm)	54.8	81.2
USDA textural class	Sandy clay loam	Loamy sand

3.2 Composition of Organic Amendments Used in the Study

Selected properties of the organic amendments used in the study are presented in Table 3. The biomass from leguminous plants generally had higher levels of N with more than 2.5% N compared to the mixed biomass and cow manure traditionally used by farmers as organic inputs, both of which had less than 2% N. The organic inputs had low P contents of less than 0.5%. Cow manure and the mixed biomass had higher levels of K of about 2.4% compared to the leguminous organic inputs, most of which had less than 2% K except velvet beans which had 2.2% K.

The C: N ratios of the organic inputs ranged from 12:1 for velvet beans to 47:1 for the mixed biomass. The C: P ratios ranged from 68:1 for cow manure to 448:1 for *Tephrosia vogelii*, while C: S ratios ranged from 231:1 for sunn hemp to 742:1 for pigeon pea.

Table 3. Means of selected properties of organic amendments used in the study

Parameters	Cow manure	Mixed biomass	Pigeon pea	Sunn hemp	*Tephrosia vogelii*	Velvet beans
N (%)	1.76	1.23	2.53	4.43	2.75	4.79
P (%)	0.46	0.30	0.16	0.36	0.14	0.43
K (%)	2.42	2.46	1.43	1.63	1.03	2.21
Ca (%)	2.06	1.04	0.88	3.60	1.08	1.67
Mg (%)	0.24	0.19	0.21	0.36	0.20	0.32
S (%)	0.13	0.17	0.10	0.24	0.14	0.15
Org C (%)	31.47	57.47	66.40	55.20	62.13	58.00
C:N ratio	18:1	47:1	26:1	13:1	23:1	12:1
C:P ratio	68:1	191:1	424:1	153:1	448:1	134:1
C:S ratio	250:1	344:1	742:1	231:1	449:1	395:1

3.3 Effect of Treatments on Maize Grain Yield

3.3.1 Misamfu Research Station

Figure 1 shows the average maize grain yields for treatments at Misamfu in the first and second growing seasons. In the first season the highest yield was obtained from plots with chemical fertilizer. The maize yield from plots with chemical fertilizer was significantly ($p < 0.05$) higher than that of plots with *Tephrosia vogelii* and pigeon pea. Maize yields from plots with *Tephrosia vogelii* and pigeon pea were about 78% and 67% respectively compared to yields from plots with chemical fertilizer.

In the second season plots with the fundikila treatment had the highest maize grain yield. This was significantly ($p < 0.01$) higher than yields from plots with modified fundikila, pigeon pea, and *Tephrosia vogelii*, but not significantly different from yields from plots with chemical fertilizer. The first maize harvest from plots with fundikila and modified fundikila was in the second growing season. Relative yields of maize from plots with organic inputs to the mean yield of plots with chemical fertilizer were about 110% for fundikila, 74% for modified fundikila, 24% for *Tephrosia vogelii* and 23% for pigeon pea.

Very notable declines in maize grain yields occurred on plots with *Tephrosia vogelii* and pigeon pea in the second season compared to the yields obtained in the first season. The decline in yield on plots with *Tephrosia vogelii* was about 72%, and about 69% on plots with pigeon pea compared to yields obtained in the first growing season. Fundikila treatment, which represented the traditional practice used by farmers had much higher maize yields compared to organic amendments from leguminous plant species which researchers have been trying to promote as 'improved technologies' for adoption by farmers.

3.3.2 Msekera Research Station

Figure 2 shows the average maize yields from plot with different treatments at Msekera in first and second growing seasons. In the first season, plots with organic inputs generally had higher maize yields than plots with chemical fertilizer. The average maize yield for plots with organic amendments was 6075 kg/ha, compared to 3567 kg/ha for plots with chemical fertilizer. Treatments with cow manure and *Tephrosia vogelii* had significantly ($p < 0.05$) higher maize yields than the treatment with chemical fertilizer. The relative yields of maize from plots with organic amendments to the yield from plots with chemical fertilizer, were 192% for cow manure, 180% for *Tephrosia vogelii*, 163% for pigeon pea and 144% for sunn hemp.

In the second season plots with chemical fertilizer, had the highest maize yields among the treatments at Msekera. Plots with chemical fertilizer had significantly ($p < 0.05$) higher yields than plots with sunn hemp, *Tephrosia vogelii* and pigeon pea, but not cow manure. The relative yields of maize from plots with organic inputs to yields obtained on plots with chemical fertilizer were about 74% for cow manure, 63% for sunn hemp and pigeon pea, and 62% for *Tephrosia vogelli*.
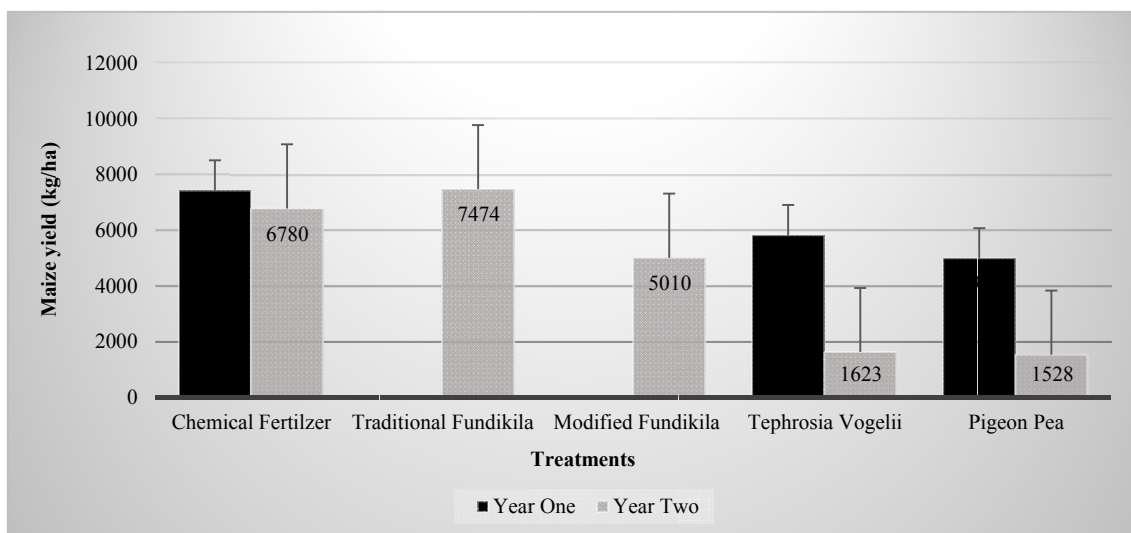
Figure 1. Maize grain yields of treatments at Misamfu in the first and second growing seasons

At Msekera maize yields from plots with organic input in the second season did not significantly (p < 0.05) differ from those obtained in the first season. The composted cow manure which represented traditional practice used by farmers in Chipata had the highest maize yield among treatments with organic inputs in the two growing seasons. Its performance as a soil amendment was superior to that of organic input from leguminous plants that researchers had been trying to promote as improved practices for adoption by farmers.
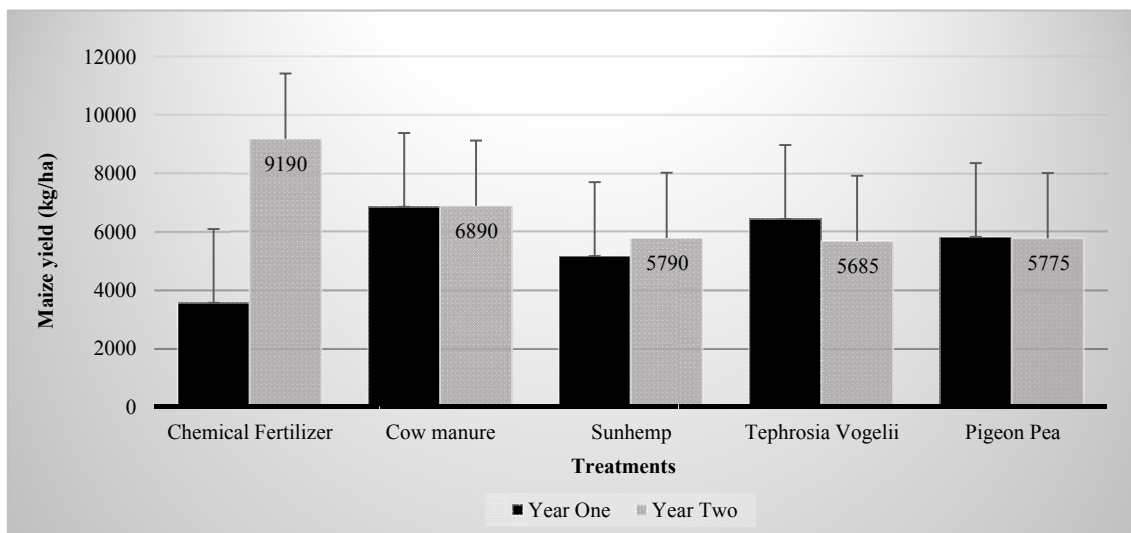

Figure 2. Maize grain yields of treatments at Msekera after the first and second growing seasons

3.4 Effect of Organic Amendments on Selected Chemical Properties of Soils

Tables 4 and 5 show mean values of selected soil properties at Misamfu and Msekera respectively after two growing seasons. No significant (p < 0.05) change in soil pH was observed on all treatments at Misamfu compared to the baseline value. The soils from all the treatments remained very strongly acid. At Msekera (Table 5) there was a significant (p < 0.001) increase in the pH on soils from plots with organic inputs but not on plots with chemical fertilizer.

Table 4. Means of selected soil chemical properties in different plots at Misamfu after two seasons

Treatments	pH	SOM	Total N	Available P	Exchangeable K
Chemical fertilizers	4.34a	2.48ab	0.04c	33.28a	0.33bcd
Pigeon pea	4.24a	2.58ab	0.15a	24.75a	0.24d
Tephrosia vogelii	4.23a	2.88ab	0.07bc	29.50a	0.26cd
Modified fundikila	4.29a	2.96a	0.13ab	37.37a	0.25cd
Traditional fundikila	4.17a	2.90ab	0.14a	34.76a	0.44bcd
Baseline	4.37a	2.28b	0.10bc	25.06a	0.47ab

Note. Mean values within a column followed by the same subscript are not significantly different at 0.05 level using Duncan's Multiple Range Test.

Table 5. Means of selected soil chemical properties in different plots at Msekera after two seasons

Treatments	pH	SOM	Total N	Available P	Exchangeable K
Chemical fertilizers	4.45cd	2.14b	0.15a	24.20a	0.65ab
Pigeon pea	4.78bc	2.17b	0.14a	5.67b	0.59b
Tephrosia vogelii	4.82b	2.00bc	0.10a	5.62b	0.61b
Sunn hemp	4.90ab	2.11b	0.11a	4.24b	0.61b
Cow manure	5.26a	1.72c	0.12a	8.14b	0.77a
Baseline	4.39d	1.86bc	0.03b	5.38b	0.69ab

Note. Mean values within a column followed by the same subscript are not significantly different at 0.05 level using Duncan's Multiple Range Test.

A significant ($p < 0.05$) increase in SOM compared to the baseline value was observed on plots with modified fundikila at Misamfu. No significant change in SOM was observed on plots with other treatments. At Msekera, no significant ($p < 0.05$) change in the levels of SOM were observed on all treatments compared to the baseline value.

Significant ($p < 0.05$) increases in total N of 50% and 40% were observed on plots with pigeon pea and fundikila respectively compared to the baseline values at Misamfu. At Msekera all plots with organic amendments had significantly ($p < 0.05$) higher levels of total N compared to the baseline value of 0.03% N. No statistically significant ($p > 0.05$) increase in plant available P was observed on all treatments at Misamfu compared to the baseline value of 25.06 mg P/kg soil. At Msekera (Table 5) soils from plots with chemical fertilizer had a significant ($p < 0.05$) increase in available P compared to the baseline value. None of the soils from plots with organic inputs had significantly higher levels of available P than the baseline value.

At both sites, none of the treatments significantly ($p < 0.05$) increased levels of the exchangeable K compared to the baseline values. At Misamfu all soils from plots with organic inputs had significantly ($p < 0.05$) lowers levels of K than the baseline value, while at Msekera only soils from the plots with chemical fertilizer had higher levels of exchangeable K comparable to the baseline value. In general soils at Misamfu had lower levels of exchangeable K than soils at Msekera.

4. Discussion

4.1 Effect of Organic Amendments on Maize Grain Yield

At Misamfu in the first season, significantly ($p < 0.002$) higher maize grain yields were obtained from plots with chemical fertilizer than from plots with the organic inputs that were *Tephrosia vogelii* and pigeon pea. This could be because of the higher levels of N, P and K supplied by the chemical fertilizer compared to the organic inputs at this site.

Substantial declines in maize grain yield of about 72% and 69% were observed on plots with *Tephrosia vogelii* and pigeon pea respectively in the second season compared to yields observed in the first season. These results corroborate earlier findings by Mathews et al. (1992) who reported significant decline in maize yield after four years on plots under alley cropping with leguminous agroforestry tree species at Misamfu. The rapid decline in maize yields on plots with leguminous organic inputs after one growing season at Misamfu could be attributed to various factors. The first being the nutrient uptake by maize harvested in the first season. The second could be the ecological conditions at Misamfu reflected in the nature of the soils and high rainfall.

There was probably significant leaching of nutrients at Misamfu because of the sandy nature of the soils and the high rainfall at Misamfu. Kalala et al. (2020) reported high seasonal organic matter decomposition rates of about 10.3% on the highly permeable sandy soils at Misamfu. A combination of high organic matter decomposition rates and high rainfall are conducive to high rates of leaching of nutrients. Consequently a rapid decline in the productivity of the soils is expected accompanied with a rapid decline in crop yield. It is therefore, not surprising that at Misamfu significant decline in yield were observed on plots with *Tephrosia vogelii* and pigeon pea in the second season. The agro-ecological conditions at Misamfu characterized by high rainfall and sandy soils are probably not suitable for the use of pigeon pea and tephrosia as organic inputs for growing maize.

At Msekera there was a significant ($p < 0.05$) increase in maize grain yield on plots with chemical fertilizer in the second season. This may have been a result of the higher amount of water soluble P that was supplied by the chemical fertilizer of approximately 17.5 kg P/ha compared to the organic amendments which all had low levels of P. For example cow manure which had a total of approximately 20 kgP/ha, had less than 5% or 1 kg P/ha mineralized in the growing season.

In the first season maize yields from plots with pigeon pea and *Tephrosia vogelii* at Msekera and Misamfu were comparable. There was a marked difference between maize grain yields obtained from the same plots at Msekera and Misamfu in the second season. In the second season maize yields at Msekera were 280% higher than yields at Misamfu plots with pigeon pea and 250% higher at Msekera compared to yields at Misamfu on plots with *Tephrosia vogelii* maize yields. The observed differences in maize grain yield could be attributed to differences in the soil and climatic conditions at the two locations. The agro-ecological conditions at Msekera were probably better suited for the use of *Tephrosia vogelii* and pigeon pea for improving maize production than at Misamfu. According to Kalala et al. (2020), the loamy soils at Msekera had seasonal organic matter decomposition rates of about 4.9% compared to the high rates of about 10.3% observed on the sandy soils at Misamfu. The combination of the higher rainfall at Misamfu and high organic matter decomposition rates on soils with high permeability and low nutrient retention may have resulted in greater leaching of nitrogen and other nutrients at Misamfu compared to Msekera. This may have led to the observed much lower maize yields at Misamfu compared to Msekera in second season.

4.2 Effects on Soil Chemical Properties

There was an increase in the pH of soils with organic inputs at Msekera, but not at Misamfu According to Ruijin and Fuxing (2005), the observed increase in the pH of plots with composted cow manure could be attributed to the effect of organic compounds produced during the decomposition of organic matter that are able to complex exchangeable acidity. A similar observation of an increase in pH from 4.10 to 5.29 after one growing season in plots where manure was applied has been reported by Duruigbo et al. (2007).

4.3 Total N

An increase in N was observed in Chipata on all plots with organic amendments as well as on plots with chemical fertilizer. With the observed levels of increase in N on plots with organic inputs , as much as 120 kg N/ha could be mineralized from the top 20 cm plough layer assuming a bulk density of 1.4 g cm^{-3} and a seasonal N mineralization rate of 4%. This is in accord with the findings of Aguiar, Amorim, Coêlho and Moura (2009) who reported increases of more than 220 kg N/ha in a year on plots under leguminous alley cropping systems in Brazil. The high levels of total N observed in plots with pigeon pea are further in agreement with results of Abunyewa and Karbo (2005) who reported a significant increase in total N in fallow plots with pigeon pea compared to plots under the natural fallow regrowth in Ghana.

At Misamfu where no significant increase in total N was observed, the lowest levels of total N were in plots with chemical fertilizer. This could be attributed to uptake by maize crop and leaching of readily soluble nitrogen from the chemical fertilizer, on the loamy sands in a region that receives relatively high rainfall. According to Stevenson (1986), nitrate nitrogen is the most mobile form of N, which is very susceptible to leaching, and is influenced by factors such as the amount and time of rainfall, the infiltration and percolation rates, and water holding capacity of soils. The sandy soils of Kasama have greater infiltration and low water holding capacity, both of which favour N losses by leaching. In addition to the stated factors, Kalala, Shitumbanuma, Adamtey, and Chishala (2020) observed that soils in Kasama have rapid decomposition of organic matter which might have led to readily mineralization of N which was latter leached out.

4.4 Soil Organic Matter

At Misamfu the only significant increase in SOM compared to the baseline values for the site occurred on plots with modified fundikila treatment. This could be attributed to the substantial amount of biomass that was

contributed by the velvet beans that was grown on the plots in addition to the native grass and shrubs compared to plots with traditional fundikila. The resulting higher quantity of biomass on plots with modified fundikila compared to other treatments with organic inputs, is the only factor that could be attributed to the higher SOM contents of plots with modified fundikila. It is unfortunate that the actual biomass applied to the different plots was not measured. The absence of significant increases in SOM in other treatments could be attributed to the relatively the rapid decomposition of the residues in the soil, especially in view of the fact that most of the residues applied had low C: N ratios.

4.5 Available P

Soils at Misamfu (Table 2) had high initial levels of available P of 25 mg /kg soil. Juo and Franzluebbers (2003) report that tropical soils containing 12 mg P/kg soil or more extracted by the Bray-1 method have sufficient levels of P for most cereals such as maize and legumes such as cow pea. It was therefore not surprising that levels of available P in soils from all treatment plots at Misamfu were still high in the second season as shown in Table 4. Sandy soils derived from acidic parent materials such as those at Misamfu generally have a low to moderate P sorption capacities, and tend to show increases in available P after additions of P fertilizers earlier compared to fine textured soils with high P sorption capacities (Tisdale et al., 1985). The standard phosphate requirement (SPR) of the soil is defined as the quantity of P adsorbed by the soil to attain an equilibrium soil solution concentration of 0.2 mg/L, from the six day P adsorption isotherms described of Fox and Kamprath (1970). It is the amount of P that is likely to supply adequate amounts of P in soil solution to meet the requirements of most crops. The SPR for the soil at Misamfu was 185 mg P/kg soils. This level of P sorption may be considered to be moderate, based on the classification of Juo (1987) who defined high P fixing soils with SPRs of more than 250 mg P/kg soil.

At Msekera a significant ($p < 0.05$) 4.5 times increase in available P compared to the baseline value was observed on plots that received chemical fertilizer. No significant increase in available P compared to the baseline value was observed on plots with organic inputs. The increase in P on plots with chemical fertilizer can partly be attributed to the much higher content of P in the chemical fertilizers compared to the organic inputs. The chemical fertilizer used contained 8.73% P, while the organic input with the highest level of P, cattle manure contained 0.46% P. Furthermore, the soils at Msekera had low initial levels of available P of 5.38 mg/kg soil, and a high P fixing capacity, with a SPR of 323 mg P/kg soil. The combination of the low P contents of the organic inputs, coupled with the high P fixing capacity of the soils at Msekera may account for the observed low levels of available P in plots with organic inputs after two growing seasons. The observed increase in the levels of available P on plots where chemical fertilizer was applied was expected, and was consistent with expectations since the fertilizer used had high concentrations of water soluble P. Yli-Halla (2016), and Börling, Barberis, and Otabbong (2004), both report that repeated applications of P to the soil increase the P saturation of soils and that applying P fertilizers to soils generally increases the levels of available P.

4.6 Exchangeable K

There was a general decline in the levels of exchangeable K in treatment plots in Kasama compared to the baseline values. This could be attributed to the combined effect of the uptake of K by plants and to the leaching of K from soils because the soils had a low CEC, and are located in a region which receives relatively high rainfall of more than 1300 mm per annum over a period of about 5 months. The decomposition rate of organic matter on the Misamfu soils was rapid, as indicated by high season carbon mineralization constants (k) of 0.0645 on soils without fertilizer and of 0.141 on soil with chemical fertilizer corresponding to seasonal organic matter decomposition rates of 6.5% and 14% as reported by Kalala et al. (2020). Such high rates of organic matter decomposition coupled with high rainfall, are conducive for the rapid leaching of K on soils with low CECs. Since the levels of K in the organic inputs were generally low, K was one of nutrients that was likely to be limiting for growing maize on the soils at Misamfu.

4.7 Comparison of Local and Introduced Organic Soil Fertility Management Practices

Interestingly, at both sites, plots with organic puts used by local farmers, namely fundikila at Misamfu and composted cow manure at Msekera had higher maize yields than the leguminous organic inputs from leguminous tree species that researchers have been advocating as alternatives to natural fallows. The observed poor performance of organic inputs suggested as 'improved soil fertility management practices' that researchers have been trying to encourage farmers to adopt, may partly explain why farmers have been reluctant to adopt these soil management practices despite the great efforts by researcher and extension staff in promoting their adoption. It may be worthwhile for researchers to invest a bit more time in trying to understand the reasons why farmers have adopted the farming practices they use, before rushing to introduce so called improved practices, which are

often based on theoretical ideas that have not been subjected to long term field test. Many of the practices that farmers have adopted are results of many years of on-farm trials and that have proved to be viable under local biophysical and socio-economic conditions.

5. Conclusions

After two crop growing seasons, organic inputs significantly increased soil pH and total N in soils compared to baseline levels at Msekera in the medium rainfall region but not at Misamfu in the high rainfall region of Zambia. No significant increase in SOM was observed on plots with organic inputs except where modified fundikila was used at Misamfu. None of the organic inputs used significantly increased levels of available P and K. Higher maize grain yields were obtained on plots with organic inputs compared to plots with chemical fertilizer in the first season at Msekera, while at Misamfu only fundikila had significantly higher yields than chemical fertilizer. The benefits of using organic inputs on soil chemical properties and on maize grain yield were generally greater on the loamy soils at Msekera than on the sandy soils at Misamfu. It is concluded that effects of organic inputs on soil chemical properties and maize yields are largely influenced by soil properties and climatic conditions of the site.

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