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Use of Organic and Inorganic Resources to Increase Maize Yields in some Kenyan Infertile Soils: A Five-Year Experience

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Abstract

Use of organic and inorganic resources to increase and sustain agricultural productivity of soils has been practiced worldwide over a long period. Positive effects from these materials are known to be the enhanced nutrient inputs to soils and improved soil physical and biological properties. Effects of separate or individual and combined applications

of organic and inorganic materials to soils have been studied rather extensively and the results are complex. But, it appears for certain, that the quality and quantity attributes are the driving forces towards basic processes in soils such as nutrient mineralisation and release and the overall effectiveness of added materials on crop yields. However, many studies have considered mainly the immediate or one seasonal effects of organics and inorganics on crop yield. Therefore the monitoring of soil process studies in relation to crop growth and yield, as well as considerations on economic benefits arising from the use of these external resources seem to have been slighted. In this paper we present results of field studies at four on-farm, researcher managed sites that vary widely with climate and soils (acrisols, ferralsols and luvisols).

In 1994 first rains, the effectiveness of crop residues (maize stover, groundnut trash and *acacia mearnzii* prunings) on-farm manures and Minjingu phosphate rock (PR) was tested on maize yields at Ndeiya, Gatuanyaga and Malava sites. The organics above were incorporated into soils individually or in combinations giving a target or economical rate of 60 kg Nha^{-1}, while the PR was added at a uniform rate of 40 kg P ha^{-1} in various combinations of the organics. Maize yields in that season ranged from 1256 - 3761 Kgha^{-1} (at Ndeiya and Malava sites only with adequate rainfall). Although maize yield increases did not attain statistical significance, the high N organics (poultry manure, *Acacia mearnzii* and groundnut trash), with PR combinations, gave overall high yield increases. The study period was too short to monitor residual effects of treatments and the solubilisation of PR. But in the Chepkoilel Campus ferralsol (Moi University), maize has been cropped over four consecutive years (1997 - 2000) in plots receiving annual maize stover, wheat straw and initial superphoshate application of 100 kg Pha^{-1} plus combined urea combinations from 20-100 kg Nha^{-1}. Maize yields over the entire study period have ranged from 751-6836 kg ha^{-1} with significant variations occurring from rainfall variations. Nevertheless, again the combined applications of organic and inorganic resources favoured maize production. There are favourable effects of the materials used to improve the soil fertility status of soils. The results suggest an economic potential, to the smallhold farmers, arising from combined use of organic and inorganic resources.

Introduction

Low input agriculture mainly explains the cause of low and declining crop yields in many countries south of the Sahara (Makken, 1993; Simpson *et al.*, 1996; World Bank, 1996). But specifically the prices of imported (inorganic) fertilizers, without subsidies, are unfavourable to most smallhold farmers in the region. Thus in Kenya, where nitrogen (N) and phosphorus (P) nutrients are widely deficient in cropped soils (Okalebo *et al.*, 1992; FURP, 1994; TSBF, 1994), attempts have been and continue to be made to find affordable technologies to correct nutrient deficiencies in soils. These include agroforestry practices especially the use of improved fallows (Jama *et al.*, 1997; Sanchez *et al.*, 1997), combinations of organic and inorganic resources (Palm *et al.*, 1997; Okalebo *et al.*,1999) and use of direct and combined applications of the reactive Minjingu (Tanzania) phosphate rock (PR) with organic materials (Okalebo *et al.*, 1991/1995; Okalebo and Woomer, 1994; Okalebo and Nandwa, 1997; Jama *et al.*, 1997; Woomer *et al.*, 1997). These PR and organics combinations have focussed on the provision of cheap N inputs from organics and the solubilisation of PR through formation of favourable acid environments that result when organics (in contact with PR) decompose in soils (Nahas et al, 1996; Mutuo *et al.*, 1999; Nyambati, 2000; Waigwa *et al.*, 2000). In this paper we present results of field studies whereby organic and inorganics were combined and tested on maize yields across the Kenyan infertile soils; mainly the acrisols (ultisols), ferralsols (oxisols) and luvisols (alfisols). The trial sites also varied with climatological characteristics, mainly the rainfall and its distribution.

Materials and Methods

Two types of field experiments were conducted:

Experiment 1

A randomised complete block design (RCBD) experiment with 4 replicates per site, was set up on smallholder farms at Ndeiya (Lat 10 14'S, Long 360 28'E), Kiambu district; Gatuanyaga (Lat 10, 22'S, 340 45'E), Thika district; and Malava-Kabras (Lat 00 18'N, Long 34° 45'E), Kakamega district. Both Ndeiya and Gatuanyaga receive annual rainfall of about 800 mm distributed within 2 seasons, March to May and October to December. Malava site is within the highlands of western Kenya, with a rainfall of 1000-1800 mm falling from March to September (Jaetzald and Schmidt, 1983). Some properties of surface (0-20cm) soils for the sites including Chepkoilel (for Experiment 2), taken before treatment applications are given in Table 25.1.

Table 25.1: Some properties of surface (0-20cm) soils from on-farm field trials in Kiambu, Thika, Kakamega and Uasin Gishu districts, Kenya

Properties	Kiambu Ndeiya	Thika Gatuanyaga	Kakamega Malava	Uasin Gishu Chepkoilel
		1994		1997
pH (H_2O, 1:2.5)	5.31	4.84	4.10	4.85
Total Carbon (%)	2.59	1.48	2.15	1.30
Total Nitrogen (%)	0.223	0.138	0.214	0.110
Olsen P (mg/kg)	11	10	7	4
Soil Order	Luvisol	Acrisol	Acrisol	Ferralsol

Soil properties for the sites indicate low pH levels (<5.5) favourable for PR dissolution (Sanchez *et al.*, 1997 and also low soil test P values close to or below 10mg P kg^{-1}, the level below which P responses are expected (Okalebo *et al.*, 1993).

In this on-farm, researcher-managed experiment, the main objective was to identify the readily available organic materials (crop residues, tree prunings, manures) at farm level that would increase the N and P levels in soils when incorporated with PR. Target N and P rates from combinations of these materials were 60 Kg N ha^{-1} and 40 Kg P ha^{-1} (applied as PR). These 2 rates appear to be economical for annual high and sustained maize production for the test sites (Okalebo, 1987).

Table 25.2: Treatment combination used in Experiment 1 in 1994 at Ndeiya, Gatuanyaga and Malava sites

Treatment	Nitrogen Combination (kg N ha^{-1})	Total (desired) N (kg N ha^{-1})	Desired P (kg P ha^{-1} PR)
Control	0	0	0
AM + MS	30N, AM + 30N, MS	60	-
MS + PM	30N, MS + 30N, PM	60	-
PM	60N, PM	60	-
UREA	60N, UREA	60	-
PR	-	-	40
UREA + PR	60N, UREA	60	40
MS +PR	60N, MS	60	40
AM + PR	60N, AM	60	40
FYM + PM	30N, FYM + 30N, PM	60	-

Notes:
AM = *Acacia mearnzii* (wattle prunings) used in Ndeiya and Gatuanyaga but groundnut trash used at Malava only.
MS = maize stover
PM = Poultry manure (broiler, from NARC Muguga/KARI)
FYM = on-farm yard manure or 'boma' manure; but compost was used at Gatuanyaga site only.
PR = Minjingu phosphate rock (0-30-0).

It is noted that the quantities of dry organic materials were calculated to give the above N combinations (Table 25.2) using their total N contents from prior laboratory analysis at NARC Muguga (Table 25.3). It was also assumed that the materials (with low P contents) had negligible P inputs. Overall, the experiment sought information from a wide range of treatment combinations.

At all three sites, all materials (above) were broadcast to fine seedbeds and incorporated into soil using a hoe. Maize (H511) was planted as a test crop with a plant density to 4.4 plants m^{-2}. Recommended husbandry practices (weeding, stalkborer control) were followed. A parallel N and P (inorganics) response trial was conducted at Gatuanyaga site only) with adequate on-farm land for experimentation.

Experiment 2

A randomised complete block design (RCBD) trial was set with 4 replicates at Chepkoilel Campus, Moi University, Eldoret, Uasin Gishu district (Lat 00 35'N, Long 350 18'E). This site receives annual rainfall of 1124 mm in one season from March to September (Jaetzold and Schmidt, 1983). At this site, treatments included incorporating N fertilizer with wheat straw and soybean. Treatments consisted of chopped (15 cm length) crop residues (above) applications at a uniform rate of 2 t ha^{-1} for each organic material. Urea (fertilizer N) was combined with these two organics at the rates of 0, 20, 40, 80 and 100 kg N ha^{-1} each. These treatments were applied at maize (H 614D hybrid) planting, first in March 1997, and were repeated in the subsequent years upto March 2000. To eliminate P and K limitations, 100 kgP ha^{-1} singlesuperphosphate and 100 kg Kha^{-1} muriate of potash were applied only at the start of the experiment.

Table 25.3: Some characteristics of organics applied in 1994 field experiments (Expt. 1): The nitrogen data were used to calculate N inputs

Material	% dry matter				Abbreviation
	ash	N	P	K	
Maize Stover-Muguga	9.5	0.79	0.085	1.94	MS
Maize Stover-Malava	5.3	0.76	0.084	0.56	MS
Acacia mearnzii-Muguga	5.0	2.21	0.092	0.85	AM
Groundnut trash - Malava	6.1	1.56	0.072	0.43	AM
Poultry Manure - Muguga	17.8	3.12	1.733	1.91	PM
FYM - Malava	53.5	1.30	0.227	1.14	FYM
Compost - Ndeiya	62.9	1.24	0.193	1.09	FYM

Source: NARC/KARI Muguga, Soil Chemistry Station, 1994

Notes:

a) Apart from *Acacia mearnzii* (AM) and poultry manure (PM) from Muguga applied to all 3 sites in 1994 Expt. 1 all other organics originated at on-farm level per site.

b) All materials vary in characteristics.

All inputs for both experiment 1 and 2 were incorporated into the seedbed by hand tillage and starter N for all nitrogen treatments was applied at 20 KgNha^{-1} at planting. At harvest, cobs and stover were separated. Sub-samples of these components were dried (40-50^{o}C) until constant weight, to obtain yield measurements.

Soil Sampling and Analysis

In all sites, surface (0-20cm) soils were sampled at random across all experimental fields before treatment applications. Samples (30 auger borings for each site) were bulked and mixed thoroughly and composite soils taken. After maize harvest at Chepkoilel, soils were sampled from each plot (9 borings per plot at random) and analysed to take measurements on changes in soil properties due to treatments. Soils were processed and analyzed for pH (H_2O), total carbon and extractable phosphorus (Olsen), following the procedures outlined in Okalebo *et al.* (1993).

Results and Discussion

Maize Yields

In 1994, maize grain was harvested only at the Ndeiya and Malava sites (Experiment 1), while due to severe drought at Gatuanyaga, only the biomass (above ground parts) data was obtained as given in Table 25.4. In that year grain yields ranged from 1256 to 3761 Kg ha^{-1} at the 2 sites where maize grew to maturity. On the average, the organics and inorganics applied individually or in combinations, tended to increase maize yields above the treatment with highest yield increases being obtained at the lowest soil test P site of Malava in Expt. 1 (Tables 25.1 and 25.4). At this site, the groundnut trash plus phosphate rock (AM + PR) treatment gave the highest grain yield, increase of 102% above control, while the poultry manure (PM) treatment resulted in an increase of 48%, followed by a PR yield increase of 43%.

Further, in this site, significant yield increases have been reported (Okalebo, 1987). In an earlier field study at this site (Okalebo and Lekasi, 1993), in which maize stover, groundnut trash and on-farmyard manure were applied at 0, 2, 4 and 6 t ha^{-1} each, in combination with 40 KgPha^{-1} PR for each organic resource rate, the groundnut trash significantly outyielded the maize stover organic material in terms of maize grain yield increases. At Ndeiya semi-arid site, the maize stover (MS) plus poultry manure (MS+PM) treatment gave the highest grain yield increase of 73% above control, followed by the PM treatment alone, with a yield increase of 42%.

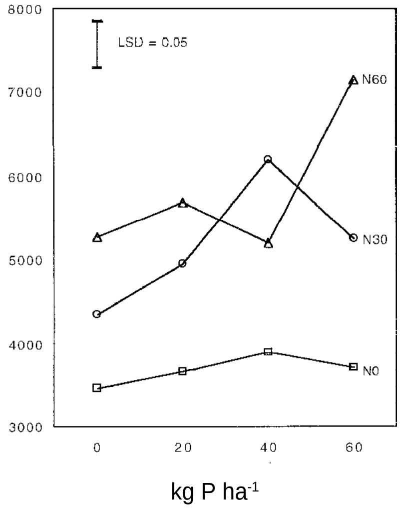
Table 25.4: Effect of crop/tree residues, manure and compost in combinations with phosphate rock on maize yield (kg ha^{-1}) in 1994

Treatment	Ndeiya (grain)	Gatuanyaga (biomass)	Malava (grain)
Control	2172	2924	1384
AM + MS	2536	3804	1256
MS + PM	3761	4034	1750
PM	3091	4030	2048
UREA	2550	4567	1543
PR	2580	3163	1974
UREA + PR	2425	4145	1567
MS + PR	2590	4241	1708
AM + PR	2549	3037	2802
FYM + PM	2646	2789	1570
Mean	(2690)	(3673)	(1760)
LSD (p = 0.05)	NS	NS	NS

AM = *Acacia mearnzii* (wattle prunings) used in Ndeiya and Gatuanyaga, but groundnut trash used at Malava only.
MS = Maize stover
PM = Poultry manure (broiler, from NARC, Muguga, KARI)
FYM = On-farm yard manure (boma manure), but compost used at Gatuanyaga.

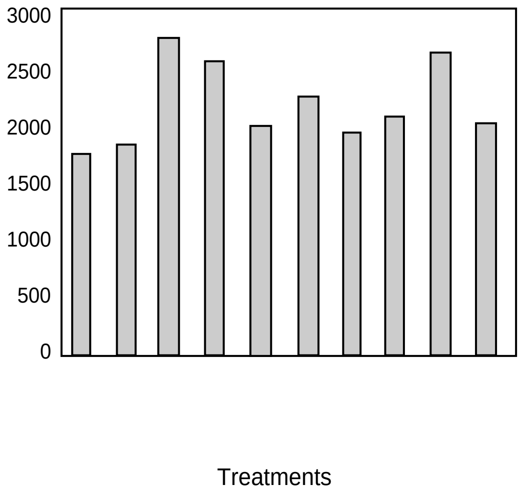
In a study in semi-arid eastern Kenya (Probert *et al.*, 1992), addition of PM at 5 t ha^{-1} (NARC Muguga broiler quality) gave the highest maize yield increases compared to the on-farm yard manure applied at 10 t ha^{-1} and combined inorganic fertilizers: 60 kgNha^{-1} calcium ammonium nitrate plus 40 kg P ha^{-1} triplesuperphosphate. Thus on infertile soils, PM appears to boost the nutrient and organic matter levels and also to improve soil physical properties, such as infiltration and soil moisture retention. The highest maize biomass yield at Gatuanyaga site was obtained from the urea alone treatment (at 60 kg N ha^{-1}) where a yield increase of 56% was obtained, implying a nitrogen limitation in this low C and N site (Table 25.1). This observation is supported from the data in a parallel experiment (Expt. 1) at this site whereby a significant N response was found from urea applications at 0, 30 and 60 kg N ha^{-1} rates (Figure 25.1). In summary effect of treatments varied with site and Figure 25.2 shows an overall picture/overview of the performance of treatments across the 2 sites (Ndeiya and Malava) harvested for grain in 1994 (Expt. 1). The rather overall outstanding performance from MS + PM, AM + PR and PM treatments is noted. Despite these guidelines or trends, Expt. 1 in this research has illustrated the complexity in studying and adopting the use of organic resources for soil fertility restoration/ replenishment, particularly in the TSBF AfNet region, where factors such as the availability of the resource, its quality and quantity and methods of application, play significant roles.

Figure 25.1: Maize biomass (kg ha^{-1}) as affected by nitrogen and phosphorus fertilizers at Gatuanyaga (on farm), Thika, long rains



N source was urea
P source was TSP

Figure 25.2: An overall effect of crop residues, tree prunnings, manure with Phosphate Rock combinations on maize grain yields (kg ha^{-1}) at 2 sites in 1994



NB:
Nitrogen as applied at 60 kg/ha for each material and urea and phosphurus was added at 40kg P/ha.

AM – Acacia mearnzii
MS – Maize stover
PM – Poultry manure
FYM – Farmyard manure
PR – Phosphate Rock (Minjingu)

In the Chepkoilel Campus experiment (Expt. 2), where the low quality wheat straw (0.67%N) and higher quality soybean trash (1.07% N) were compared from 1997 to 2000, maize grain yields varied with the treatments and years of cropping (Okalebo *et al.*, 1999). In 1997 grain yields ranged from 875 to 1876 kg ha^{-1}; from 2832 to 6836 kg ha^{-1} in 1998; and from 1363 to 2272 kg ha^{-1} in 2000 (Table 25.5).

Table 25.5. Effect of continued addition of crop residues and nitrogen fertilizers on maize grain yield (kg ha^{-1}) in Chepkoilel soils (Ferralsols)

Treatment	Year		
	1997	1998	2000
Control	875[a]	2832[a]	1363
80 N	1016[a]	4883[b]	1704
WS + 0N	960[a]	2051[a]	1477
WS + 20N	1321[a]	2930[a]	1363
WS + 40N	1304[a]	3223[a]	1363
WS + 80N	1666[b]	4785[b]	1704
WS + 100N	1677[b]	5469[b]	1591
SYT + 0N	751[a]	2832[a]	1818
SYT + 20N	1465[b]	2500[a]	2159
SYT + 40N	1444[b]	3711[a]	2272
SYT + 80N	1500[b]	5567[b]	2272
SYT + 100N	1876[b]	6836[b]	1931
Overall LSD (p=0.05)	555	1030	926 NS

Means followed by the same letters or none in a column are not significantly (p = 0.05) different (using Duncan's multiple range test).

WS = Wheat Straw applied annually at 2 t ha^{-1}
SYT = Soybean trash applied annually at 2 t ha^{-1}
N = Nitrogen applied as urea at 0, 20, 40, 80 and 100 kg N ha^{-1}

Grain yield variations are partly explained in terms of low and poor rainfall distribution (considering the 10-day periods), particularly at the maize maturity months of August and September. This is illustrated from yields obtained in 1997, 1998 and 2000 when total rainfall received in these two months was 232, 380 and 283 mm for the 3 respective years (Chepkoilel Campus Meteorological Records). This magnitude of rainfall in 1997 and 2000 did not probably favor adequate soil moisture and nutrient availability, contributing to overall low maize yield in those 2 years. Nevertheless, many treatments gave significant increases in maize yield (P<0.05), particularly from 2 tha^{-1} wheat straw and soybean trash combined with fertilizer N (urea) above 80 kgN ha^{-1} rate of incorporation (Table 25.5). Favourable rainfall and its distribution in 1998 most likely contributed to larger maize yields in that year. Again higher yields were found from the higher quality soybean trash and N fertilizer applied above 80 $kgNha^{-1}$. Past work in field nutrient limiting study has pinpointed a nitrogen limitation in Chepkoilel soils (Mwaura, 1998).

Changes in soil properties

Data for soil pH, C and available P parameters obtained in surface (0-20 cm) soils sampled before application of treatments in March 1997 and soils taken soon after harvesting the fourth maize crop in November, 2000 are summarised in Table 25.6. There were positive changes from organic matter inputs (and possibly continued urea addition) to increase the levels of these three parameters in soils.

Table 25.6: Changes in soil (0-20cm) properties as influenced by cumulative incorporation of crop residues and urea at Chepkoilel, Kenya, during 4 years of maize cropping

Treatment	Soil parameter		
	pH	Local C (%)	Available P (mg/kg)
After maize harvest, November, 2000			
Control (No inputs)	4.80	2.16	11.6
80 $kgNha^{-1}$ as urea	5.06	2.26	10.4
Wheat straw + N*	5.32	2.47	14.4
Soybean trash + N*	5.41	2.78	14.3
Initial contributions, March 1997	4.85	1.30	3.9

*Wheat straw and soybean trash data include all treatments receiving urea at 0, 20, 40, 80 and 100 kg N ha^{-1}

A similar trend was found from soils sampled soon after harvesting the second maize crop in October 1998 (Okalebo *et al.*, 1999). Marked increases were found in C and P levels. These are very likely due to their accumulation from consecutive organic and mineral nutrient additions made from 1997 to 2000 except P which was added only once at 100kg P ha^{-1} at the beginning of the experiment in 1997. Other additions of P probably originated from the decay and release of the organically bound P held in organic resources applied as previously described by Rusell (1973). As reported by Okalebo *et al.* (1999), there were large amounts of total N found from surface soil in all treatments (including the control) after four years of cumulative organic matter and urea incorporations into soil. Probably analytical errors contributed to these large N levels. Nevertheless, for better estimates of the N status of soils, analysis for mineral N (NH_4 and NO_3 mainly) could have been done. Mineral N gives better measurements of N released from decomposing organic resources. It also gives better estimates of N leached down the soil profile. Unfortunately the Moi University laboratory does not have facilities or equipments to analyse mineral N components in soils. Other indicators of soil fertility build-up from organic matter additions (such as an increase in particulate light fraction in soils) would also be useful.

Conclusions and Recommendations

1. In the one year (1994) of field experimentation at three on-farm researcher-managed trials (at Ndeiya, Gatuanyaga and Malava), maize yield increases were obtained from combined application of organics and inorganics. But the largest yield increases were found from incorporation of high quality poultry manure (3.1% N), groundnut trash (1.6% N) and phosphate rock (13.2% P). The effectiveness of each resource varied with site.
2. The longer-term (4 years) study of Chepkoilel site (with a major N limitation has demonstrated the positive effect of incorporating crop residues with N fertilizer into the seedbed to improve their decomposition and nutrient release characteristics. The two forms of residues tested (wheat straw and soybean trash) were each applied at a uniform rate of 2 tha^{-1}. It is quite feasible that this rate of residue be retained in croplands even while alternative requirements (for example fuel, feed are also being met)
3. Comparisons of different rates of residues are suggested to obtain responses to both residues and N fertilizer rates.
4. Organic matter fractionation needs to be done after cropping in the long-term trial, to determine the dynamics of important labile fractions (such as the proportions and contents of C, N and P in those fractions).
5. Investigations on economics of combined organic and mineral sources will provide useful information on crop/tree residue and manure management practices.
6. The study in one year (1994) was not able to pinpoint the enhanced dissolution of PR and the associated mechanisms through combined organic matter and PR incorporations into soil. This task needs pursuing.

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