"ECONOMIC EVALUATION OF ORGANIC AND INORGANIC RESOURCES FOR RECAPITALIZING SOIL FERTILITY IN SMALLHOLDER MAIZE-BASED CROPPING SYSTEMS OF CENTRAL KENYA"

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A poster paper prepared for presentation at 26th Conference of the International Association of Agricultural Economics (IAAE), Gold Coast, Australia on 12-18th August 2006

ABSTARCT

Structural adjustments programs (SAPs) in the last two decades have eliminated all farm-support programs leading to low usage of fertilizers by Kenyan smallholders. One way of addressing this problem is use of organic nutrient resources. This paper examines their cost-effectiveness as capital investments in replenishment of Nitrogen (N), Phosphorus (P), Potassium (K) and soil organic matter (SOM) in smallholder, Maize-based cropping systems. On-farm trials were established in Maragwa and Kirinyaga Districts in 2003/04. Maize was planted in 3 replicates in randomised complete block design (RCBD) using different levels of organic and inorganic fertilizer resources. A blanket rate of 40kg P/ha was applied in all treatment except the control to increase organic N-utilization efficiency. The test crop was harvested, oven-dried and weighed. Net Present Values (NPV) were computed using Partial Budgeting Analysis Model. Increasing levels of inorganic N increased maize yields significantly (P<0.05). However, higher yields were necessary but not sufficient criteria to determine profitability of different treatments. Manure + 60 kg N/ha gave highest NPV (USD 564), Manure + 40kg N/ha gave second highest NPV (USD 511) in Maragwa District while Manure + 60kg N/ha gave highest NPV (USD 633) and Manure + 40kg N/ha second highest NPV (USD 618) in Kirinyaga District. These results suggested that higher N-levels were not necessarily the most economical. Use of organic resources with modest amounts of mineral fertilizers seemed more profitable and held the key to enhancement of nutrient budgets, food security and rural livelihoods.

Keywords: Natural resource capital, Net present values (NPV), Nutrient budgets, Smallholder farmers, Soil organic matter (SOM), Structural adjustment programs (SAPs)

INTRODUCTION

Integrated soil fertility management (ISFM) paradigm is a holistic and systematic approach that takes into account all aspects of soil fertility degradation (Kimani et al., 2003). It embraces all biological, physical, chemical, socio-economical and political driving factors and consequences (Gichuru et al., 2003). ISFM therefore aims at judicious application of all possible soil fertility management options for productive and sustainable agro-ecosystems. The main cornerstone of ISFM approach is recognition of importance of soil organic matter (SOM) in preservation of soil fertility and soil physical properties (Kauffman, 1999). This is because plant nutrients, water availability and soil degradation are dependent on SOM content of soil (Kimani, et al., 1999). SOM also synchronizes nutrient release from organic inputs with crop needs and improves nutrient use efficiency.

ISFM has led to renewed interests in organic resources as potential sources of major plant nutrients and SOM, the so-called 'organic input' paradigm (Vanlauwe and Sanginga, 2004). Consequently, a whole range of organic soil amendments in combination with modest levels of inorganic fertilizers has been tested in Kenya (Kimani et al., 2000; Gitari et al., 1999). Such low-external input SFM technologies include use of crop residues, legume-cereal intercrops, animal manures, compost and leguminous green manure cover crops (GMCC). It has been established that GMCC offer great advantages in soil fertility restoration, conservation and recycling of soil mineral nutrients, weed suppression and soil erosion control (Mafogonya et al, 2003). However, incorporation of non-food legumes requires that a sacrifice of land, labour and capital normally devoted to crop production be made (Jama et al., 1997). According to Breman (1997), GMCC approach also takes considerable time before returns to investments from soil improvement can be fully realised.

It has also been established that small-scale, resource poor farmers use animal manures extensively (Webster and Wilson, 1996). However, prospects for optimizing productivity of smallholder farming systems through use of locally available, organic resources alone are limited by insufficient quantities and quality of these resources (Murwira, 2003). Accordingly extensive work has been done on manure application, management and potential in central Kenyan Highlands (Lekasi et al., 1998; Kimani et al., 2000). Little work though has been done on costs and benefits associated with adoption of such SFM technologies. On the other hand, blanket fertilizer recommendations across different farm typologies ignore specific deficient nutrients or recommend unnecessary nutrients (Wendt and Jones, 1993). They have failed to acknowledge heterogeneity of small-scale farming systems and that soil fertility is dynamic in space and time. Such diversities are likely to affect farmers' perception of and ability to invest in high-external input SFM technologies

OBJECTIVES OF THE STUDY

1. Determination of Net Present Values (NPV) associated with different low-external input technologies (farmyard manure, composts, GMCCs, maize stovers) as nitrogen (N), phosphorus (P) and soil organic matter (SOM) amendments

2. Use of NPV for ranking of organic and inorganic fertilizer resources in enhancement of soil fertility, food security and livelihoods for low-income smallholders in Maize-based cropping systems of central Kenya Highlands.

MATERIALS AND METHODS

Study Sites

The study was carried out in two districts of central Kenya, Maragwa and Kirinyaga. Maragwa District covers about 1065 square kilometres and lies at 1100-2950m a.s.l. (Jaetztold and Schmidt, 1983). It has a population of 409,299 persons with a population density of 384 persons /Km^2 and an average farm size of 0.93 hectares. Average annual rainfall is 1300-1600 mm per annum (p.a.) with mean annual temperatures of 19.7-18.0 ^{0}C. FIGURE 1 shows the typical rainfall patterns for the study districts in 2003/04.

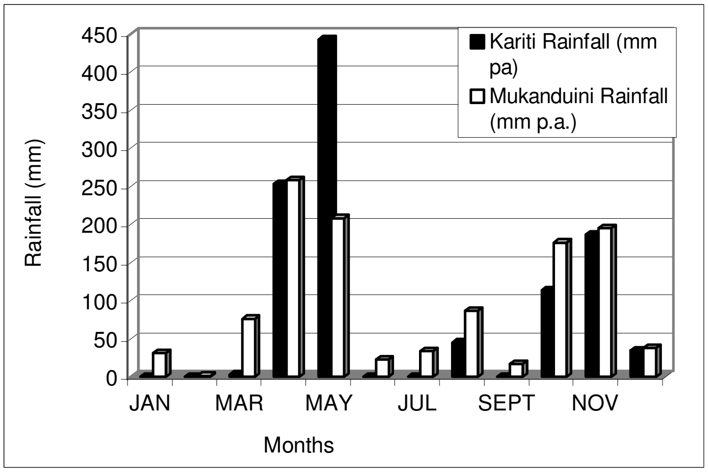

FIGURE 1: Average annual rainfall for Maragwa and Kirinyaga Districts respectively[1].

Kirinyaga District is on the southern slopes of Mt. Kenya with a size of 1437 square kilometres. It has a population of 490,974 persons and a population density of 342 persons per Km^2. Average annual rainfall of the district is 1100-1250 mm p. a. with mean annual temperatures of 20.1-20.6 ^{0}C. In both study districts, land fragmentation is prevalent with average farm size of 0.9 hectares. Nutrient depletion is widespread due to continuous cropping with little nutrient replenishment. The major enterprises included maize, beans, tomatoes, coffee, bananas and dairy.

Experimental Design

To evaluate alternative SFM practices that are profitable and appropriate to farmers' socio-economic circumstances, on-farm trials were established in each study district. Researcher-farmer managed trials with 15 different soil treatments were set up for two seasons in 2003/04. Plots were measuring 6 x 4 m in a randomized complete block design (RCBD) in 3 replicates were set up. Maize (*Zea mays*) at 90 x 30 cm was planted as test crop. Various treatments applied and their rates are shown in TABLE 1.

[1] *Source: District Water offices, Maragwa and Kirinyaga*

TABLE 1: Applied soil treatments and their rates in kilogram or tons per hectare[2]

Treatment No.	Level of Amendments (Kg, ton/ha)	**Treatment No.**	Level of Amendments (Kg, ton/ha)
T1	Unfertilised Control	T2	*Mucuna pruriens*
T3	*Crotalaria ochroleuca*	T4	*Dolichos Lablabs*
T5	*Tithonia diversifolia* (5 ton/ha FW)*	T6	Manure (5 t) + Fertilizer (20 kg N/ha)
T7	Manure (5 t) + Fertilizer (40 kg N/ha)	T8	Manure (5 t) + Fertilizer (60 kg N/ha)
T9	Manure (5 t) + Fertilizer (80 kg N/ha)	T10	Fertilizer (100 kg N/ha)
T11	Maize Stover (5 t/ha)	T12	Maize Stover + EM1
T13	Manure (5 tons/ha)	T14	Compost (10 tons/ha)
T15	Manure (10 tons/ha)		

(i) Green Manure Cover Crops (T1 – T5)

The legumes planted included velvet bean (*Mucuna pruriens*), sun hemp (*Crotalaria ochroleuca*) and dolichos (*Dolichos purpureus).* Mexican sunflower (*Tithonia diversifolia)*, was applied at 5 tons/ha fresh weight (FW) during planting time in both seasons. ***Mucuna, Crotalaria*** and *Lablab* planted in 1st season were harvested, weighed and plowed back in the 2nd season.

(ii) Manure + Inorganic Fertilizers (T6 – T10)

Different combinations of manure organic-inorganic nutrient were used. Cattle manure (1.8 %) and inorganic fertilizers (17:17:17) were applied at planting to supply different N levels in both seasons.

(iii) *Stovers, Compost and Animal manure (T11- T15)*

Maize stover was incorporated (5 tons/ha DW[3]) at plowing time in T_7 but was treated with Effective Micro-organism (EM1) in T_8. Compost (1.7 %) was applied at 10 tons/ha while Farmyard manure (1.8 % N) was applied at 5 and 10 tons/ha at sowing time in both seasons.

[2] N = Nitrogen, EM = Micro-organisms (to hasten microbial decomposition), * 1 ton dry weight (DW) of *Tithonia* contains 33kg N, 3.1 kg P & 30.8 kg K, ** 66.7 kg FW *Tithonia* is equivalent to 1 kg DW (Rommelse, 2000)

[3] DW = dry weight

Beans (*Phaseolus vulgaris*) were planted in plots where leguminous GMCCs were not incorporated. A blanket rate of 40 kg/ha of P (TSP)[4] was applied in all treatments in second season while T_1 served as unfertilized control. Monitoring, data collection and treatments evaluation were jointly done by farmers, researchers and extension officers during field visits and field days.

Agronomic Analysis

At harvest maturity, test crop was harvested, and grain yields per plot recorded. The grain sub-samples were oven-dried to 13 percent moisture content and the dry weight taken. To obtain realistic yields by farmers under their own circumstances, on-farm yields were depressed by 20 percent (CIMMYT, 1998). Farmers are unlikely to be exact in input procurements, planting dates, input measurements, spacing and timeliness of other farm operations.

Percentage yield increases (%) from different treatments with respect to unfertilized control were also computed whereby:

$$\text{Yield Increase}^{5} = \frac{[\text{Yield}_{\text{treatment}} - \text{Yield}_{\text{control}}]}{\text{Yield}_{\text{control}}} \times 100$$

Economic Analysis

Economic analysis was done using Partial Budgeting Analysis Model (PBAM). Partial budgeting implies that only costs that are significantly affected by alternative treatments were considered. Such included costs of fertilizers and farmyard manure, GMCCs and compost, stovers and Effective Micro-organisms (EM). This helped in comparison of benefits and costs across different treatments with respect to unfertilised control. Wage rates, inputs and produce prices were taken as those prevailing in

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[4] TSP = Triple Super Phosphate (46 % P_2O_5)
[5] *Source: Gachengo et al., 1999*

local markets while opportunity cost of using maize stovers for incorporation instead of fodder was considered. Harvesting-related coats are yield-dependent and therefore were deducted from farm gate prices of crop produce.

Partial budgeting analysis was carried out on economic data to evaluate the Net Present Value (NPV) from different treatments where NPV is defined as "present worth of benefits less present cost of a project" (Gittinger, 1982). NPV can thus be expressed as:

$$NPV = \sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+I)^t}$$

Where: $(B_t - C_t)$ = Net Benefits at time t years

$(1 + i)^t$ = Discounting Factor

i = interest rate (%)

In this study, different treatments were considered as an investment in natural resource capital and represented different mutually exclusive projects. The discount rate was taken as the opportunity cost of capital, which is defined as "that rate which will result in utilization of all capital if all possible investments were undertaken". Interest rate of capital was taken as 20 percent per year and time t, as one year. Different treatments were ranked on basis of their NPV value and those with NPV ≥ 0 were acceptable as economically viable investments.

RESULTS AND DISCUSSION

(a) Agronomic analysis

Before undertaking economic analysis of the pooled data, it was necessary to assess crop yield response data from an agronomic point of view (CIMMYT, 1988). For ease of comparison of data across different soil treatments, the latter were grouped into three categories by type:

(i) Green manure cover crops (GMCC) + Tithonia

(ii) Farmyard manure (FYM) + Inorganic fertilizers

(iii) Stovers, compost and FYM alone

(i) Green manure cover crops (GMCC) + Tithonia

In Maragwa District, the highest mean maize yield for two seasons was from *Tithonia (*3.8 tons). This was significantly higher ($p < 0.05$) than all green manure cover crops (GMCC). This is an equivalent of 399 percent yield increase over unfertilized control (TABLE 2). *Dolichos* gave second highest mean maize yield (3.0 tons), which was significantly higher than *Crotalaria* and *Mucuna*. Of the GMCCs, *Mucuna* gave the lowest mean maize yield (2.4 tons), which was equivalent to 220 percent increase over unfertilised control.

TABLE 2. Mean crop yields (tons per hectare) and percent (%) yield increase in Maragwa District.

Nutrient level	Yields		Yield increase	
	Maize (t ha^{-1})	Beans (t ha^{-1})	Maize (%)	Beans (%)
Control	0.75	0.16	0	0
Mucuna	2.40	0.40	220	150
Crotalaria	2.42	0.29	223	81
Dolichos	3.02	0.19	303	19
Tithonia	3.75	0.11	400	-31
M+20 kg N/ha	4.46	0.11	495	-31
M+40 kg N/ha	4.87	0.16	549	0
M+60 kg N/ha	5.28	0.24	604	50
M+80 kg N/ha	3.94	0.14	425	-13
100 kg N/ha	3.84	0.17	412	6
Stover	2.29	0.17	205	6
Stover + EM	2.25	0.25	200	56
Manure 5 t/ha	2.68	0.21	257	31
Compost10t/ha	3.37	0.20	349	25
Manure 10t/ha	4.25	0.15	467	-6
MSE[6]	0.40114	0.04833		
LSD $_{(0.05)}$	1.05930	0.11630		

[6] MSE = Mean square error, LSD = Least significant difference

Mean bean yields displayed a different response to that of maize. Although *Tithonia* did quite well in maize yields, it did quite the opposite in bean yields in Maragwa. It gave the lowest bean yields (0.11 tons) while it gave the highest mean bean yields (0.41 tons) in Kirinyaga. The lowest bean yield in the latter site was recorded in *Dolichos* (0.07 tons) representing a yield decrease of 36 percent.

In Kirinyaga District, the highest mean maize yield (3.58 tons) was also observed in *Tithonia* representing a yield increase of about 298 percent (TABLE 3).

TABLE 3. Mean crop yields (tons per hectare) and percent (%) yield increase in Kirinyaga District.

Nutrient level	Yields		Yield increase	
	Maize(t ha^{-1})	Beans (t ha^{-1})	Maize (%)	Beans (%)
Control	0.90	0.11	0	0
Mucuna	1.50	0.15	67	36
Crotalaria	1.94	0.14	116	27
Dolichos	1.09	0.07	21	-36
Tithonia	3.58	0.41	298	273
M+20 kg N/ha	4.98	0.26	453	136
M+40 kg N/ha	5.16	0.39	473	255
M+60 kg N/ha	5.31	0.48	490	336
M+80 kg N/ha	4.37	0.35	386	218
100 kg N/ha	3.90	0.33	333	200
Stover	1.71	0.21	90	91
Stover + EM	1.97	0.20	119	82
Manure 5 t/ha	3.04	0.32	238	191
Compost 10t/ha	2.74	0.29	204	164
Manure 10t/ha	3.81	0.45	323	309
MSE	1.15167	0.02265		
LSD $_{(0.05)}$	1.7720	0.11320		

This is significantly higher ($p < 0.05$) than unfertilised control and all other GMCC. Of this category, *Dolichos* had the lowest mean yield (1.09 tons), which is equivalent to 21 percent increase over unfertilised control. *Mucuna* grew vigorously during the 1st season smothering maize and therefore depressing grain yields significantly. This effect was greater in Kirinyaga than in Maragwa. This is because warmer weather conditions favoured faster *Mucuna's* establishment and growth in Kirinyaga than in Maragwa.

(ii) Farm yard manure (FYM) + Inorganic fertilizers

In Maragwa District, the highest mean maize yield (5.28 tons) was observed from Manure + 60kg N/ha, equivalent to 604 percent increase over unfertilised control. Mean maize yields from Manure + 20 kg N/ha and Manure + 40 kg N/ha ($P < 0.05$) did not differ significantly in Maragwa. Manure + 60 kg N/ha also gave the highest mean bean yields while Manure + 20 kg N/ha the lowest in both sites. Fertilizer alone at 100 kg N/ha did not give the highest maize or bean yields, as one would expect in both sites. Similarly, Manure + 60 kg N/ha, Manure + 40 kg N/ha and Manure + 20 kg N/ha gave the highest, second highest and third highest crop yield in Kirinyaga.

(iii) Stovers, compost and FYM alone:

Mean maize yields from Manure (10 tons/ha) in both sites, were significant different ($P < 0.05$) from yields from compost and stovers. In Maragwa, doubling manure rates from 5-10 tons/ha almost doubled maize yields while this was not the case in Kirinyaga. An extra 5 tons/ha of manure increased maize yields by about 60 percent in Maragwa but only 25 percent in Kirinyaga. This implies that Maragwa soil (UM3) is moister and therefore more responsive to soil organic matter (SOM) addition, and therefore doubling manure rate had a very dramatic response on maize yield. Such a phenomenon was not observed in Kirinyaga (UM4). This implies that the optimal rate of manure application should be 10 and 5 tons/ha in Maragwa and Kirinyaga respectively. Compost (10 tons/ha) gave higher mean maize yield in Maragwa than Kirinyaga (3.4 and 2.7 tons respectively) about 350 and 200 percent over unfertilised control in Maragwa and Kirinyaga respectively. Bean yields from compost were significantly different ($P < 0.05$) from Maize stovers in Maragwa, but were not significantly different from stovers in Kirinyaga.

Of all treatments in this category, stovers gave poorest maize yield response in both sites. However, there was some significant yield increase from treating stover with effective microorganism (EM1). Bean yields seemed to increase slightly due to this treatment in Maragwa but not in Kirinyaga. It is important to note that farmers are more interested in variability in benefits than variability in yields. Economic analysis therefore provided a useful way of examining benefit variability associated with different SFM treatments from on-farm trials during this study.

(b) Economic analysis

NPV across different SFM treatments were computed and compared since different treatments were assumed to represent different investments of the same time length (TABLE 4).

TABLE 4. Net present values (NPV) in USD per hectare of maize-bean intercrop in different SFM treatments in Maragwa and Kirinyaga Districts.

Nutrient level	Maragwa		Kirinyaga	
	NPV	NPV Rank	NPV	NPV Rank
Control	0	15	0	13
Mucuna	116.0	14	-111.6	14
Crotalaria	170.4	13	40.2	12
Dolichos	238.9	8	-114.3	15
Tithonia	223.7	9	278.3	8
M+20 kg N/ha	466.7	3	586.1	3
M+40 kg N/ha	511.0	2	617.9	2
M+60 kg N/ha	564.1	1	632.5	1
M+80 kg N/ha	283.9	6	407.0	6
100 kg N/ha	310.5	5	531.9	4
Stover	215.1	10	125.8	10
Stover + EM	207.7	11	139.1	9
Manure 5 t/ha	263.1	7	344.9	7
Compst 10 t/ha	175.2	12	92.9	11
Manure 10 t/ha	435.6	4	447.1	5

Amongst the GMCC, *Dolichos gave* the highest NPV (USD[7] 238.9) in Maragwa while *Tithonia* recorded highest NPV (USD 278.3) in Kirinyaga. Of the FYM + inorganic fertilizers combinations, Manure + 60 kg N/ha gave the highest NPV in Maragwa and Kirinyaga. The NPV values for this treatment in both sites were USD 564 and USD 632.5 respectively. The second highest NPV was recorded in Manure + 40 kg N/ha in both sites with NPV values of USD 511 and USD 617.9 respectively. Manure + 20 kg N/ha had the third highest NPV values in both sites. Among the organic resources, NPV ranked Manure (10 tons) as the best in both sites. NPV values for manure (10 tons/ha) in both sites were USD 435.6 and USD 447 respectively.

In Maragwa, all SFM treatments had positive NPV leading to rejection of null hypothesis (H_0) that "all low-external input SFM technologies are cost-ineffective in enhancement of soil fertility, crop yields and livelihoods in smallholder maize-based production systems". Accordingly these results suggested that all treatments in Maragwa are economically viable as their NPV values are greater than zero (NPV > 0). However, in Kirinyaga *Mucuna* and *Dolichos* had negative PNV values (NPV < 0) suggesting that these two treatments are economically non-viable. All other treatments had positive NPV values. The higher the NPV value the more economical a particular treatment is and therefore treatments with highest NPV ranking should be recommended to farmers. Form NPV ranking it was established that treatments from far*m*yard manure (FYM) + Inorganic fertilizers category had the highest NPV ranking in both sites.

CONCLUSION

The optimum application of nitrogen (N) was found in Manure (5 tons/ha) + Fertilizer (60 kg N/ha). As the level of inorganic nitrogen increased from 20 to 60 Kg N/ha, yields increased dramatically. Beyond 60 Kg N/ha, yields started increasing at a decreasing rate indicating an excess application of N. This then implies that if all other factors of production were held constant, additional increases in

[7] 1 USD = 75 Kenya Shilling (KES)

maize output resulting from each additional application of N beyond 60 kg/ha will begin to decrease. Based on their SFM and socio-economic circumstances, farmers should use FYM (5 ton/ha) + 20, 40 and 60 kg N/ha respectively as the optimal recommendations for maize production in both sites. It would be uneconomical to apply N above or below this range.

Combinations of FYM + Inorganic fertilizers were widely practiced by farmers in both study sites. Therefore, such SFM technologies could be more acceptable than FYM alone enhancing recapitalization of smallholders' soil fertility, farm incomes and food self-sufficiency. From partial budgets, it was observed that treatments with the highest yields were not necessarily the most economical. Farmers were also interested to know the extra costs and benefits involved in adopting a new technology. FYM + Fertilizers ranked between 1 – 5, Manure alone between 6 – 10 while GMCCs ranked between 11 – 15 in terms of NPV ranking. Treatments with NPV value of more than zero were considered to be economically viable and should be adopted. The higher the NPV value, the more viable the treatment.

ACKNOWLEDGEMENTS

The authors wish to thank the Rockefeller Foundation for providing financial support for field experimentation. They also greatly appreciate the contribution of Kenya Agricultural Research Institute (KARI) Muguga South, Tropical Soil biology and Fertility Institute (TSBF-CIAT) and University of Nairobi (UON) Department of Agricultural Economics for technical and logistic support. Lastly we wish to thank the extension staff from Ministry of Agriculture (MOA) and farmers from both Maragwa and Kirinyaga Districts for their collaboration.

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