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Evaluating and Upscaling Effectiveness of Fertilizer Materials to Replenish Soils of Western Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Authors JRO and KWNM designed the study and wrote the protocol. Author MAO wrote the first draft of the manuscript. Authors RN and AKK managed the literature searches, analyses of the study and performed the spectroscopy analysis. Authors JOO and WKN managed the experimental process. Author CLR identified the species of plant. All authors read and approved the final manuscript.

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ABSTRACT

In western Kenya soils are acidic and have low fertility. A study was carried out to examine the effectiveness of four recommended soil fertility management practices. There were four treatments, DAP, DAP + lime, MPR + CAN, Rutuba + DAP and a control where no fertilizer was applied. P was applied at the rate of 26 kg P ha, N 75 kg N ha and 60 kg K ha. Application of DAP resulted in pH decline. Minjingu PR and Rutuba commercial organic manure had no effect on the soil pH in Siaya. There was significant increases ($p<0.05$) in soil pH with the addition of Minjingu PR in Uasin Gishu

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and Trans Nzoia counties. Siaya county had the lowest maize yields but with the highest response to fertilizer application. Trans Nzoia gave the highest grain yields, but did not show significant differences ($p<0.05$) between the fertilizer treatments. From the analysis of Minimal Return of Rates (MRR), it is economical to use DAP in Trans Nzoia, a combination of DAP and Lime in Uasin Gishu and MPR and CAN in Siaya county.

Keywords: Management practices; low fertility; treatment.

1. INTRODUCTION

Maize (*Zea mays* L.) is the stable food crop in Kenya, supporting 90% of its population [1]. Apart from its direct use as food, maize is also used as industrial crop. Its uses include manufacturing of cooking oils and animal feed in Eastern African region. In the recent years it has been used in the manufacture of bio-fuels in the developed world because of global warning originating from the use of fossil fuels [2]. The small holder farmers (SHF) play a very important role in maize production in Kenya since they contribute over 90% of the annual production which, is equivalent to 2.4 million tons from 1.5 million hectares [3].

In comparison to the rest of the world, fertilizer use in sub-Saharan Africa (SSA) is low and declining. In 1996, sub-Saharan Africa consumed only 1.2 million tons of fertilizer (equivalent to 8.9 kilograms per hectare of arable land). By comparison, global fertilizer use reached approximately 11135 million tons in 1996, equivalent to 97.7 kilograms per hectare [4]. High external input technologies, lack of infrastructure, research, development, and even extension are major obstacles to increasing fertilizer application rates in sub-Saharan Africa. The fertilizer supply is limited and the cost is prohibitive for SSA farmers because fertilizer may cost as much as five times the global market price [5]. Despite the low application rates of fertilizer in SSA, relative to other parts of the world, studies have shown that fertilizer use in Kenya has increased dramatically since its market was liberalized in the early 1990s in relative to the countries in the region. Kenya is the only country in sub-Saharan Africa region that has achieved at least 30% growth in fertilizer use per cropped hectare over the past decade and which already started from a relatively high base (25 kg per hectare or more by the early 1990s) [6]. The increase is due to good marketing policy introduced in 1990; dense network of fertilizer retailers operating in rural areas, leading to enhanced farmers' access to fertilizer [6]. The use of fertilizer is expected to continue increasing in Kenya because of the GOK-run program which provides subsidy on fertilizer. In addition, the GOK and donors through a program called NAAIAP (National Agricultural accelerated Input Access Programme) has been providing free fertilizer and seed to resource poor farmers. However, increase in the use of fertilizer in Kenya has not been reflected in maize production per unit area probably because the soils in the maize growing zones of Kenya are overused, acidic and poor.

Soil acidity is attributed to the abundance of mainly hydrogen (H^+), aluminium (Al^{3+}) and manganese (Mn^{2+}) cations in soils at levels that interfere with normal plant growth. Soil acidity has a negative effect on crops/yields mainly through P unavailability due to P fixation in soils whereby the Fe and Al soil components (sesquioxides) fix sizeable quantities of P. It is mainly due to the parent materials and overuse of acidifying fertilizers such as Di-Ammonia Phosphate [7]. In Kenya grains are grown on acid soils in which, aluminium (Al) toxicity, deficiencies of P and N reduce grain yields by about 16, 28 and 30%, respectively [8]. To sustain crop yields, high amounts of P fertilizer requirements are therefore required [9]. However this is not a solution to smallholder farmers (SHFs) who are resource poor and cannot afford the fertilizers.

Management of acidic soils by liming to restore soil health has largely been reported [10], but there is little awareness of this by farmers in western Kenya. Therefore by testing available fertilizers in the current recommended rates through on farm trials, farmers can learn importance of fertilization and liming, and are able to choose the best technologies suitable to their resource endowment. Lime is available in Koru, western Kenya, making it cheap (US$ 2 per 50 kg bag) [11] and affordable to farmers. Thus the objectives of the study were (1) to increase productivity among the small scale farmers of western Kenya through development of technologies that improves soil fertility and (2) To compare the agronomic and economic effectiveness of different P fertilizers and lime under small scale farmer management.

2. MATERIALS AND METHODS

2.1 Study Sites

2.1.1 Uasin Gishu county

It is a highland plateau. Its terrain varies greatly with altitude which ranges between 1500 to 2100 m above sea level. The average rainfall is between 900 mm -1200 mm. Due to high altitude in the county, temperatures are relatively low. The highest is 24°C and the lowest is about 8.8°C, average temperatures in the county are 18°C during the wet season with a maximum of 26.1°C during the dry season [12]. The types of soils and land use pattern in the county have been influenced by variation in altitude, rainfall, temperature and underlying geology. The soils are developed from acid igneous rocks and other parent materials with low inherent fertility and are underlain by murram (petro phylite) in the bottom levels and are mainly imperfectly drained [13]. Due to favourable topographical and climatic conditions, the entire county has a high potential for agricultural and livestock production [14].

2.1.2 Trans nzoia county

This county is part of the North Rift Valley of Kenya, another “bread basket” county, providing the bulk of maize to the country. It is situated at the 1°01′N 35°00′E / 1.017°N 35°E / 1.017; at an altitude ranging from 1700 to 2100 m above sea level, rainfall is unimodal with a mean of 1145 mm [15]; average of 30 years), with peak periods in May to August and dry spells in December to March. Mean maximum and minimum temperatures are 27.8 and 10ºC respectively. The soils are predominantly the Ferralsols, with pockets of Acrisols, Nitisols according to FAO-UNESCO classification and other orders in some areas.

2.1.3 Siaya county

The county lies between latitude 0°03’N and longitude 34°25’E. The altitude varies from 1140 to 1400 m above sea level. The county receives a bimodal rainy pattern, with long rains (LR) from 700 – 800 mm falling between March and June (peak in April/May and short rains (SR) from 500 – 700 mm, occurring between September and November (peak in October). The average rainfall ranges from 800 to 2000 mm. the annual mean maximum temperatures vary between 27 and 30°C, while the annual mean minimum temperatures range between 15 and 17°C [16]. The soils are developed from basalt which is of volcanic origin; the soils are well drained in general, deep and friable, but in some places shallow over petro ferric (with murram). The predominant soil types in the county are Nitisols, Ferralsols and Acrisols [17] according to FAO-UNESCO classification.

2.1.4 Soil sampling

Prior to treatment, surface (0-15) cm depth soil samples were randomly (random sampling method) taken using a soil auger (15 cm long) from several points at the experimental sites and thoroughly mixed together to make a composite sample. Six weeks after planting and during harvesting composite samples were again taken from each plot at the depth of 0-15 cm to monitor changes in soil available P and pH.

2.1.5 Soil physicochemical properties

The above-mentioned soil samples collected were air-dried, ground, passed through a 2.0 mm sieve and analysed for some physiochemical properties. They were analysed for pH (1:2.5, soil: H_2O) and available P (Olsen P). Samples taken after treatment application were also analysed for pH (1:2.5, H_2O) available P.

2.1.6 Participatory evaluation of different fertilizer types

In each county, four locations were randomly selected for the Participatory Rural Appraisals (PRAs) and administration of questionnaires to collect data on farmer characteristics, their farming resources, maize inputs and outputs. During the PRAs, tools such as group discussions transect walks and participatory mapping of the village were used [18]. Participants discussed their production constraints and criteria for choice of fertilizers and the decision making procedure at the household level. During PRA, farmers were also asked to identify and rank soil fertility amelioration technologies.

To address the low adoption of fertilizer in maize production in western Kenya, field experiments were carried out in farmers’ fields with farmers participating in the trials by managing the fields and evaluating the results. Recommended maize varieties for each area was selected with the participation of the farmers and used for the trials. Hybrid maize variety H 6213 was planted in Trans Nzoia and Uasin Gishu counties while the H513 was planted in the Siaya field trials.

Five soil fertility amelioration technologies considering the different fertilizer treatment DAP,

$CaCO_3$, CAN, MPR and Organic manure trading under the name Rutuba were tested in farmer managed farms. Farmers from the neighborhood were invited to participate in all farming activities during crop establishment stages. During data collection farmers were asked to rank the fertilizers on their potential to improve maize productivity by assessing their influence on the vegetative growth, plant vigor and maize yield and their own perceptions.

The treatments were allocated to plots of 10 m x 25 m in a randomized complete block design. To compare the technologies with farmer's practice (control), a strip of 3 m x 25 m was delineated from each plot and planted without any inputs. Potassium (K) was applied at 30 kg K_2O_5 as Muriate of potash in all plots except the control, to minimize K deficiency while N (CAN) was top dressed when plants were at knee height. The established agronomic practices, such as planting of quality maize seed, spacing (75 cm x 30 cm), weeding, pest and disease control, were adopted. To enhance technology adoption farmers provided their own labor and participated in all field activities. After each harvest, maize stover was incorporated into each plot.

In each farm the following technologies were installed:

i) FURP recommendation [75 kg N (urea) and 26 kg P (DAP)] per ha
ii) FURP recommendation (as above) plus agricultural lime (2 t /ha)
iii) FURP recommendation [75 kg N (urea) and 26 kg P (Minjingu PR)] per ha
iv) Rutuba bio Agric Organic Manure (2.5 t /ha) Plus ½ FURP recommendation (13 kg P ha DAP and 37 kg N ha)
v) Absolute control with no N or P applied

2.2 Statistical Analysis

A Proc. Mixed model using SAS package was used to analyze the variance [19]. The farms were allocated as the random variable, while the treatments were considered as the fixed factors as shown in the model:

$$Y= X\beta + Z\gamma + \varepsilon$$

Where: Y= Yield, β= treatment effect with known design matrix X, γ= replicates (farms) is a random-effects parameters with known design matrix Z, and ε is an unknown random error vector whose elements are no longer required to be independent and homogeneous.

Means were separated using Fisher's protected LSD test.

2.3 Economic Analysis Model Used to Assess Soil Fertility Technologies

All technologies were analyzed for their economic performance using discounted partial budget and marginal analysis, and estimating a maize production profit function. In order to carry out a partial budget analysis, outputs were first organized in a matrix *Yi* for each farmer *i* where each as the maize output of farmer *i*. maize prices was fairly constant across the counties at Kshs. 2000 (US $ 25) per 90 kg bag. The input prices were found to be comparable in all the counties. Thus, the total cost of maize production (C_{ik}) for a farmer *i* using a fertilizer type *k* was $X_{ik}.q$ where *q* is the price vector *q* with the input matrix X_{ik}, being the matrix of all inputs (land, labor, seed, and fertilizer) used by farmer *i* using fertilizer type *k* in maize production.

Thus,

$$C_{ik} = q.\, X_{ik} \quad (1)$$

The profit (worth) of farmer *i* in maize production using *k* is calculated as:

$$\pi_{ik} = p.Y_{ik} - q.X_{ik} \quad (2)$$

Marginal analysis [20] was used to compare costs and benefits of the different fertilizer types as the extra benefit of moving from one technology to the other. Ratio of the marginal net benefit over marginal cost gives the marginal rate of return of adopting technology *k1* from *k2,* where *k1* is the treatment under analysis and *k2* is the control or the best alternative.

An extension of marginal analysis can be made to analyze the output/nutrient (O/N) ratio that shows how many kg of additional maize output a farmer can obtain from a kilogram of fertilizer type *k*. Although there is no acceptable rules-of-thumb for this ratio, scientists generally agree that a ratios of ten or higher are considered efficient for cereals.

In the present study, Value Cost ratio (VCR) of using the different types of fertilizers was computed as could give an indication of the farmer decision process. This method can be used as an indicator that can predict decrease or increase in fertilizer use due to changes in input and output prices. VCR is the ratio of the product unit price to fertilizer unit price multiplied by the fertilizer response rate.

Thus:

VCR = FRR * (Product price/input prices)

where: FRR = fertilizer response rate = output (kgs)/fertilizer (Kgs).

The rule-of-thumb for VCRs is that they must be at least two before a farmer will consider fertilizer use [21] but preferably more than 4 in order to accommodate price and climate risks [22].

3. RESULTS AND DISCUSSION

3.1 Characterization of the Soils in the Three Site Sites

Soil test data at the inception of the trials showed widespread acidity (pH<5.5) and low available P (<10 mg / kg) as shown in Table 1. Before fertilizer and lime applications, the pH of surface (0 – 15 cm) soils ranged from 4.67 to 5.45 in Uasin Gishu, from 4.25 to 5.8 in Siaya, while the range was 5.16 to 5.77 in Trans Nzoia County. Farms in the three counties formed two distinct groups with low soil pH (<5.5) in Uasin Gishu and moderate acidity in Trans Nzoia and Siaya Counties. Available P from bicarbonate [23] extraction was quite low ranging from 5.24 to 9.43 mg P kg in Uasin Gishu County, while for Trans Nzoia County, Olsen P ranged from 5.2 to 9.4 mg P kg soil. Siaya site had the lowest available P levels (5.4 to 8.6 mg P kg soil). The soil pH finding concurs with research from other workers e.g. [24] who reported on low soil pH values in soils of Western Kenya. The results point out the need to consider application of liming materials to raise soil pH to the optimal levels of about 6.5 to 7.5 to minimize nutrient imbalances, toxicity and unavailability. Low soil pH values below pH < 5.5 have potential to cause toxicity problems and deficiency of some essential plants nutrients as well as affect soil microbial activities [25]. Soil pH < 5.5 could also cause dissolution of aluminum and iron minerals which precipitates with phosphorus effectively causing its fixation and further lowering the soil pH [26]. Low available P in the studied soils of Siaya may be attributed to low P inherent in the parent materials (which have developed mainly on basement rocks like granite, but also on colluviums from quartzite) [16] and because of the effects of low soil pH that normally favours P immobilization [26]. Phosphorus availability to plants is strongly influenced by soil pH, and maximized when pH is between 5.5 and 7.5 [27].

3.2 Effect of Treatments on Soil pH and Available P

The soil pH was generally low before treatment application. In the three soils, addition of lime increased soil pH from 5.5 to 6.2 in Siaya, from 4.9 to 6.5 in Uasin Gishu and from 5.2 to 5.6 in Trans Nzoia within the first season of application (2010 LR). Soil pH increase was also noted in plot with Minjingu PR in Uasin Gishu and Trans Nzoia. Treatment effects on plant available P is shown in Fig. 1. Generally, the response to P application was higher in highly acidic soils of Uasin Gishu. In this site, liming the soils using either Koru lime, Minjingu PR or commercial organic manure resulted to adequate P levels in the soils. Lime increased soil pH because of the likely displacement of Al^{3+}, H^{+} and Fe^{3+} ions by Ca^{2+} ions it contains. Similar studies have reported increased soil pH, available P, reduction in Al levels and P sorption in acid soils due to lime application [27]. The significant increase in P above the control by MPR indicates that the soil conditions at the three sites were conducive to its dissolution. Some of the factors known to increase the dissolution and subsequent release of P in PRs include low soil pH, low exchangeable Ca, and low P [28]. The soils at both sites generally met these criteria.

3.3 Effect of Treatments on Maize Grain Yields

Performance of treatments varied with site (or agro-ecological zone) and ultimately the soil characteristics. Siaya County had the lowest maize yields and showed the highest response to fertilizer and soil amendment materials application (Fig. 2) while Trans Nzoia had the highest grain yields (Table 2). In Uasin Gishu and Trans Nzoia Counties, maize grain yields did not differ significantly over theseasons, but application of P fertilizers at recommended rates had significantly higher grain yields than the control (Tables 3 and 4). Over the four cropping season (2009SR – 2011LR), cumulative fertilizer application effect was noted in Siaya (Fig. 2). The grain yields in this county improved with seasons, the highest yields being noted in 2011LR. On average, seasonal addition of P fertilizers improved grain yields by 31 to 45% in Trans Nzoia and Uasin Gishu Counties respectively (Figs. 3 and 4). Despite the application of N and P at recommended rates, maize yields was quite low compared to the yield potential (9 t /ha) of the KH 6213 variety used [28].

The general increase in maize grain yield with the application of Minjingu Rock phosphate can be attributed to its significant effect due to the presence of carbonate in apatite (francolite) and in accessory minerals (calcite and dolomite) and because when MRP dissolves, it can consume two moles of H^+ for every mole of P dissolved [29,30]. Lime, on the other hand, reduces the activity of Al ions resulting in increased extractable P [31]. According to [10] lime reduces the levels of exchangeable Al^{3+}, Fe^{3+} and Mn^{4+} in acid soils and thus reduces P sorption. This makes both the native soil P and applied P fertilizers available for plant uptake hence increased yields.

In Siaya county, DAP + lime and Minjingu PR out yielded the control and the rest of the fertilizers across the four seasons, while Rutuba commercial manure, though significantly better than the control, was inferior to the other fertilizers in all seasons (Fig 3; Picture 1). In addition, maize head smut disease was prevalent in plots with Rutuba in the three Counties, dissuading farmers from adopting this commercial organic manure.

3.4 Economics of Fertilizer Use in Maize Production

Using the experimental data, a higher gross income was obtained in Trans Nzoia compared to Uasin Gishu and Siaya experimental sites. During the 2009 season, maize performed better in Trans Nzoia compared to the other counties. The control treatment resulted in the least net benefits (NB). The 2010 benefits were however better in Siaya and Uasin Gishu compared to 2009 NB (Fig. 5).

The price for maize was found to be about $230/ton in the local markets during the study period. The cost of the different technologies depended on the quantities and prices of the inputs used. The average fertilizer prices, obtained from local agro-dealers during the time of study, were $460/ton for DAP and $375/ton for CAN. Maize seed prices was US $ 30 per the recommended 25 kg/ha. The value of stover was estimated at Kshs 3300 per ton using market prices of animal feed. For every ton of stover, farmers made about 33 bags of animal feed selling at Kshs. 100 per bag.

Table 1. Initial soil chemical characteristics of the test sites pre trial initiation

Site		Soil pH	Extractable P (mg P/ kg)
Trans Nzoia	Mean	5.20	7.70
	Range	5.16- 5.77	5.2- 9.4
Uasin Gishu	Mean	4.83	7.12
	Range	4.67-5.45	5.24- 9.43
Siaya (Sega)	Mean	5.56	7.52
	Range	4.25- 5.8	5.4- 8.6

Table 2. Effect of different P amendment fertilizers applied at the FURP recommended rate on maize grain yield over three seasons in Siaya, Kenya

Treatment	2009SR	2010LR	2010SR	2011LR	2011SR
Control	1.93a	2.3a	1.5a	2.2a	1.5a
DAP	2.74b	3.5b	3.6d	4.5c	2.9cd
DAP+ 2 t/ ha lime	3.19b	4.5c	3.3ac	5.0 d	3.1d
MPR + CAN	3.3b	3.7b	3.4ac	4.4c	2.7c
Rutuba (2.5 t/ha) + DAP	2.6a	3.2b	2.9b	3.9b	2.4b
Mean	2.8	3.4	2.9	4.0	2.5
p (0.05)	<.0001	<.0001	<.0001	<.0001	<.0001

NB: K was applied as muriate of potash (60 kg K /ha) in all plots. DAP = Diammonium phosphate (18-46-0), Lime, (21% CaO) was sourced locally at Koru, Kisumu, Kenya. Minjingu PR = Minjingu phosphate rock from Tanzania (11 – 13% total P; and 38.3% CaO), CAN = Calcium ammonium nitrate (26-0-0), Rutuba is a local market refuse processed organic source containing about 5% total N; SR = short rains season, LR = long rains season. 60 kg K ha was also applied in all plots

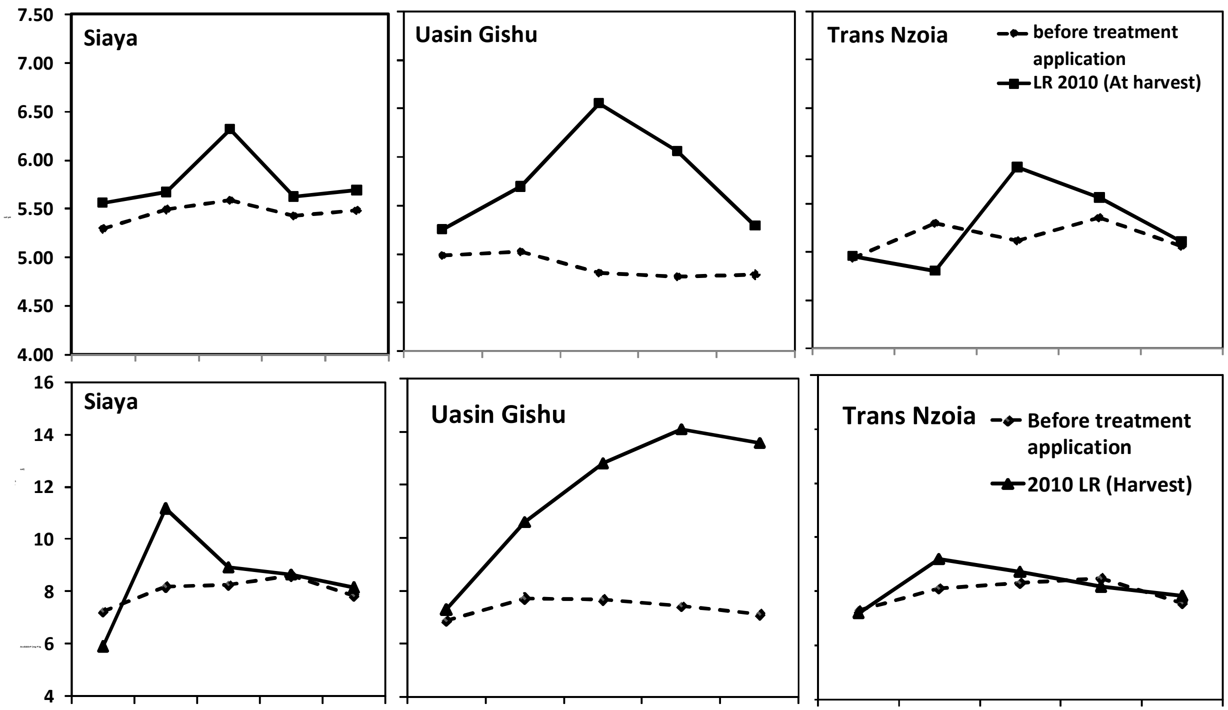

Fig. 1. Effect of different soil amendment materials on soil pH and Olsen available P at the three sites

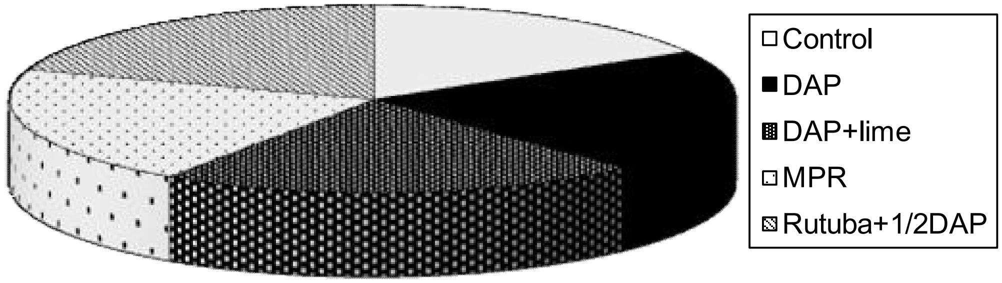

Fig. 2. Seasonal average maize grain yields in Trans Nzoia between 2009LR to 2011LR season

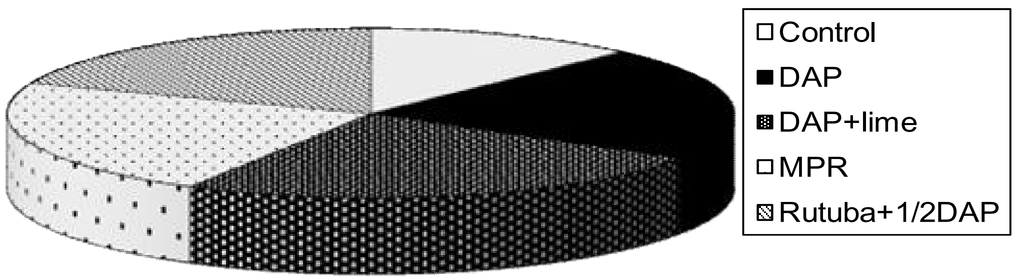

Fig. 3. Seasonal average maize grain yields in Sega between 2009SR to 2011SR seasons

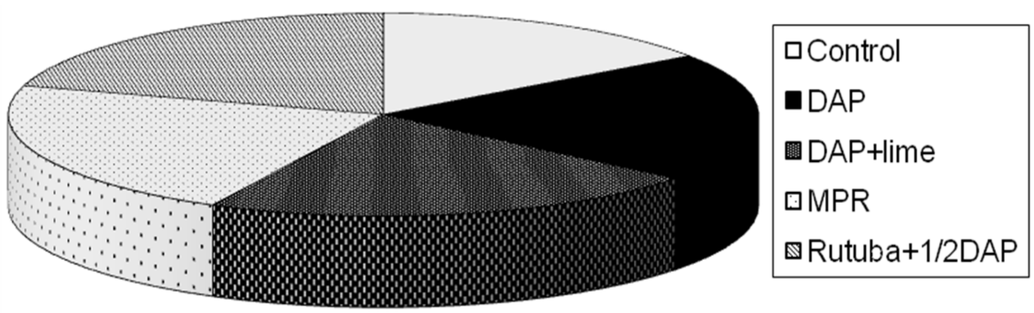

Fig. 4. Seasonal average maize grain yields in Uasin Gishu between 2009LR to 2011LR seasons

Table 3. Effect of P amendment technologies on maize grain yield (t ha) during 3 seasons in Uasin Gishu county

Treatment	2009 LR season		2010 LR season		2011 LR season	
	Grain yield (t ha^{-1})	RAE (%)	Grain yield (t ha)	RAE (%)	Grain yield (t ha)	RAE (%)
Control	2.47a		3.67a		5.3	
DAP	3.47b	40.5	5.94b	62	6.2	17
DAP+ lime	3.99b	62	5.6b	53	6.7	26
Minjingu PR+ CAN	4.02b	62	5.91b	61	6.7	26
Rutuba+ DAP	4.25b	72	5.66b	54	5.5	4
Mean	3.64		5.36		6.08	
SED	0.564		0.504			
p value	<0.001		<0.001			

Picture 1. Effect of P fertilizers applied as per FURP recommendation

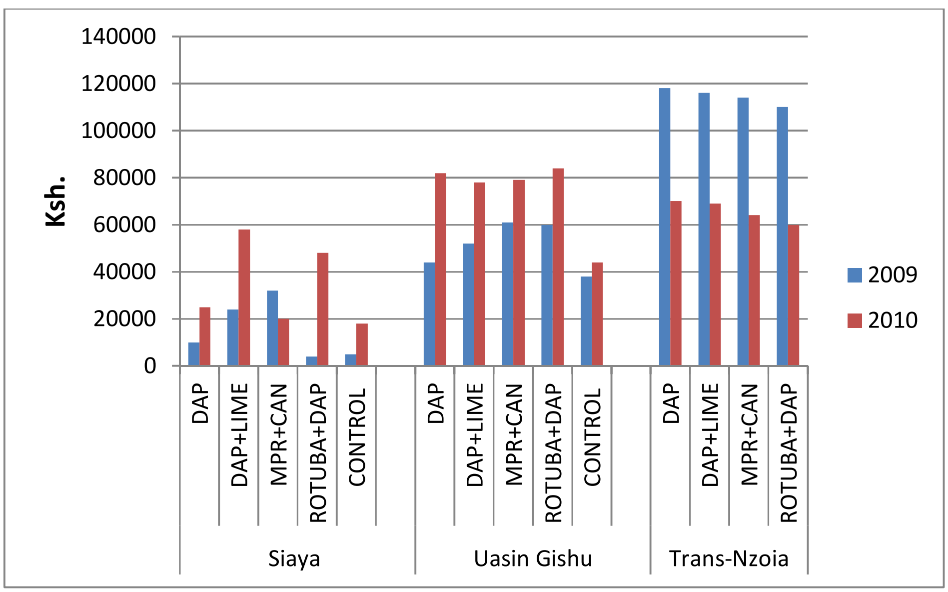

Fig. 5. The net benefits of different fertilizers in the three counties of Kenya

The highest marginal rate of return (MRR) based on the experiments of Kshs 40,729 was obtained from combination of DAP and lime (Table 5). Rutuba + DAP yielded the least MRR compared to other treatments with the cost. MPR + CAN also had a higher MRR ranging from Kshs. 12113 in Siaya to Kshs. 41,602 in Uasin Gishu. This could be because liming of soil and use of MPR raised the soil pH thus enabling plants to absorb and utilize plant nutrients such as N, P and K. This resulted in improved crop yields and therefore profitability of maize enterprise. This means that except for the high capital requirements needed in the adoption of the technologies, farmers can greatly improve their incomes by adopting any of the technologies. [32]. From the analysis of MRR, it is possible to recommend DAP for farmers in Trans Nzoia and

Table 4. Effect of P amendment technologies on maize grain yield (t/ha) during 3 seasons in Trans Nzoia county

Treatment	2009 LR season		2010 LR season		2011LR season	
	Grain yield (t/ha)	RAE (%)	Grain yield (t/ha)	RAE (%)	Grain yield (t/ha)	RAE (%)
Control	5.27a		3.34a		6.10a	
DAP	6.91b	31	5.41b	62	6.94b	14
DAP+ lime	6.99b	33	5.26b	57	6.72b	10
Minjingu PR+ CAN	6.33b	20	4.93b	48	7.12b	17
Rutuba+ DAP	6.71b	27	4.85b	45	6.20a	2
Mean	6.44		4.758		6.64	
p value	<0.001		0.002		0.011	

Values followed by the same letters along each column are not significantly different at (p<0.05)

Table 5. The marginal rate of return (MRR) of different soil fertility technologies

County/soil fertility technology	Maize production season/county					
	Siaya		Uasin Gishu		Trans Nzioa	
	2009	2010	2009	2010	2009	2010
DAP	5820.3	16467	5950.3	38199	20173.0	32302
DAP+ lime	14890.3	40729	14496.3	28723	18941.8	26488
MPR+ CAN	23984.6	24981	23001.4	41602	12113.3	26398
Rutuba+ DAP	DA	4600.4	23561.5	28988	16039.6	17760

DA meaning domineered activity where the change in marginal cost was higher that the marginal revenue obtained

a combination of DAP and Lime for farmers in Uasin Gishu. Farmers should therefore be advised to take into account profitability differences in their technology choice decisions.

4. CONCLUSION

The soil amendments increased the yields compared to previous seasons. Intensive cropping without liming in the tropical humid regions increases soil acidity and use of acidifying fertilizers particularly accelerate the process. Acid soils are made more suitable for agricultural use by liming which raises soil pH. On acid soils, judicious use of fertilizers and liming in combination seems to be the best practice, though this also poses a problem towards adoption. Due to the widespread culture that DAP is the only fertiliser that can give a good crop in western Kenya, farmers should be encouraged to lime their soils either with agricultural lime or MPR. For the early adopters MPR, the biogenic fertiliser, should be encouraged for use due to its dual purpose (CaO and P source) as well as its cost and the fact that it stays in the soil longer hence high profitability.Although MRR analysis shows the use of DAP as the most economical fertilizer in Trans Nzoia county, its negative effects on soil pH clearly proves that the fertilizer enhances soil acidity. Since this county is considered as the ‘granary’ of the country, farmers who consistently use DAP should be advised to lime their soils to maintain the desirable soil pH for maize production and reduce the negative environmental effects of this acidifying fertilizer.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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