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Maize production in the central Kenya highlands using cattle manures combined with modest amounts of mineral fertilizer

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Abstract

Smallholder farmers in sub-Saharan Africa have limited options for soil fertility replenishment due to low resource endowments, especially of cash to purchase mineral fertiliser and access to sufficient organic resources. In recent years there has therefore been a renewed interest in the combined use of inorganic and organic nutrient sources for soil fertility replenishment. The objective of this study was to use cattle manures combined with modest amounts of mineral fertiliser in maize production central Kenya. Manures collected from smallholder farms were characterised in order to define quality. They were also evaluated in a laboratory leaching tube incubation experiment for nutrient release potential and in on-farm field experiments at two sites in central Kenya over two growing seasons. The results indicated that well-managed manures can release nutrients, particularly N for immediate crop uptake during the first season of application. Combining manures with mineral fertilizer was more effective in the production of maize, compared to singular application of manures (5 t ha^{-1}) and mineral fertilizer alone applied at rates below 100 kg N ha^{-1}. Economic analysis showed higher benefits to cost ratios when manures (5 t ha^{-1}) were combined with (40 kg N ha^{-1}) mineral fertilizer.

Keywords: Economic analysis, organic and inorganic interactions, soil fertility

Introduction

Maize (*Zea mays*) is the staple food crop in Kenya and is grown over a wide range of agro-ecological zones. The area under maize production is estimated has presently stagnated at 1.5 million hectares, with an expected national production of 2.52 million tonnes and a national consumption of 3 million tonnes (Government of Kenya, 2002), indicating a production deficit, which will have to be met through increased imports. Soil fertility depletion in smallholder farms is the major biophysical root cause for the declining per-capita food production in most of sub-Saharan Africa (Sanchez *et al*., 1997). The central Kenya Highlands, where this study was carried out, covers approximately 18% of the land area of the country but contains around 64% of the population, with population densities in excess of 1,000 people per square kilometre in many areas (Braun *et. al.*, 1997). In this highly populated region, an on-going long-term experiment has shown that maize yields can decline by about 30% in the absence of fertiliser and/or manure application (Quereshi, 1987). The use of inorganic fertilisers can overcome most of this soil fertility decline but inorganic fertiliser use in smallholder farms is associated with several constraints. A survey in Kiambu district, central Kenya listed high cost of fertiliser and its unavailability as major constraints to fertiliser use in maize production (Makokha *et al*., 2001). An alternative to inorganic fertilisers is the utilisation of farm-derived sources of crop nutrients such as crop residues, composts and farmyard manure (see for example, Delve, 2001; Lekasi, 2000, Kihanda, 1996). Legume cover crops and biomass transfer from trees and shrubs growing along farm borders have also been used as alternative sources of nutrients(Jama *et al.* 1999; Mafongoya and Nair, 1997).

Staal *et al.* (1997) found that in Kiambu District of the Central Kenya Highlands 80% of farming households kept ruminant livestock, of these 95% used zero grazing for their livestock. As a result manure is the most widely used organic fertiliser, by approximately 80% of households (Makokha *et al*. 2001). Of these about 90% of farmers use manure from their farms, while 10% either purchase it or are given free. However, in the majority of farms, the available manure is not enough to fertilise the farms (Makokha *et al.* 2001; Lekasi *et al.*, 1998; Kihanda, 1996; Kagwanja, 1996). The housing of livestock varies enormously from open roofed units on soil to roofed houses with concrete floors allowing separate collection of faeces and urine. Unfortunately most housing types are the former and consequently the manures collected from these units are usually of poor quality and are particularly low in total N, with most having less than 1% N and therefore do not contain enough nutrients to sustain crop production. (Giller *et al.,* 1997). In comparison, legume cover crops can have over 3% N (Palm *et al.,* 2001). In addition, manures can have beneficial effects on other factors, for example, improvement in soil physical conditions such as improved moisture retention and addition of nutrients, other than N and therefore play an important role in production systems (Kihanda and Gichuru, 1999). Because of these multiple benefits farmers are unwilling to stop applications of manures to their soils, so under this situation, and specifically for central Kenya, the best option would be to overcome the nutrient deficiencies through the combined use of cattle manures with modest amounts of inorganic fertilizers as a strategy to maintain and enhance soil fertility.

To date there are no recommended guidelines for combining organic and inorganic nutrients because of inadequate experimental design and little information on the quality of organic inputs used (Palm *et al.,* 1997). Thorough characterization of organic inputs linked to crop responses is critical if we are to be able to explain the positive responses observed in field experiments when manure is applied. Some initial work has indicated that crop responses maybe linear to the initial N content of added plant materials but the relationship for manures is not as clear.

The objectives of this study were therefore to (i) to characterize cattle manures from on-farm and on-station sources (ii) determine the nitrogen mineralization potential of these manures (iii) determine the effects of combining cattle manure of known quality with modest amounts of inorganic fertiliser on maize yield and (iv) to compare economic returns of the integrated use of manures and inorganic fertilizers

Materials and methods

Characterisation of cattle manures

During a participatory rural appraisal (PRA) exercise in Kiambu district, central Kenya (Makokha *et al.*,2001), 65 cattle manure samples were collected from farms in Kiambu district. Five manure samples were collected from the Kenya Agricultural Research Institute farm at the NARC Muguga station. These manures differed in the way they were managed both on-station and on-farm. The manures were analysed for nitrogen (Kjeldahl digestion followed by steam distillation; Tecator); Total soluble N (Kjeldahl digestion); total soluble C following an adapted wet digestion using potassium dichromate (Dalal,1979); acid detergent fibre (ADF, measures cellulose), neutral detergent fibre (NDF, measures hemi-cellulose and cellulose) and acid detergent lignin (ADL, measures lignin) (Ankom Technology Corporation, Fairport, USA; van Soest *et al*. 1987); NDF-N (Ankom incubation followed by nitrogen determination) and total ash (4 h at 500°C).

Experimental sites and soils

On-farm trials were conducted at two sites in central Kenya that had been found to be N deficient through limiting nutrient experiments in an earlier study. The sites were at Kandara division, Kariti (0° 52' S, 37° 01' E, 2000 m a.s.l.) and at Thika division, Gatuanyaga (1° 05' S, 37° 11'E, 1,700 m a.s.l.). At Kandara, mean annual rainfall is 1300-1600 mm and annual mean temperatures of 19.7-18.0°C. The soils are well-drained, extremely deep, dusky red to dark reddish brown, friable clay (Humic Nitisol). In Thika, average annual rainfall is 750-900 mm and a mean temperature of 20.7-19.9°C. The soil at the Thika site is best described as imperfectly drained, dark to grey to black (Pellic Vertisol). The soils were sampled (0-15cm), air-dried and ground to pass a 2 mm sieve and characterized for pH (in water), total C (Walkley-Black), total N (Kjeldahl), total P Ca, Mg and K (extracted in NH_4OAc). Details of the analytical methods are described by Anderson and Ingram (1996). From the manures identified in the characterization stage, eight of them with varying quality plus one from an on-station experiment were taken for further investigation in the incubation experiment

Laboratory incubation of manures

N mineralization was measured using leaching tube incubations following a modified method of Stanford and Smith (1972). Air-dried soil (50g) was mixed with acid-washed sand (1:1 w/w). The soil (0-15cm) had the following properties: 6.6 pH in water, 1.33 % organic carbon, 0.103% total N, 34% clay, 33% sand and 34% silt. The sand-soil mixture was mixed with cattle manure at an equivalent of 100kg N ha^{-1} (approximately 60 mg N kg^{-1} soil). The mixture was brought to 70% water holding capacity. There were nine treatments with three replicates randomized in racks and incubated in a growth room at 25°C. Leaching was done at intervals of 0, 1, 2, 4, 8, 16, 20 and 24 weeks with 150 ml of leaching solution (1 m*M* $CaCl_2$; 1 m*M* $MgSO_4$; 0.1 m*M* KH_2PO_4 and 0.9 m*M* KCl) in three 50 ml aliquots and the leachate collected in conical flasks.

After leaching, moisture of the mixture in the tube was brought back to approximately 70 % of the water holding capacity by removing the excess water with mild suction. The ammonium and nitrate nitrogen concentration of the leachate was determined and the net N mineralization calculated by subtracting the N mineralization in the soil only control tube from the N mineralization in the cattle manure amended tubes.

Organic and inorganic fertiliser trial

The on-farm experimentation consisted of a nitrogen and phosphorus response curve with four treatments (control, 20 kg N ha^{-1}, 40 kg N ha^{-1}, 100 kg N ha^{-1}) and cattle manures alone (manure-1, manure-2) or in combination with inorganic fertilizer (manure-1 + 20N, manure-1 x 40N, manure-2 x 20N and manure-2 x 40 N). Inorganic fertiliser was applied as di-ammonium phosphate (46% P_2O_5; 18% N). Thus for every kg N applied, P_2O_5 was applied at 2.6 kg. From previous studies, P application for the site is recommended at 40 kg P ha^{-1}, so it is unlikely that the higher levels of P application may have confounded the results. Cattle manures were prepared at NARC Muguga Research Centre. One cattle manure was the same as was used in the incubation experiment (manure-1), which comprised of faeces plus feed refusals manually-mixed and composted for 4 months. Manure-2 comprised of faeces plus feed refusals mixed by the animal in the stable. The manures were applied at an iso-nitrogenous level of 80 kg N ha^{-1} and were point applied in the planting holes. Plot sizes were 6 x 4 m^2 and planted maize seeds were spaced at 75 cm x 30 cm. Two maize seeds were initially sown and were later thinned to one plant per hill after emergence (plant population of 44,444 plants ha^{-1}).

Above-ground biomass yields were determined at harvest. Yield components included stover and grain yield. Following harvest, the plots were ploughed by hand, cleared of weeds and crop residues and sown with maize as described for the first season, to monitor residual effects.

Statistical analysis

Data were analysed using SAS (SAS Institute Inc., 1988). Significant differences are reported at the P<0.05 level. Correlations between net N mineralized and the chemical components of the incubated samples were conducted to identify the main factors affecting N release form the manure samples.

Economic Analysis

Costs and benefits were calculated and compared with the unfertilised control. The manure, fertiliser and labour prices were determined according to a survey conducted in the area (Makokha *et al*. 2001). Labour was valued at the wage rate of hired casual workers in the study. Maize price was determined according to the market costs during harvest.

Results and discussion

Characterization of cattle manures

The manures collected from farmers in Kiambu District had a wide range of qualities (Table 1.), with total N contents ranging from 0.87% to 1.77% with an average of 1.43% and C:N ratios of 13 to 32. Higher ash contents reported in the on-farm manures may be due to soil contamination of the manures when they are removed from the housing unit. The soluble fractions of N, P and C are higher in the on-station manures. The high soluble C: soluble N ratio for both types of manures suggests that these may immobilize N when added to the soil. The recommended rate of N application for maize in the Central highlands is 60 kg N ha^{-1}, therefore on average 4.2 and 3.5 t ha^{-1} on-farm and on-station manure respectively is required to supply this recommended rate of N. However, not all the nutrients will be released from the manure in one season. Studies have shown that only 11-33% of this N is released from cattle manures in the first season (Kimani *et al*. 1999), which means that the required quantities of these manures is three to four times higher. This manure requirement is far in excess of the available resources at the farm level and farmers are faced with the option of applying less quantities to a large area or to concentrate the manure on smaller areas of land. Or farmers will need to supplement their manures with other sources of N.

Laboratory incubation of manures

The manures used in the incubation study showed a range of quality (Table 2). All manure samples showed immobilisation of N for the first 5 weeks of incubation, the time to net mineralization varied for each manure sample with all but one sample showing net mineralization of N after 12 weeks (Table 3). This initial immobilisation after incorporation of manures has been reported (Delve *et al*. 2001; Kirstensen, 1996).The recovery of added N after 24 weeks expressed as a percentage of that added varied widely between the different quality manures (Table 3).

Addition of manures to soil resulted in a small amount of net N mineralization over the first two weeks for some manures and initial immobilization for others (Figure 1). All but one manure showed a net N release throughout the duration of the 24 week incubation. The highest net release of N was 44.5% and the lowest was –27.4 % at the end of the 24 week period (Table 3). Delve et. al. (2001) reported N recoveries in incubation experiments ranging from –9 to 30% of added N depending on the diet of the cattle.

The C:N ratio of the soluble fraction in the manure samples ranged from 13 to 30 (Table 1) The data was further subjected to simple correlations at p = 0.05 level (Table 4). The results showed that initial %lignin was significantly (P<0.1) correlated with net N mineralization in the first four weeks and the derived ratios soluble C:solube N and (lignin+ADF-N):N were significantly (P<0.1) correlated with net N mineralization in the first four and two weeks respectively. After four weeks no quality indicator was correlated to net N release. Kristensen (1996) reported that the In this study, the rate of N release from the different quality manures was negatively related to the NDF, ADF and lignin of the manures, with the fibre fractions lignin and lignin+ADF best explaining the observed N mineralization results. Other workers have reported close negative relationships between C:N and N mineralization in faeces (Serna and Pomares, 1991)

Table I. Selected analysis parameters for on-farm and on-station manures.

On-farm manures

Parameter	*Max*	*Min*	*Mean*
Ash (%)	25.52	3.98	14.26
Organic C (%)	41.4	11.70	29.33
Total N (%)	1.77	0.87	1.43
Lignin (%)	20.82	4.98	13.71
NDF-N (%)	1.53	0.7	1.17
ADF (%)	51.67	38.86	47.31
Ca (%)	0.3	0.2	0.24
Mg (%)	0.18	0.12	0.15
K (%)	2.6	1.9	2.2
Soluble fractions			
C (mg/g)	4.63	0.76	2.44
N (%)	0.14	0.01	0.06
C: N	66.5	166.5	65.79
P (%)	0.16	0.03	0.09

On-Station manures

Parameter	*Max*	*Min*	*Mean*
Ash (%)	16.11	8.67	12.47
Organic C (%)	39.60	28.2	35.1
Total N (%)	2.0	1.33	1.72
Lignin (%)	31.69	15.04	23.87
NDF-N (%)	1.93	1.23	1.51
ADF (%)	59.99	51.29	56
Ca (%)	0.7	0.18	0.47
Mg (%)	0.6	0.41	0.39
K (%)	*4.1*	*2.4*	*3.2*
Soluble fractions			
C (mg/g)	7.42	3.19	5.6
N (%)	0.18	0.02	0.09
C:N	351.79	31.49	82.42
P (%)	0.15	0.08	0.11

Table 2 Characterisation of the manures used in the incubation study. NARC Muguga is from KARI Muguga Research station while the rest of the manures were from farms in Kiambu district, central Kenya

Source/Division	Total N (%)	Lignin (%)	Soluble C (%)	Soluble N (%)	NDF-N (%)	Ash (%)	Soluble P (%)	C:N
NARC Muguga	1.69	17.59	4.41	0.14	1.20	11.34	0.14	24.29
Limuru	1.10	10.53	1.97	0.01	0.80	12.78	0.10	29.73
Kikuyu-1	1.33	10.95	2.06	0.02	0.97	10.44	0.11	21.43
Githunguri-1	1.53	15.03	3.05	0.02	1.37	9.90	0.05	19.02
Githunguri-2	1.20	11.72	1.64	0.06	1.17	25.54	0.08	14.75
Githunguri-3	1.87	16.55	4.05	0.14	1.70	19.42	0.16	13.32
Tigoni	1.60	15.42	2.56	0.06	1.40	12.03	0.07	18.94
Githunguri-4	0.87	17.13	1.80	0.06	0.60	17.67	0.06	32.76
Kikuyu-2	1.77	14.58	1.92	0.12	1.53	16.34	0.12	17.29

Table 3. Recovery of added N (%) after 24 weeks

Manure sample source	Weeks to net mineralization	N recovery (% of that added)
NARC Muguga	6.4	19.0
Limuru	> 24	-27.4
Kikuyu-1	6.1	44.5
Githunguri-1	7.8	22.3
Githunguri-2	7.5	17.8
Githunguri-3	< 1	36.8
Tigoni	< 1	38.3
Githunguri-4	< 1	12.3
Kikuyu-2	8.5	14.9

Table 4. Correlations between cumulative Net N mineralized with initial quality parameters and derived ratios

	Time (weeks)							
	0	**1**	**2**	**4**	**8**	**16**	**20**	**24**
%N	-0.051	0.177	0.187	0.405	0.657	0.480	0.473	0.473
%Lignin	0.492	0.670	0.664	0.636	0.406	0.319	0.305	0.300
%Soluble C	0.264	0.245	0.230	0.340	0.458	0.337	0.320	0.299
%NDF-N	-0.078	0.168	0.222	0.449	0.508	0.508	0.488	0.482
%Ash	0.072	0.155	0.278	0.242	-0.044	-0.044	-0.031	-0.052
%Soluble P	0.104	0.000	0.031	0.121	0.251	0.102	0.125	0.127
%Soluble N	0.208	0.441	0.476	0.539	0.445	0.253	0.268	0.261
%C	-0.102	-0.103	-0.216	-0.238	-0.190	-0.218	-0.240	-0.225
%ADF	0.324	0.506	0.524	0.374	-0.074	-0.108	-0.079	-0.094
SolC:solN	-0.387	-0.774	-0.801	-0.801	-0.565	-0.484	-0.503	-0.499
C:N	0.111	-0.154	-0.220	-0.452	-0.421	-0.573	-0.588	-0.574
Lignin:N	0.483	0.395	0.393	0.152	-0.299	-0.200	-0.194	-0.192
Lignin+ADF	0.418	0.614	0.624	0.509	0.107	0.050	0.064	0.052
ADF:N	0.281	0.142	0.152	-0.100	-0.520	-0.396	-0.380	-0.381
solC:N	0.421	0.211	0.179	0.129	0.042	0.026	0.010	-0.013
Lignin:NDF-N	0.470	0.331	0.307	0.056	-0.373	-0.262	-0.248	-0.240

Table 5. Soil characterisation of the on-farm field sites

Location	Depth	pH	C (%)	N (%)	P (ppm)	K	Ca	Mg
						mg 100g^{-1} soil		
Gatuanyaga	0-20	5.2	2.34	0.09	10.19	42.95	78.36	20.89
	20-40	5.2	1.06	0.09	6.33	27.62	68.60	19.04
	40-60	5.2	0.94	0.07	2.29	17.40	91.75	26.80
Kariti	0-20	5.2	1.90	0.14	38.29	18.13	112.12	26.37
	20-40	5.4	1.50	0.13	15.07	14.48	138.45	31.96
	40-60	5.6	1.42	0.17	6.82	149.23	149.23	39.02

Table 6. Some characteristics of the two manures used for the field study. Sol, Tot, indicate soluble and total respectively. Lig, Ash indicate lignin and ash contents respectively. NDF-N indicates neutral detergent fibre nitrogen.

Manure type	% Sol C	% Sol N	Sol. C:N	%C Tot	%N Tot	C:N	%NDF -N	% Sol P	% Lig	% Ash
Manure-1	7.2	0.06	120.0	35	1.74	20.06	1.52	0.08	28.46	11.73
Manure-2	6.38	0.07	92.13	32.2	1.86	17.41	1.65	0.11	25.91	13.75

Table 7. Yield data at final harvest at Kariti and Gatuanyaga in 1998

Treatment	Grain yield t ha^{-1}			
	Season 1		Season 2	
	Kariti	Gatuanyaga	Kariti	Gatuanyaga
Unfertilised Control	2.53	2.03	0.43	Crop failure
DAP-100 Kg N ha^{-1}	7.51	4.48	0.44	
DAP-20 Kg N ha^{-1}	5.09	2.65	0.42	
DAP-40 Kg N ha^{-1}	5.36	3.06	0.47	
Manure-1 (80 Kg N ha^{-1})	4.82	3.04	0.46	
Manure-1 + 20 Kg N ha^{-1}	5.64	3.16	0.45	
Manure-1 + 40 Kg N ha^{-1}	6.01	3.44	0.39	
Manure-2 (80 Kg N ha^{-1})	5.08	3.09	0.49	
Manure-2 + 20 Kg N ha^{-1}	5.75	3.83	0.39	
Manure-2 + 40 Kg N ha^{-1}	6.33	3.95	0.44	
Lsd (0.05)	1.31	1.03	0.09	

Manure in the combinations treatments applied at 80 Kg N ha^{-1}

Table 8. Fertiliser equivalencies (%) for the manure and manure-fertilizer combinations

Treatment	Kariti Season 1	Gatuanyaga Season 1
Manure-1 (80 kg N ha^{-1})*	30.4	49.3
Manure 1 + 20 kg N ha^{-1})**	48.3	55.5
Manure 1 + 40 kg N ha^{-1})**	55.4	70.1
Manure 2 (80 kg N ha^{-1})*	33.9	51.9
Manure 2 + 20 kg N ha^{-1})**	50.0	90.4
Manure 2 + 40 kg N ha^{-1})**	60.6	96.7

* Organic N source, ** Combined organic (80 kg N ha^{-1}) and inorganic N source.

Organic and inorganic fertilizer trial

Soil characteristics at the two field sites are shown in Table 5. The levels of the most limiting nutrients (N and P) were relatively higher at Kariti compared with Gatuanyaga. The Gatuanyaga soil was also sandier, indicating the possibility of higher rates of mineralisation of applied nutrients. The manures used in the on-farm experiment were selected from the five on-station composted manures (referred to characterisation Table 1). Manure-1 comprised of faeces plus feed refusals, which were removed from the animal stable daily, and composted in a heap for a period of four months. The heaped compost was manually turned every two weeks to enhance decomposition. Manure-2 comprised of feaces plus feed refusals mixed by the animal in a stable deep litter system, a common practice by farmers in central Kenya. Again the composting period was four months. The manure-1 was also used in the incubation experiment, and is referred to as NARC Muguga (Tables 2 and 3). The chemical characteristics of these two manures are shown in Table 6.

All treatments resulted in significantly higher grain yields compared with the unfertilised control at the Kariti site (Table 7). At Gatuanyaga addition of manure-1 alone did not increase yields significantly but the combination with 20 and 40 kg N did increase yields significantly compared with the unfertilised control. Addition of manure-2 alone or in combination with 20 and 40 kg N increased the maize yield significantly compared with the unfertilised control (Table 7). All maize yields were lower in Gatuanyaga and in particular, the inorganic fertiliser response was not as pronounced in this site compared with Kariti, possibly arising from water shortages at Gatuanyaga. However, in none of the combination treatments where 20 or 40 kg N were added to the manures did the yields increase significantly. This implies that there is no added synergistic response to the extra 20 Kg inorganic N., suggesting that for the combinations, the lower inorganic N was equally effective as the higher inorganic N level. Where organic resources, in this case, manures are available in insufficient quantities and the farmers are unable to afford to apply solely inorganic fertilizers, the combination of the two may be more economically viable.

During the residual season, short rains 1998, rainfall was low and unreliably distributed. There was a total of 300 mm rainfall from October through February, of which 60% was received in November. There was a crop failure in the Gatuanyaga site during this season. Yields at Kariti were low ranging from 0.4 to 0.5 t ha^{-1} (Table 7). The drought during this season may also have confounded the residual effects of the manure treatments.

Fertilizer equivalencies of the treatments

Fertilizer responses (FR) of the manures were obtained by comparing the yield from manures to that of a nitrogen response curve derived from Table 7. The N response curve at Kariti shows that at 100 kg N ha^{-1} maize production was peaking at around 7.5 t ha^{-1} . In contrast, at Gatuanyaga the fertilizer response was still linear up to 100 kg N ha^{-1} Assuming a quadratic function with the equation Y= aFR^2+bFR+C, the following formula for solving the quadratic equation was used:

FR=(-b±"(b2-4ac))/2a

Where a, b and c are constants obtainable from the quadratic equation of the derived response curves using data in Table 8.

The fertilizer (nitrogen) response curves enabled calculation of fertilizer equivalencies (FE) as:

$$\%FE = \frac{\text{Fertiliser response x 100/}}{\text{N applied}}$$

This method of calculating fertilizer equivalencies is well documented (Murwira et al., 2002; Kimetu et al., 2004). The fertilizer equivalency (FE) of the manure treatments alone and in combination were calculated from the derived fertilizer response graphs for both sites using data in Table 7. Addition of inorganic N to the manures alone increased the FE for both sites, although the effect was lower in Kariti (Table 8).

Combining cattle manure with 40 kg N from mineral fertiliser gave a higher fertiliser FE compared with the lower 20 kg .The differences in the FE's in the two sites are most likely due to the different soil types (Table 5), where Kariti has a more fertile soil and more rainfall and Gatuanyaga is a sandier soil and drier. The increased FE at Gatuanyaga is probably due to the increased retention of the inorganic fertilizer by the manure in the soil and to the more responsive soils to inorganic N

Economic analysis

The data used in the economic analysis in our study area is shown in Table 9. This included the price of the mineral fertilizer and manure, transport, labour costs, price of maize and the opportunity cost of capital. DAP at 100kg N/ha gave the highest net benefits (NB) of US$ 455.3 and 446.9 at Kariti and Gatuanyaga sites respectively. However when considering benefit: cost ratios (BCR's) of different fertilizer treatments, DAP at 20 kg N/ha gave the highest BCR in Kariti while DAP at 100 kg N/ha gave the highest BCR at Gatuanyaga. The more efficient fertilizer use at Kariti may be attributed to the relatively higher rainfall in that site compared to Gatuanyaga. The results also show that NB

Table 9. Data used in the cost-benefit analysis

Item	Cost
Price of DAP	0.39 USD kg^{-1} fertilizer
Price of N in DAP	0.07 USD kg^{-1} fertilizer
Price of P (as P_2O_5) in DAP	0.18 USD kg^{-1} fertilizer
Transport of DAP to the homestead	2.0 USD 100 kg^{-1}
Price and Transport of N in DAP	0.074 USD kg^{-1}
Labour cost	0.18 USD h^{-1}
Baseline labour cost for fertiliser application	
spot placement method	3.0 USD ha^{-1}
Price of manure	26.67USD t^{-1} dry manure
Baseline labour cost of manure application Spot placement	5 USD ha^{-1}
Price of maize	18.67USD 100kg^{-1}
Opportunity cost of capital	20% per annum

Exchange rate of 75 Kenya shillings = 1 U.S. dollar (USD)

Table 10. Net Benefits and Benefit Cost Ratios for different Soil Fertility Technologies at Kariti and Gatuanyaga (USD)

Treatment	Net Benefits		Benefits/Cost Ratio	
	Site		Site	
	Kariti	Gatuanyaga	Kariti	Gatuanyaga
Unfertilised control	0	0	0	0
100 kgN ha-1	455.3	446.9	44.8	44.0
20 kgN ha-1	233.5	111.3	53.1	25.8
40 kgN ha-1	261.9	186.3	44.9	32.8
Manure-1	184.9	156.9	6.8	6.0
Manure-1 + 20 kgN ha-1	256.0	174.8	8.1	5.8
Manure-1 + 40 kgN ha-1	283.4	225.6	8.5	7.0
Manure-2	176.3	130.6	3.6	2.9
Manure-2 + 20 kgN ha-1	234.0	273.2	4.7	5.3
Manure-2 + 40 kgN ha-1	291.3	294.1	5.5	5.6

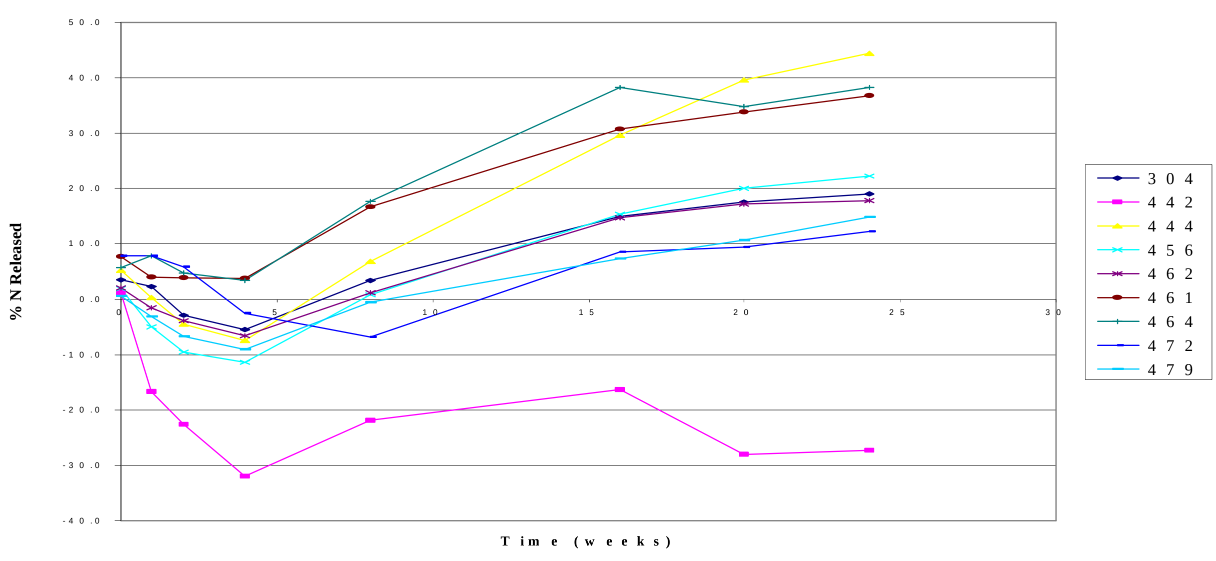

Figure 1. Cumulative N release over time. Manure identification: 304, NARC Muguga; 442, Limuru; 444, Kikuyu-1; 456, Githunguri-1; 462, Githunguri-2; 461, Githunguri-3; 464, Tigoni; 472, Githunguri-4; 479, Kikuyu-2.

alone may not be an adequate index on which to base one's economic decisions. BCR gives return per USD used in every treatment and the higher its value the better the option. Higher BCRs were recorded in Kariti than Gatuanyaga from all treatments since soils in Gatuanyaga are highly depleted of N and P (Table 5) thus requiring higher rates of fertilizers than Kariti, and that rainfall is relatively higher at Kariti

Manure - gave better return per shilling invested in both sites than Manure-2. However the BCR for the manures were higher in Kariti than Gatuanyaga showing a better response of the soil to manure application in the latter site than the former. A similar trend was also observed with Manure-2.

Combinations of different levels of both fertilizer and manures gave BCR values without distinctly marked trends. This is due to the extra costs associated with manure purchase and application labour, which is not reflected on similar proportion to the grain yield (Table 10). Higher BCRs were recorded in Manure-1 + Fertilizers than Manue-2 + Fertilizer, and BCRs were higher in Kariti than Gatuanyaga for Manure-1 + Fertilizer while the opposite was the case for Manure-2 + Fertilizer (Table 10). Manure + 40 kg N/ha in both cases gave the highest BCRs indicating that manure and modest amounts of fertilizer is the most affordable and economical option for smallhold maize growers in the study sites and the central Kenya region.

Conclusion

Organics sources of nutrients continue to draw the attention of both farmers and scientists in the developing countries. However, while guidelines for mineral fertilizer use are generally available, the use of these mineral nutrient sources is sub-optimal for instance in central Kenya due to low farm incomes, among other socio-economic factors. In contrast, guidelines for using organics are generally limited or not available, and, considering the wide diversity of these materials with regard to quality, there is need to formulate some guidelines on organic resource use. The situation is further compounded when the organics have to be combined with mineral nutrient sources. While plant litter contain higher levels of N for instance, manures and other commonly used crop residues have relatively lower nutrient concentrations. In this study we have shown that manure containing 80 kg N ha^{-1} has a fertilizer equivalency of 30-50%. Suffice it to say that quantities required to supply 100% fertilizer equivalency are unlikely to be available at the farm level. This necessitates the need to combine manures with modest amounts of mineral fertilizers.This study was a model of optimising the use of cattle manure, an organic nutrient source, by firstly defining the resource quality, followed by studies on nutrient release, and finalising with on-farm field trials which combined the manure with modest amounts of mineral fertiliser. Combinations of the manures with mineral fertilizer increased the fertilizer equivalencies by 50-97%.

The paper also shows that well-managed manures can mineralise N during the first season of application. Previous work by Lekasi et al. 2003, shows that there is scope to develop some decision tools to predict manure-compost quality from at least some manure characteristics. From our results in this study, we can extend the same argument that it is also possible to develop some guidelines to combine such manures of known quality with mineral fertilizers, thus improving nutrient use efficiency.

Economic analysis showed that singular application of mineral fertilizer resulted in higher benefits to cost ratios compared to the other treatments. However, manures have other benefits apart from supplying nutrients to the soil, hence the preference by most smallhold farmers to combine the two nutrient sources. For the cattle manure and mineral fertilizer combinations, manure applied at 5 t ha^{-1} with 40 kg N ha^{-1} as mineral fertilizer gave the highest benefit to cost ratio indicating that manure and modest amounts of fertilizer is the most affordable and economical option for smallhold maize growers in the study sites and the central Kenya region. The work provides a basis for both scaling up and scaling out in smallhold farms of East Africa and related agro-ecosystems.

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