Maize productivity as influenced by organic inputs and mineral fertilizer in a Nitisol soil in Meru South District

Daniel Mugendi[A], Monicah Mucheru-Muna[A], Pieter Pypers[B], Jayne Mugwe[A], James Kung'u[A], Bernard Vanlauwe[B], and Roel Merckx[C]

[A]Kenyatta University, Department of Environmental Sciences. P.O. Box 43844-00100, Nairobi, Kenya, Email dmugendi@yahoo.com
[B]Tropical Soil Biology and Fertility, (TSBF) Institute of CIAT, P. O. Box 30677 Nairobi, Kenya
[C]K.U.Leuven, Faculty of Bioscience Engineering, Laboratory for Soil and Water Management, Kasteelpark Arenberg 20, 3001 Heverlee, Belgium

Abstract
Declining land productivity is a major problem facing smallholder farmers in Kenya today. This decline primarily results from a reduction in soil fertility caused by continuous cultivation without adequate addition of external nutrient inputs. Improved fertility management combining organic and mineral fertilizer inputs can enable efficient use of the inputs applied and increase overall syste productivity. Field trials were established at two sites with different soil fertility status in Mucwa with the aim of determining the effects of various organic sources (tithonia, mucuna, calliandra and manure) and their combinations with mineral N fertilizer on maize grain yield and soil chemical properties. Sole tithonia and sole calliandra treatment generally recorded the highest maize grain yields for Mucwa poor and Mucwa good sites, respectively. Generally the maize grain yields were lower in the treatments with fertilizer alone compared to the treatments with organics in the two sites in the seven cropping seasons. There was a general decline in soil chemical properties over the seasons, even with the seasonal input application in both sites. Manure was superior in terms of improving soil chemical properties for instance, it supported an increase in soil pH, magnesium, potassium, calcium and nitrogen.

Key words
Manure, tithonia, soil pH, Soil organic carbon

Introduction
The central highlands of Kenya cover both areas with high potential for crop production on inherently fertile nitisols and drier areas with lower potential on lighter, fragile soils, prone to quick degradation. The soil fertility in the central highlands has declined over time, with an annual net nutrient depletion exceeding 30 kg N (Smaling 1993) as a result of continuous cropping with inadequate nutrient replenishment (Mwangi *et al.* 1998). In most smallholder farms, these deficiencies could be replenished through the use of mineral fertilizers and cattle manure. However, few farmers can afford mineral fertilizers and farmer using them hardly ever use the recommended rates (60 kg N/ha) for the area, with most of them applying less than 20 kg N/ha (Adiel 2004), on the other hand the use of manure is also limited by its low quality (Kihanda 1998). As a result, soil fertility has continued to decline as has the productivity of the land (Adiel 2004). Trials using organic and mineral fertilizer inputs were established in 2004 with the main objective of addressing the decline in soil fertility. The study aimed to determine the effects of different organic sources and combinations with mineral fertilizer inputs on maize grain yield and soil chemical properties.

Materials and Methods
The study was conducted in Meru South District in the central highlands of Kenya. In Meru South the experiment was conducted in Mucwa (00º 18' 48.2" S; 37º 38' 38.8" E) which is located in the upper midland with an altitude of approximately 1373 m above sea level. The soils are Rhodic Nitisols (Jaetzold *et al.* 2006), which are deep, well weathered with moderate to high inherent fertility. The study was conducted in two farms one that had relatively good soils (in terms of soil pH, total soil carbon, and available P) and another that had poor soils. The rainfall is bimodal, falling in two seasons, the long rains (LR) lasting from March to June and short rains (SR) lasting from October to December. The area receives an annual mean rainfall of 1400 mm.
The experiments were established in Mucwa good and poor sites and were laid out as a randomized complete block design replicated thrice with the plots measuring 6 x 4.5 m. The test crop was maize (*Zea mays* L, var. H513) planted at a spacing of 0.75 and 0.5 m inter- and intra-row, respectively. External nutrient replenishment inputs were applied to give an equivalent amount of 60 kg N/ha (this is the recommended rate

of N to meet maize nutrient requirement for an optimum crop production in the area) with the exception of the herbaceous legume treatment where by the amount of N was determined by the biomass harvested and incorporated in the respective treatments. P was applied in all plots at the recommended rate (60 kg P/ha) as triple super phosphate (TSP). Maize grain and stover was harvested at maturity from a net area of 21.0 m^2 (out of the total area of 27 m^2). Maize grains were dried and yield was expressed in terms of dry matter content.

At the beginning and end of the experiment, soil samples were collected at 0-15 cm. The soil samples were analysed for soil organic carbon, total nitrogen, available P (Olsen), Ca, Mg and K, and pH using standard methods (Anderson and Ingram 1993). Data was subjected to analysis of variance using Genstat software. The means were separated using Least Significant Differences of means (LSD at $p < 0.05$). To determine changes in soil chemical properties during the two year cropping period, *t* tests comparing means between the two sampling periods (October 2004 and August 2006) were done.

Results and Discussions

Maize grain yield

For Mucwa good and poor sites there was a significant ($p < 0.001$) effect of seasons on maize grain yield. There was a significant interaction between the sites during the SR 04, LR 06 and LR 07 with $p < 0.001$, $p = 0.021$ and $p < 0.001$ respectively. The treatments with sole organic and organic integrated with mineral fertilizers increased the maize grain yield in comparison to the recommended rate of sole mineral fertilizer (60 kg N/ha) at Mucwa good site.

Table 5. Maize yields (t/ha) under different treatments during seven cropping seasons at Mucwa good and poor sites, Meru South District

Treatment	SR 04	LR 05	SR 05	LR 06	SR 06	LR 07	SR 07
Mucwa good							
Calliandra	3.39	5.21	4.75	3.70	4.90	5.38	6.17
Calliandra + 30 kg N/ha	2.01	5.39	2.93	2.60	3.71	3.29	4.92
Mucuna	0.66	6.47	3.04	2.23	2.82	4.45	4.75
Mucuna + 30 kg N/ha	0.82	6.09	3.00	2.67	3.80	4.50	6.40
Tithonia	2.97	6.04	3.07	2.86	3.93	4.03	3.4
Tithonia + 30 kg N/ha	1.85	6.05	3.51	2.75	3.03	3.19	5.1
Manure	1.35	5.45	3.51	2.28	4.38	4.06	5.6
Manure + 30 kg N/ha	1.01	5.89	2.97	0.79	3.00	3.33	3.66
Fertilizer (60 kg N/ha)	1.35	5.84	3.02	1.69	3.76	3.30	4.09
Control	0.64	3.32	1.62	0.34	0.84	1.04	1.24
SED	0.16***	0.39***	0.86*	0.38***	0.67***	0.79**	1.03**
Mucwa poor							
Calliandra	2.10	5.57	2.60	2.91	3.42	3.50	6.26
Calliandra + 30 kg N/ha	2.82	4.80	1.74	1.08	2.36	2.64	5.22
Mucuna	0.28	4.79	1.44	1.05	1.67	2.39	3.0
Mucuna + 30 kg N/ha	0.21	5.88	2.65	2.74	3.32	4.39	4.8
Tithonia	2.88	6.65	2.80	3.06	4.17	3.85	5.6
Tithonia + 30 kg N/ha	2.34	5.00	2.18	1.78	3.11	2.53	3.67
Manure	0.73	5.85	2.76	1.80	4.66	2.81	4.11
Manure + 30 kg N/ha	1.17	4.79	1.70	0.73	2.39	2.16	4.15
Fertilizer (60 kg N/ha)	0.76	4.27	1.68	0.52	2.87	1.00	3.39
Control	0.76	2.35	0.76	0.54	0.50	0.63	1.41
SED	0.53***	0.76**	0.53*	0.52***	0.74***	0.58***	0.72***

*, **, *** = significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively, SED = Standard error of differences

At Mucwa poor site, the treatments with sole organics performed better than the ones with integration of organic and mineral fertilizer across the seven seasons (Table 5). The treatments with sole organics and integration of organics with mineral fertilizers increased the maize grain yield in comparison to the control during all the seasons in Mucwa poor site. The treatments with sole organics and organics integrated with mineral fertilizers increased the maize grain yield in comparison to the recommended rate of the sole mineral fertilizer (60 kg N/ha).

The application of organic alone or in combination with mineral fertilizers led to increased maize yield compared to the control. Several authors have reported increased yields as a result of applying tithonia, calliandra and manure inputs in other areas (Kimetu *et al.* 2004; Mucheru-Muna *et al.* 2007). In Western Kenya, yield increases of up to 200% was reported following application of tithonia biomass (Jama *et al.* 2000).

Generally, the maize grain yields were lower for the treatments with fertilizer alone compared to treatments with sole organic or organic combined with mineral fertilizers in both sites and the seven cropping seasons. Mtambanengwe *et al.* (2006) reported a yield increase of 104% following manure application against sole fertilizer. This implies an increased nutrient recovery in the sole organic and organic plus mineral fertilizer treatments compared to sole mineral fertilizer treatment.

Soil chemical properties

At Mucwa good site, the soil pH, Ca, Mg, and K, were not statistically different ($p < 0.05$) in 2004, however, in 2006 they were statistically different (Figure 1). Soil carbon decreased in all the treatments during the two years of continuous cultivation. At Mucwa poor site, in 2004 soil pH, Ca, Mg, K, exchangeable P, total N, and organic carbon were not significantly different ($p < 0.05$) between treatments while in 2006, soil pH, Mg, and K were significantly different between treatments. Soil pH increased in the sole manure treatment ($p = 0.013$).

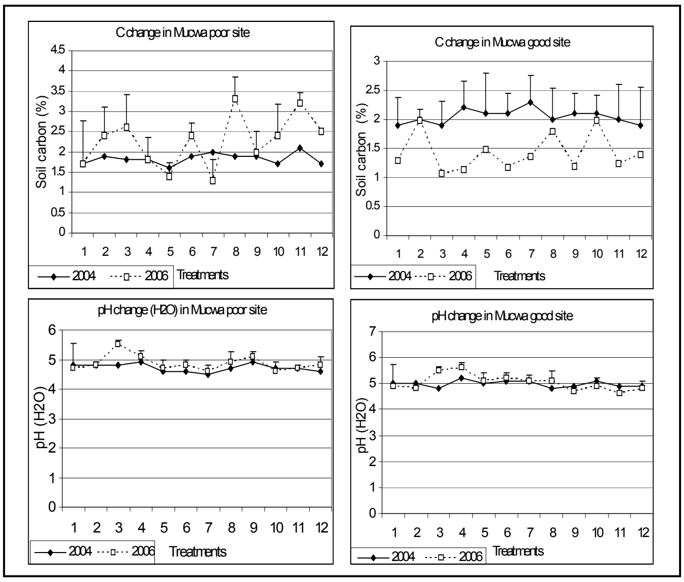

Figure 1. Carbon and pH changes for Mucwa good and poor sites between 2004 and 2006

The significant pH increase for Mucwa good and poor sites with manure treatment corresponds with the findings by Bayu *et al.* (2005). It is well documented that OH^- produced by lime raises soil pH, whereas the increase in soil pH due to green manure is less obvious and open to discussion (Hunter *et al.* 1997). It has been proposed that ligand exchange reactions between manure-derived organic anions and terminal OH of the soil solid phase are involved in, or even responsible for, such pH increases (Hue 1992). The pH increment in manure treatment could also be explained by the high increment in the concentration of base forming cations (calcium, magnesium and potassium). Any process that will encourage high levels of exchangeable base forming cations will contribute towards a reduction in acidity (Brady 1990) as was the case in this study.

Soil carbon decreased for most of the treatments at Mucwa good site. The reduction in C levels could be attributed to rapid decomposition rates in the area. Soil carbon increased with the application of manure as opposed to the other treatments. The increase of soil organic carbon in the manure treatment could be as a result of lower quality (low N and high ash content) and lower decomposition rates compared to the other organic materials. In addition, the organic carbon of manure is usually more humified and consequently, more resistant to mineralization (Saviozzi *et al.* 1999).

Conclusions and recommendations

Generally the treatments with application of organics resulted in higher maize grain yields compared to the treatments with sole mineral fertilizer, demonstrating the superiority of the organics in yield improvement due to their beneficial roles other than the addition of plant N as in the case of mineral fertilizer treatments. The seasonal addition of organic and mineral fertilizers to the soil was not able to prevent the decline in soil fertility due to cultivation. The treatments that had very high maize grain yields did not lead to improved soil fertility. This therefore means that there is a need for tradeoffs when selecting the treatment to apply to the soil.

Acknowledgements

The authors wish to thank Vlaamse Inter-Universitaire Raad (VLIR) and International Foundation of Sciences (IFS) for providing financial support for the field experimentation.

References

Adiel RK (2004) Assessment of on-farm adoption potential of nutrient management strategies in Chuka division, Meru south, Kenya. Msc Thesis, Kenyatta University, Kenya.

Anderson JM, Ingram JSL (1993) Tropical Soil Biology and Fertility: A Handbook of Methods. CAB International, Wallingford, UK.

Bayu W, Rethman NFG, Hammes PS (2005) The role of manure in sustainable soil fertility management in sub-Saharan Africa. *Journal of Sustainable Agriculture* **25**, 113-136

Brady NC (1990). The nature and properties of soils. Macmillan Publishing Company, New York. Tenth Edition

Hue NV (1992). Correcting soil acidity of a highly weathered Ultisol with chicken manure and sewage sludge. *Communication in Soil Science Plant Analysis* **23**, 241-264

Hunter DJ, Yapa LGG, Hue NV (1997) Effects of green manure and coral lime on corn growth and chemical properties of an acid Oxisol in Western Samoa. *Biology and Fertily of Soils* **24**, 266-273

Jaetzold R, Schmidt H, Hornetz B, Shisanya CA (2006). Farm management handbook of Kenya. Natural conditions and farm information. 2nd Edition. Vol.11/ C. Eastern Province. Ministry of agriculture/GTZ, Nairobi, Kenya.

Jama B, Palm CA, Buresh RJ, Niang A, Gachengo C, Nziguheba G, Amadalo B (2000) Tithonia diversifolia as a green manure for soil fertility improvement in western Kenya: A Review. *Agroforestry Systems* **49**, 201-221.

Kihanda FM (1998) Improvement of farmyard manure quality through composting with high quality organic residues. Research proposal funded by the African Science-Based Development Career Awards of the Rockefeller Foundation (1998-1999). KARI, Nairobi, Kenya.

Kimetu JM, Mugendi DN, Palm CA, Mutuo PK, Gachengo CN, Bationo A, Nandwa S, Kungu JB (2004) Nitrogen fertilizer equivalencies of organics of differing quality and optimum combination with inorganic nitrogen source in central Kenya. Nutrient Cycling in Agroecosystems **68**, 127-135

Mucheru-Muna MW, Mugendi D, Kungu J, Mugwe J, Bationo A (2007) Effects of organic and mineral fertilizer inputs on maize yield and soil chemical properties in a maize cropping system in Meru South District, Kenya. .*Agroforestry Systems* **69***,* 189-197

Mtambanengwe F, Mapfumo P, Vanlauwe B (2006) Comparative short-term effects of different quality organic resources on maize productivity under two different environments in Zimbabwe. *Nutrient Cycling in Agroecosystems* **76**, 271-284.

Saviozzi A, Biasci A, Riffaldi R, Levi-Minzi R (1999) Long-term effects of farmyard manure and sewage sludge on some soil biochemical characteristics. *Biology and Fertility of Soils* **30**, 100-106.

Smaling E (1993) Soil Nutrient Depletion in sub-Saharan Africa. In "The role of plant nutrients for sustainable food crop production in sub- Saharan Africa' (Eds H Van Reuler, W Prins) (VKP Leidschendam, The Netherlands)