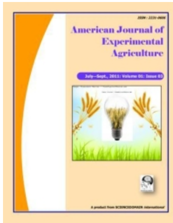

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Response of Maize to Organic and Inorganic Sources of Nutrients in Acid Soils of Kenya

P. A. Opala[1*], R. O. Nyambati[2] and P. O. Kisinyo[3]

[1]*Department of Soil Science, Maseno University, P.O. Box, Private Bag, Maseno, Kenya.*
[2]*Kenya Forestry Research Institute, Maseno Regional Centre, P.O. Box 5199, Kisumu, Kenya.*
[3]*Rongo University College, Rongo, P.O. Box 104-40404, Rongo, Kenya.*

Authors' contributions

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

Original Research Article

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ABSTRACT

Maize yield in Kericho County, Kenya is limited by infertile acidic soils. The effect of inorganic sources of nutrients and amendments; triple superphosphate (TSP), calcium ammonium nitrate (CAN) and lime, were compared to a range of organic nutrient sources; Farmyard manure (FYM) of low and high quality, dried cow dung, goat manure, tithonia applied as green manure or dried, in a greenhouse and field experiment. Two soils collected from two farmers' fields in Sigowet and Litein locations (Hereafter referred to as Sigowet and Litein) were used in the greenhouse where maize was grown for six weeks and its biomass yield determined. The treatments that showed promise were used in a subsequent field experiment where maize was grown to maturity and grain yield determined. In the greenhouse, maize responded to application of all the sources of nutrients and amendments, except lime when applied without TSP, on Sigowet's soil. On Litein's soil, maize did not respond to application of lime alone or with TSP, TSP and dried tithonia. High quality FYM gave the highest increase (136%) in dry matter yields on Litein's soil. In the field experiment, goat manure gave the highest grain yield. Maize failed to significantly respond to either CAN or TSP when applied alone but the application of the two in combination (TSP + CAN) effected a significant response indicating that both N and P were deficient in this soil. All the manures, except low quality FYM, gave yields that

**Corresponding author: Email: ptropala@yahoo.com;*

were higher or comparable to the standard recommended fertilizer practice (TSP + CAN) and could be economically attractive substitutes as they are locally available. There was a poor correlation between dry matter biomass yield in the greenhouse and grain yield in the field. Extrapolation of greenhouse findings to different fields should therefore be treated with caution.

Keywords: Acid soils; inorganic fertilizers; maize yield; organic materials.

1. INTRODUCTION

The densely populated humid regions of western Kenya have experienced high rates of soil fertility depletion [1]. In addition to the widespread P-deficiencies, nitrogen and potassium limitations are common, especially when P limitations have been overcome [2]. The situation is exacerbated by the high acidity of these soils with possibility of aluminum toxicity. Such conditions are common in Kericho County. Thus althoug h most parts of Kericho receive favorable rainfall, crop productivity is seriously constrained with yield of maize, the staple food crop, rarely exceeding 1 ton ha^{-1} on smallholder farms. Consequently, food insecurity is common in the region.

Management of nutrient deficiencies requires addition of organic or inorganic fertilizers or their combinations. Present management practices for amelioration of P-deficiencies and soil acidity include the utilization of the low input strategy consisting of spot or band fertilizer placement and use of soil amendments such as lime [3]. Use of the low input strategy, however, remains negligible among the smallholder farmers in Kenya due to the ever increasing costs of purchased fertilizer in particular and lime inputs. In addition, inorganic fertilizers alone cannot guarantee long-term productivity on many soils since they are not effective in maintaining the soil organic matter (SOM) stock; hence inputs of organic materials are needed to SOM levels [4]. Thus in Kenya, there is growing interest in finding alternative, affordable, viable and sustainable technologies to replenish soil fertility with focus shifting to solutions that utilize more local resources and less external inorganic inputs [5].

The use of organic amendments, in particular could be both agronomically and economically attractive because they can serve the dual purpose of providing a range of plant nutrients while ameliorating soil acidity [6]. Several studies have demonstrated the positive effects of OM in greenhouse studies and assumed the same would hold under field conditions. There are not many studies, however, comparing the results of greenhouse and field experiments. Greenhouse experiments have the advantage of a good control of environmental variables but with a lack of realism, while field experiments are the opposite [7]. The objective of this study was therefore to i) explore the effectiveness of a range of organic amendments, commonly available on smallholder farms in Kericho County, Kenya, in terms of ameliorating soil acidity, increasing available phosphorus and nutrient uptake by maize in a greenhouse pot experiment and field experiment and ii) to correlate the results obtained under greenhouse conditions to those of field conditions.

2. MATERIAL AND METHODS

2.1 Site Description

The study was conducted at the Kabianga University College Farm, in Kericho County, Kenya. The site lies at an altitude of 2163 m above sea level and is within latitude 0º49’0N and longitude 35º49’60E. The average rainfall is 900-1200 mm per annum distributed mainly between the months of March and December with two distinct peaks in May and October. The soils at the site are Nitisols which are acidic, moderately deep and well drained [8].

2.2 Preparation of Organic Materials and Analyses

Organic materials which represent common alternatives to inorganic fertilizers on smallholder farms but varying in their chemical characteristics were used. These were farmyard manures of different composition, *Tithonia diversifolia* (tithonia) and goat manure. They were collected from the vicinity of the experimental sites and air-dried for future use. A sub-sample of each OM was then oven-dried at 70ºC and ground to pass through a 0.5 mm sieve. The nutrient content of these organic materials (total N, P, K, Ca, Mg) were determined as described by [9].

2.3 Experimental Layout and Management

Two types of experiments were conducted; a greenhouse pot experiment and a field experiment as described below.

2.3.1 The greenhouse pot experiment

Soil (0-20 cm) was collected randomly from various spots at two farmers (Sigowet and Litein) fields that were reportedly not responding to fertilizers. The properties of these soils together with those at the Bukura site are presented in Table 1.

Table 1. Initial surface (0-20 cm) soil properties at the study sites

Parameter	Value		Kabianga
	Sigowet	Litein	
pH (H_2O) (1:2.5)	4.80	5.10	5.30
Exchangeable acidity ($cmol_c\ kg^{-1}$)	0.88	0.35	0.31
Exchangeable Al ($cmol_c\ kg^{-1}$)	0.63	0.13	0.10
Exchangeable bases ($cmol\ kg^{-1}$)			
Ca	1.94	2.90	2.30
Mg	1.01	1.80	2.51
K	0.12	0.20	0.15
Organic C (%)	3.20	1.70	2.30
Total N (%)	0.30	0.30	0.25
Total P (%)	0.04	0.03	0.03
Olsen P ($mg\ kg^{-1}$)	5.60	2.50	4.80
Texture (%)			
Sand	50	52	40
Silt	18	28	10
Clay	22	20	50

The collected soil samples were air-dried, sieved through a 4 mm mesh and applied in all the pots at a rate 4 kg of soil pot^{-1}.

The experimental treatments were as follows:

1. Control
2. Lime
3. Lime + Triple superphosphate (TSP)
4. TSP
5. Dried cattle dung
6. FYM high quality
7. FYM low quality
8. Tithonia green manure
9. Tithonia dry
10. Goat manure

Note: The nutrient content hence quality of the organic materials is presented in Table 2. An experiment using the randomised complete block design with three replicates was installed. All the treatments with no organic materials application received muriate of potash (60 kg K ha^{-1}) and CAN (100 kg N ha^{-1}) to ensure that all the major nutrients (except the control) were non-limiting [10]. The organic amendment were analysed at the Mumias Sugar Company laboratory and their characteristics are given in Table 1. All organic materials were applied at a rate of 5 t ha^{-1} and TSP at 60 kg P ha^{-1}. Lime was applied at 4 t ha^{-1} to the appropriate pots receiving lime treatment and incubated for 30 days at approximately field water holding capacity to allow reaction before planting. The other treatments were applied on the day of planting (15th March 2011) after which 4 maize seeds were planted per pot at a depth of approximately 2 cm. The maize plants were thinned to 2 per pot one week after emergence from the soil. Soil water was maintained at almost equal levels for all treatments by regular watering and weeds were regularly removed by hand. Each treatment was destructively harvested at 6 weeks after planting by cutting the maize tops at soil level. The harvested plants were oven dried at 70ºC to a constant weight.

2.3.2 The field experiment

A Field trial was conducted at the Kabianga University College Farm for one season (May to November 2011) to test whether the observed responses in the green house study could be replicated under field conditions. However, lime was not included in the field experiment because of its poor performance in the greenhouse while tithonia was excluded because of its unavailability in adequate quantities in the study area. A randomized complete block design with 3 replicates was used with treatment plot sizes of 4 m x 3 m. The experimental treatments were as follows;

1. Control
2. Calcium ammonium nitrate (CAN)
3. TSP
4. TSP + CAN
5. Dried cow dung
6. FYM low quality
7. FYM high quality
8. Goat manure

All the manures were applied at 5 t ha^{-1} while TSP was applied to supply 60 kg P ha^{-1}. All the nutrient inputs were broadcasted uniformly on the plots and then incorporated into the top soil (0-15 cm) by a hand hoe prior to planting of maize. CAN at 100 kg ha^{-1} was split applied in plots without organic amendments, one third at planting and two-thirds at 5 weeks after planting. The rates of fertilizers and manures were based on recommendations [10] and previous studies in western Kenya [11]. The experiment was managed using recommended agronomic practices for the study area. The grain and stover yields were determined when maize matured.

2.4 Data Analyses

Analysis of variance (ANOVA) was conducted to determine the effects of treatments on the measured parameters. The Least Significant difference between means (LSD) was used to compare the treatment means. Mention of statistical significance refers to $p = 0.05$ unless otherwise stated. Quantitative relationships between dry matter yields obtained in the greenhouse study and stover and grain yields obtained in the field study were developed by regression analyses. Statistical analysis was conducted using the Genstat statistical package [12].

3. RESULTS AND DISCUSSION

3.1 Nutrient Content of the Organic Materials Used in the Study

Tithonia had the highest levels of N, K and Mg while FYM of high quality had the highest amounts of P Table 2. The nutrient content of the high quality FYM was almost double that of the poor quality FYM. Apart from the low P content, the nutrient content of goat manure was comparable to that of high quality FYM.

Table 2. Nutrient content of the experimental organic materials

Organic material	Parameter				
	N%	P%	K%	Ca	Mg
FYM high quality	2.27	1.50	0.88	0.41	0.24
FYM low quality	0.98	0.62	0.56	0.23	0.16
Dried cattle dung	1.18	1.30	0.64	0.32	0.21
Tithonia	4.23	0.41	2.64	1.81	0.38
Goat manure	2.21	0.36	0.52	0.53	0.31

3.2 Greenhouse Study

The dry matter yield for maize grown in the soils collected from the two sites in the greenhouse is presented in Table 3. There were highly significant ($p < 0.001$) differences among the treatments in both soils. However, the response to the application of the different nutrient sources and amendments varied with the soil. Maize responded to application of all the sources of nutrients and amendments, except lime when applied without TSP, on Sigowet's soil. Application of goat manure gave the highest yield increase (135%) above the control for this soil Fig. 1. On Litein's soil, maize did not also respond to application of lime when applied alone. In addition, maize did not respond to lime applied with TSP, TSP and dried tithonia on this soil. High quality FYM gave the highest increase (136%) in dry matter yields on Litein's soil Fig. 1. Among the cattle manures, high quality FYM was significantly better than dried cattle dung but not low quality manure on both soils. Low quality FYM had slightly higher but none significant yields compared to the dried cattle dung. Tithonia green manure gave significantly higher yields than dried tithonia on Sigowet's soil but not Litein's. Generally, organic sources of nutrients performed better than inorganic fertilizer TSP on both soils.

Table 3. Effect of nutrient sources on biomass dry matter yields

Treatment	Dry matter yield (g/pot)	
	Sigowet	**Litein**
1. Control	11.5a	11.9ab
2. Lime	15.0a	9.2a
3. Lime + TSP	19.4ab	11.4ab
4. TSP	21.6bc	15.2b
5. Dried cattle dung	20.1b	21.6c
6. FYM high quality	26.5c	27.9d
7. FYM low quality	23.3bc	25.1cd
8. Tithonia green	26.6c	17.6bc
9. Tithonia dry	20.5b	15.0b
10. Goat manure	27.9c	25.9cd
LSD	5.2	5.0
CV%	20.0	16.0

Means followed by the same letter within the same column are not significantly different at P 0.05

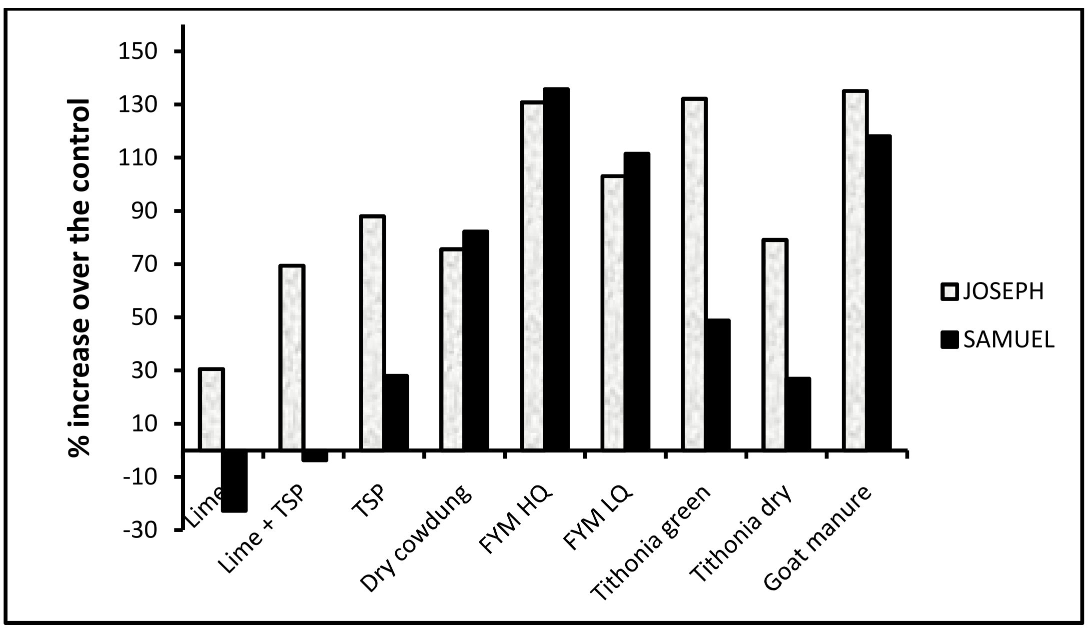

Fig. 1. % Increase in drymatter yield over the control

3.3 Field Experiment

There were significant treatment effects ($p<0.01$) on stover yields which ranged from 11.43 t ha^{-1} (control) to 16.76 t ha-^{1} (high quality FYM) Table 4. Maize did not respond to application of CAN alone or FYM of low quality but gave significantly higher stover yields relative to the control for all the other treatments. Unlike in the greenhouse study where dried cowdung was inferior to FYM of high quality, in the field experiment the two were not significantly different. Among the manures, only FYM of high quality gave higher stover yields than TSP. The rest had comparable yields with those of TSP. The maize grain yields ranged from 0.76 t ha^{-1} (CAN) to 3.25 t ha^{-1} (goat manure). Maize failed to respond to either CAN or TSP when applied alone but the application of the two in combination (TSP + CAN) effected a significant response. All the manures, except low quality FYM gave grain yields that were higher or comparable to the standard recommended fertilizer practice (TSP + CAN). The increase in grain yield was dependent on the type of the manure and followed the order goat manure > high quality FYM > dried cow dung > low quality FYM. The increases, over the control, for grain yields were much higher than those of stover. For example, goat manure increased grain yield by 242% but increased stover by only 33% Fig. 2. The trend was observed in all the other treatments.

Table 4. Maize stover and grain yields as affected by nutrient sources

Treatment	Yield t/ha	
	Maize stover	**Grain**
1. Control (no nutrient input)	11.43a	0.95ab
2. Calcium ammonium nitrate (CAN)	12.44ab	0.76a
3.Triple superphosphate (TSP)	13.71b	1.47b
4. TSP + CAN	14.72b	2.70cd
5. Dried cow dung	14.22b	2.57c
6. FYM low quality	13.20b	1.43b
7. FYM high quality	16.76c	2.93cd
8. Goat manure	15.23bc	3.25d
LSD	2.14	0.67
CV%	10	19

Means followed by the same letter within the same column are not significantly different at $P\leq 0.05$,

There was a poor correlation between the biomass dry matter yields obtained in the greenhouse and the grain yield in the field study for both Sigowet ($r^2 = 0.47$) and Litein's soils ($r^2 = 0.29$) Figs. 3 and 4. The correlation with stover was also low for Liteins's soil. However, there was a high correlation (r^{2} = 0.74) of the greenhouse biomass to stover yield for Sigowets soil.

The responses to the different nutrient sources in the greenhouse were soil specific likely due to differences in the soil properties of the two soils Table 1. Such soil specific responses have been reported by others [13]. The failure of maize to respond to TSP on Litein's soil and the low response on Sigowet's soil confirmed the farmers' observations on the ineffectiveness inorganic fertilizers on their farms. It had been hypothesized that high acidity of these soils could be causing Al toxicity but the failure of lime application to increase yields suggest other limitations. The synergism that was observed when lime was combined with TSP compared to application of lime alone or TSP alone on Sigowet's soil Table 3 suggests a simultaneous P deficiency and acidity problem which is evident from the properties of this soil presented in Table 1. However, on Litein's soil where no response to lime and TSP, whether applied alone or in combination, was observed, other factors other than acidity and P deficiency could be at play. The soil in the field study did not respond to N when applied alone (CAN) but responded to P applied alone implying that P was more limiting than N Table 1 although both N and P were deficient as confirmed by the higher yields when TSP was combined with CAN. This confirms reports by [14] that most soils in western Kenya do not respond to N unless P limitations are overcome.

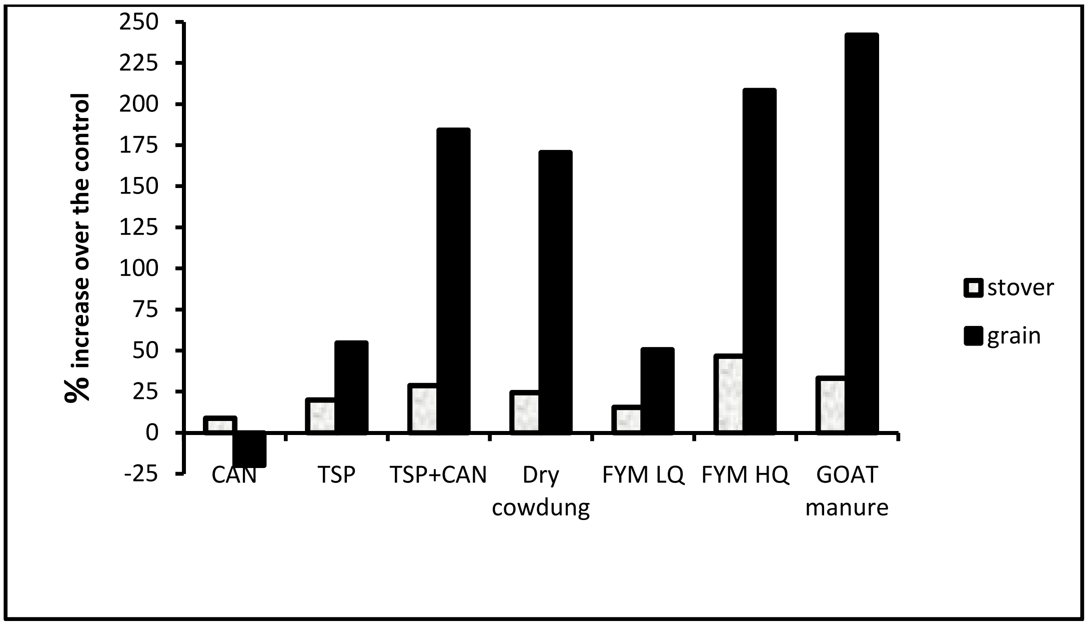

Fig. 2. % increase in stover and grain yield over the control

Application of organic materials generally had positive effects on yields but the magnitude varied with the type and quality of organic input. FYM of high quality out-performed that of low quality both in the greenhouse and field while goat manure was better than the other manures likely due to their high nutrient content. All the manures were applied at 5 t ha^{-1} and therefore the amount of nutrients supplied by them varied with their quality. For example, for the most limiting nutrients N and P, FYM of high quality provide 114 kg of N and 75 kg P ha^{-1} compared to 49 and 31 kg of N and P ha^{-1} respectively for the low quality FYM. This does not however explain the slightly higher or comparable yields obtained by the high quality OMs in the field compared to the standard to inorganic fertilizers; TSP combined with CAN, whose application provided 60 kg P ha^{-1} and 100 kg N ha^{-1} respectively. However, there are other factors other than nutrient content that could also have contributed to the responses observed among the manures. For example, low biomass yields were observed for dried tithonia compared to the green tithonia although both provided the same quantity of nutrients. This is likely due to increased polyphenol content and reduced nutrient release following drying of plant biomass [15]. In addition, organic materials positively affect other soil properties such as cation exchange capacity, improvement of soil structure and moisture holding capacity [16,17]. They also provide other nutrients such as micronutrients which were not provided by TSP and CAN. This could also have contributed to their general superiority over inorganic fertilizers.

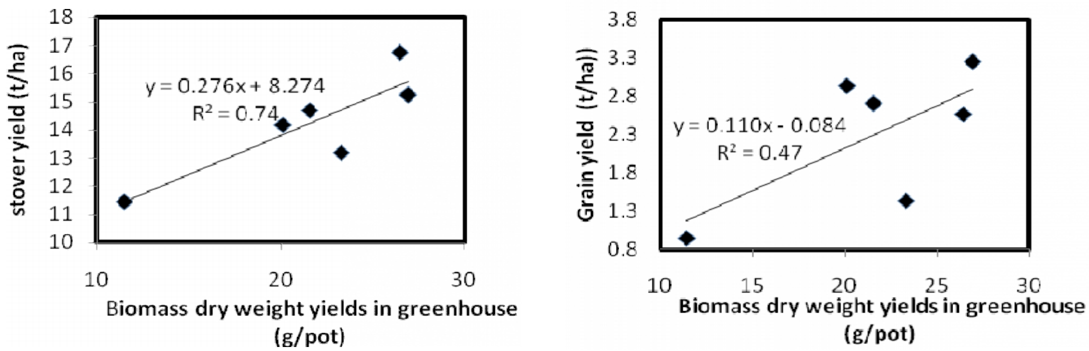

Fig. 3. Relationship between biomass dry weight yield (Sigowet's soil) in greenhouse with stover and grain yields in the field

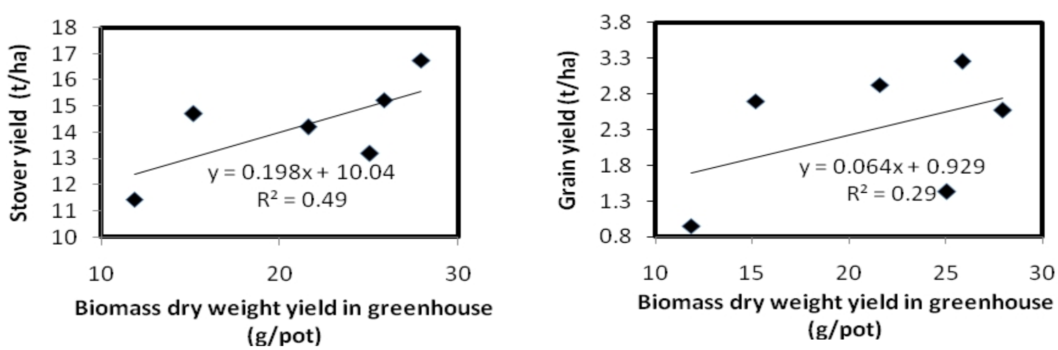

Fig. 4. Relationship between biomass dry weight yield (Litein's soil) in greenhouse with stover and grain yields in the field

The poor correlations between dry matter biomass yield in the greenhouse and grain yield in the field could be attributed to the fact that in the greenhouse, the maize was harvested before the period of high nutrient demand unlike in the field where the crop grew to maturity. Therefore some of the treatments that performed well in the greenhouse e.g., FYM of low quality may have failed to supply enough nutrients demanded for grain production in the field. This is corroborated by the generally better correlation with stover yields, especially for Sigowet's soil, suggesting that some of the inputs were able to meet the nutrient requirements of the vegetative stages of growth (biomass) but were not adequate for grain production. Furthermore, some of the manures e.g. the goat manure and dried cattle dung may not have had enough time to mineralize in the short period in the greenhouse (6 weeks) and the longer period in the field, coupled with more favorable conditions for mineralization compared to the greenhouse, allowed them to perform better in the field. Moreover, the use of different soils in the greenhouse and field experiment and differences in their environments may have contributed to the poor correlation between greenhouse and field data.

4. CONCLUSION

The responses to the nutrient sources in the greenhouse were soil specific. Sigowet's soil was more responsive to most of the organic and inorganic inputs tested while Litein's soil was none responsive to inorganic inputs and low quality manures. Among the manures, quality in terms of nutrient content and ability to mineralize seemed to have largely affected their effectiveness with goat manure and FYM performing well both in the greenhouse and field. In the field experiment, maize failed to significantly respond to either CAN or TSP when applied alone but the application of the two in combination (TSP + CAN) effected a significant response suggesting a simultaneous deficiency of N and P at this site. All the manures tested, except low quality FYM, gave grain yields that were higher or comparable to the standard recommended fertilizer practice (TSP + CAN). Differences in response by maize to the different organic and inorganic inputs on the two soils in the greenhouse and lack of correlation between biomass dry matter yields in the greenhouse with the maize grain yields in the field indicate that recommendations of nutrient sources for maize cannot easily be transposed among diverse soils of Kericho County or from greenhouse to field.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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