

Micro-Dosing of Inorganic Inputs on Maize Production on an Acid Soil in Kenya: An Agronomic and Economic Evaluation

ABSTRACT

Aims: The study determined the effect of micro-dosing of lime, P and N fertilizer on maize grain yield and economic benefits.

Study design: The experiment was a 2 x 2 x 3 split-split plot laid out in randomized complete block design with N (0 and 37.5 kg N ha⁻¹) in the main plot, P (0 and 13 kg P ha⁻¹) in the sub-plot and lime (0, 0.77 and 1.55 tons lime ha⁻¹) in sub-sub plot. 37.5 kg N and 13 kg P ha⁻¹ are 50% of the recommended fertilizer rates for maize production in Kenya while 0.77 and 1.55 tons lime ha⁻¹ are 25 and 50% of the actual requirement.

Place and Duration of Study: The study was carried on nutrient deficient acid soil on a smallerholder farmer (SHF) field in Busia County, Kenya during the years 2008 and 2009.

Methodology: Lime was applied once during the long rain in the year 2008 while P and N fertilizers each cropping season.

Results: Grain yield increased by 148 and 40% due to 50% of both the recommended N and P fertilizers, respectively and 5-17% due to 25-50% of the lime requirement. Majority (57-75%) of the production costs were due to inorganic inputs. Only combined application of 50% of both the recommended N and P fertilizers, respectively produced economically viable returns throughout the cropping period. Combination of 50 and 25% of the recommended P and lime, respectively and 50 and 25% of the recommended N and lime, respectively produced economically viable returns only during the second and third cropping seasons. A combination of 50% of both the recommended N and lime, respectively produced economically viable returns during the third cropping season only.

Conclusion: Smallholder farmers producing crops on Kenya's acid soils deficient in N and P such as in Busia County can realize economically viable returns by micro-dosing of N, P fertilizers and lime.

Keywords: Micro-Dosing, Nitrogen, Phosphorus, Acid Soil, Lime, Benefits

1. INTRODUCTION

Constraints limiting agricultural production in the Kenyan high rainfall areas and other tropical lands are soil acidity and fertility depletion particularly, phosphorus (P), nitrogen (N) deficiencies and low soil organic matter [1, 2, 3, 4]. In Kenya, most maize is grown on acid soils in which aluminium (Al) toxicity, deficiencies of P and N thereby reduce maize grain yield by about 16, 28, and 30%, respectively [5]. Due to soil fertility depletion, maize grain yield in tropical Africa are very low, rarely more than 1 ton ha⁻¹ [6].

To address low crop yield, many soil fertility replenishment technologies have been developed in the East African region with positive crop responses to nutrient inputs. These range from sole use of organic inputs to inorganic fertilizers as well as their combinations [7, 8]. For example, 75 kg N and 26 kg P ha⁻¹ are the recommended fertilizer rates for maize production in Kenya [9]. To enhance crop production on the Kenyan acid soils, use of lime is also recommended [2, 3]. The adoption of these technologies is rather low among the smallerholder farmers (SHF) due to a number of challenges. In SHF fields, the quantities of organic materials are low, they have low nutrient levels and their use require a lot of labour. Most SHF rarely apply the recommended rates of the inorganic fertilizers due to the lack of credit and their high cost [6, 8]. Despite the challenges, use of the organic and inorganic materials is vital for increasing food production in Africa [10]. Most of the recommended soil fertility replenishment technologies focuses on maximum crop production without taking into account the challenges faced by SHF [11]. In Kenya, therefore, there has been growing interest to find alternative, affordable, viable and sustainable technologies to replenish soil fertility suitable for SHF to increase food production [12].

To promote food production among resource constrained SHF, in the recent past, a lot of interest has been geared towards finding an efficient and sustainable fertilizer use [12]. Micro-dosing, which comprises of use of small and affordable amounts of inorganic fertilizers for planting or top dressing is such a technology. In Zimbabwe for example micro-dosing of 25 – 33% of the recommended N fertilizer increased maize grain yield in SHF [13]. This enhanced the adoption of fertilizer inputs among the SHF. Research has suggested that with an application of as little as 10 kg N ha⁻¹ farmers can increase their crop yield by 50-100% [10]. On acid soils, lower rates of fertilizers can be applied together with lime to achieve higher fertilizer nutrient use efficiencies since lime reduces soil

acidity related constraints [2]. Most research on micro-dosing has been carried out in Zimbabwe's semi-arid areas using mainly N fertilizers where soil acidity is not a problem. Therefore there is need to test the technology on high rainfall acid soils where Al toxicity, low N and P limit crop production such as found in western Kenya. The study objectives were to determine the effect of micro-dosing of lime, P and N fertilizer rates on: - i) maize grain production and ii) economic benefits on infertile acid soil in Busia County, Kenya.

2. MATERIAL AND METHODS

2.1 Site Description

A study was conducted on a SHF field (0°19'N & 34°12'E) in Busia County Kenya. The study site was located 1300 m asl and had an average annual rainfall of 1600 mm with bimodal distribution. It has two main cropping seasons, with long rains from March to July and the short ones from September to December [14]. The soil was moderately acid (pH 5.4), deficient in N (0.09 %), P (2.44 mg kg⁻¹ bicarbonate extractable P) and low in base cations with high Al saturation (> 20% Al) [15].

2.2 Experimental Design, Layout and Management

The experiment was a 2 x 2 x 3 split-split plot arrangement in randomized complete block design with two levels of N (0 and 37.5 kg N ha⁻¹) in the main plot, two levels of P (0 and 13 kg P ha⁻¹) in the sub-plot and three levels of lime (0, 0.77 and 1.55 tons ha⁻¹) in sub-sub plot. The zero (0) represents practice where farmers do not apply inorganic inputs. 37.5 kg N and 13 kg P ha⁻¹ are 50% of the recommended N and P fertilizer rates, respectively for maize production in Kenya [9]. A liming material with 21% calcium oxide (CaO) was acquired from Homa Lime Company in Kenya. The 0.77 and 1.55 tons ha⁻¹ are 25 and 50% of the actual lime requirements, respectively for the site [15].

Plots of 3.5 m by 3 m were demarcated after ploughed and harrowing during the long rain in the year 2008. Plots were separated from each other by a spacing of 1 m all round Lime was evenly broadcast and thoroughly mixed with the soil 30 days prior to planting to allow for adequate time for it to react with the soil only during the long rain in the year 2008. Triple superphosphate and calcium ammonium nitrate (CAN) fertilizers were spot applied into the planting holes and thoroughly mixed with soil at planting during the year 2008 long and short rains as well as the year 2009 long rain. Nitrogen was split-applied with 30 and 70% at planting and top-dress at six weeks post emergence, respectively. Two seeds of maize hybrid 513 were planted per hill at a spacing of 75 cm by 25 cm and were thinned to one plant per hill two weeks post-emergence. The recommended agronomic practices for the area were used for crop management. The crop was harvested at physiological maturity.

2.3 Determination of Crop Response to Treatment

The grain yield was computed using the following formulae:-

$$\text{Yield (kg plot}^{-1}\text{)} = \frac{\text{Total Fresh Weigh} \times \text{Sample Dry weight}}{\text{Sample Fresh Weigh}} \quad (1)$$

$$\text{Yield (kg ha}^{-1}\text{)} = \frac{\text{Yield per plot} \times 10,000 \text{ m}^2}{\text{Effective Area (m}^2\text{)}} \quad (2)$$

where effective area is part of the plot harvested which is less the guard row and plants at the end of each row.

2.4 Statistical Analysis of Grain Yield Data

Maize yield data was subjected to analysis of variance (ANOVA) with the split-split plot design using General Statistics [16]. Means were separated using pooled standard error of difference of means (s.e.d) at significance levels of $p \leq 0.05$.

2.5 Economic analyses of the grain yield data

The economically acceptable treatment(s) were determined by partial budgeting analysis to estimate the gross value of the grain yield by using the adjusted yield [17, 18] at the market value of the grain and inputs during the cropping period. In partial budgeting only costs that vary from the control are used and are referred to as total costs that vary (TCV). The prices of lime, CAN, TSP fertilizers, bags for storing maize grain, transport and maize grain were determined through market survey during planting and harvesting at the end of each cropping period. Also

labour wage rates for applying lime and fertilizers, harvesting and shelling of maize were determined through market survey. Yield data were adjusted downward by 10% since research has found out that farmers using the same technologies would obtain 10% yield lower than those obtained by researchers[15]. The discounted rate of capital was determined at the rate of 10 and 20% per season and year, respectively and was applied to cash costs only. The discounted rate reflects the farmer's preference to receive benefits as early as possible and to postpone costs. All costs and benefits were converted to monetary values in USA dollars (USD) and reported on per ha basis. The cash values used for costs and benefits in this study are presented in Table 1 below. The accrued net financial benefits (NFBs) and TCV were then compared across the treatments in dominance analysis described below.

The first step in partial budgeting was the calculation of the NFBs as shown by the formula below:-

$$\text{NFB} = (\text{Y} \times \text{P}) - \text{TCV} \quad (3)$$

where $\text{Y} \times \text{P}$ = Gross Field Benefit (GFB), Y = Yield ha^{-1} and P = Field price per unit of the crop.

Table 1. Values used for costs and benefits analysis (USD) during the years 2008 and 2009

Parameters	Long rain 2008	Short rain 2008	Long Rain 2009
TSP kg ha^{-1} applied	64	64	64
CAN kg ha^{-1} applied	139	139	139
Price of TSP kg^{-1}	1.18	0.85	0.98
Price of CAN kg^{-1}	0.66	0.48	0.47
Cost of transporting 50 kg of fertilizer to the farm	0.37	0.27	0.39
Cost of lime at the factory	1.79	-	-
Transporting 50 kg of lime from factory to the farm	1.03	-	-
Cost of A 90 kg sack for storing grain	0.37	0.27	0.46
Price of maize grain kg^{-1}	0.30	0.21	0.27
<u>Labour costs</u>			
Baseline lime application per 50 kg bag	0.37	0.27	-
Baseline application of TSP or CAN fertilizer ha^{-1}	2.22	1.59	2.36
Cost of harvesting 1 bag of maize cobs	0.30	0.21	0.33
Cost of shelling one bag of maize grain	0.59	0.42	0.52
Opportunity cost of capital per season (%)	10	10	10

Note: 2.5 bags of maize cobs = 1 bag of 90 kg grain

The second step was dominance analysis in which the treatments were listed in order of increasing TCV. Treatments with NFB less than or equal to treatment with lower TCV are dominated and were marked with a "D" while ones with higher NFB than the treatments with lower TCV are undominated. The dominated treatments were eliminated from further consideration since no farmer would choose a treatment(s) with higher TCV and receive lower NFB [17]. The marginal rate of return (MRR) analysis was carried out on the undominated treatments in a stepwise manner, starting from one treatment with the lowest TCV to the next using the formula shown below:-

$$\text{MRR} (\%) = \frac{\text{Change in NFB (NFB}_b - \text{NFB}_a)}{\text{Change in TCV (TCV}_b - \text{TCV}_a)} \times 100 \quad (4)$$

where NFB_a = NFB with the immediate lower TCV, NFB_b = NFB with the next higher TCV, TCV_a = the immediate lower TCV and TCV_b = the next highest TCV.

Changes in NFB and TCV are also referred to as marginal benefits and costs, respectively.

MRR indicates what farmers can expect to gain on the average, in return to their investment when they decide to change from one practice (or set of practices) to another with increase in costs. To make farmer recommendation (s) from the marginal analysis, the minimum rate of return acceptable to farmers was estimated. Experience and empirical evidence have shown that for majority of situations the minimum rate of return acceptable to farmers to change from one technology /treatment to another is between 50 and 100% [17, 19]. A minimum rate of return criteria of 50% was set for the MRR analysis as adequate for changing from one treatment to another that does not require the farmers to learn new skills or use new equipment ([17]. Therefore, any treatment combinations that produced MRR above 50% were considered worth an investment by farmers.

3. RESULTS AND DISCUSSION

3.1 Effect of Inorganic Fertilizers and Lime on Maize Grain Yield

All the treatments had significant effect ($p \leq 0.05$) on maize grain yield (Table 2). The mean maize yield increments during the cropping period above the control were 148 % due to 50% of the recommended rate of N fertilizer, 40% due to 50% of the recommended rate of P fertilizer and 5-17 % due to 25–50% of the actual lime requirement. Such maize yield increase due to lower rates than recommended rates of lime, N and P fertilizers have been reported. In the Kenyan highlands west of Rift valley, 50% of the recommended rate of N fertilizer increased maize grain yield by 111% while 25–50% of the actual lime requirement increased grain yield by 14-31% [19]. Similarly, in Zimbabwe, 25–33% of the recommended N fertilizer rate increased maize grain yield and adoption of fertilizer use by SHF. In Zimbabwe, farmers obtained 25–50% grain yield gain with an application of as low as 10 kg N ha⁻¹ which is about 18% of the research recommendation [17]. It is evident from the present study that a combination of any two or three of the treatments produced higher grain yield than either of them alone. This was likely because lime reduced nutrient toxicity thereby creating conducive environment for plant growth necessary for efficient nutrient absorption and utilization [4, 15]. A combination of N and P fertilizers produced higher yield than any of them due to their synergism.

Table 2. Effects of N, P fertilizers and lime on maize grain yield (tons ha⁻¹)

Treatments		Long rain 2008					Short rain 2008					Long rain year 2009				
N kg ha ⁻¹	P kg ha ⁻¹	Control	0.77 tons lime ha ⁻¹	1.55 tons lime ha ⁻¹	Mean for P	Mean for N	Control	0.77 tons lime ha ⁻¹	1.55 tons lime ha ⁻¹	Mean for P	Mean for N	Control	0.77 tons lime ha ⁻¹	1.55 tons lime ha ⁻¹	Mean for P	Mean for N
0	0	0.474	0.595	0.641	0.570	0.857	0.569	0.614	0.73	0.638	0.905	0.359	0.426	0.642	0.476	0.737
	13	0.950	1.171	1.309	1.143		1.007	1.179	1.329	1.171		0.840	0.940	1.212	0.997	
37.5	0	1.667	1.874	1.973	1.838	2.013	1.763	1.876	2.017	1.885	2.112	1.641	1.845	1.930	2.109	2.039
	13	2.009	2.181	2.372	2.187		2.139	2.333	2.544	2.338		2.170	2.305	2.465	2.313	
Mean for lime		1.355	1.275	1.455			1.369	1.5	1.655			1.244	1.361	1.558		
CV%		3.7					3.2					3.5				
s.e.d _(0.05) N		0.016					0.015					0.012				
s.e.d _(0.05) P		0.020					0.005					0.009				
s.e.d _(0.05) lime		0.021					0.012					0.022				
s.e.d _(0.05) N*P		0.010					0.016					ns				
s.e.d _(0.05) N*Lime		ns					ns					ns				
s.e.d _(0.05) P*Lime		0.024					ns					0.028				
s.e.d _(0.05) N*P*Lime		0.031					0.026					0.041				

3.2 Economic Analysis of the Treatment Effects on Grain Yield

Table 3 presents the proportions of inorganic inputs (i.e. fertilizers and lime) of the total production costs. The cost of inorganic inputs contributed to the majority (57-75%) of the production costs during three cropping seasons. During this study period, the Kenya Government did not control the prices of farm inputs. As a result, the Agro-Chemical Dealers took the advantage to set their own prices which were relatively high. In Kenya and other developing countries, farm inputs especially the inorganic fertilizers are very expensive. Due to high costs of the inorganic inputs, SHF rarely apply the recommended rates of fertilizers to replenish the nutrients removed through crop harvests [6]

Table 3. Percent added costs of the inorganic inputs

Treatments	Long Rain 2008	Short Rain 2008	Long Rain 2009
Control	0	0	0
0.77tons lime ha ⁻¹	67	0	0
1.55 tons lime ha ⁻¹	72	0	0
13 kg P ha ⁻¹	73	70	70
13 kg P + 0.77 tons lime ha ⁻¹	73	68	69
13 kg P + 1.55 tons lime ha ⁻¹	74	66	65
37.5 kg N ha ⁻¹	75	66	59
37.5 kg N + 0.77 tons lime ha ⁻¹	69	65	57
37.5 kg N/ha + 1.55 tons lime ha ⁻¹	71	63	56
37.5 kg N + 13 kg lime ha ⁻¹	62	71	66
37.5 kg N + 13kg P + 0.77 tons lime ha ⁻¹	73	70	65
37.5 kg N + 13 kg P +1.55 tons lime ha ⁻¹	74	69	64

Lime contained 21% CaO

Table 4 shows economic analysis of benefits, variable costs and marginal rate of return of treatments using partial budgeting techniques. Treatments that produced high GFBs and /or NFBs were not necessarily economically viable where MRR was less than 50% considered suitable for investment. Although majority of the treatments did not realize economically viable returns to investments due to high cost of the inorganic inputs and low maize prices, some did during the cropping period. Only a combination of 50% of both the recommended N and P fertilizers, respectively produced economically returns viable throughout the cropping period with NFBs of USD 383.99, 615.71 and 956.12 in the first, second and third seasons, respectively. A combination of 50 and 25% of the recommended P and lime rates, respectively and 50 and 25% of the recommended N and lime, respectively produced economically viable returns during the second and third cropping seasons only. The NFBs for 50 and 25% of the recommended P and lime, respectively were USD 290.86 and 432.6 during the second and third seasons, respectively. For the 50 and 25% of the recommended N and lime rates, respectively the NFBs were USD 550.28 and 899.21 during the second and third seasons, respectively. A combination of 50% of both the recommended N and lime rates, respectively only produce economically viable return with NFB of USD 956.12 during the third cropping season. Economically viable returns to lime were realized during the second and third cropping seasons but not during the first cropping season when it was applied. The effects of lime have been reported to last for several years and not all the returns are realized in the first year of application [21]. Although, not permanent, the effect of lime on soils have been reported to last longer than other inorganic fertilizers [2, 22]. Economically viable returns to lime were realized during the second and third cropping

182 seasons but not during the first cropping season when it was applied [21]. Therefore,
183 economically viable returns reported in the current study during the second and third
184 cropping seasons where lime was applied were due to its residual effects which resulted to
185 higher grain yield.

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Table 4. Gross field benefits, total costs that vary, net financial benefits and marginal rate of returns analysis of treatments during cropping period

Long Rain 2008					Cumulative Long and Short Rain 2008					Cumulative for Year 2008 and Long Rain 2009				
Treatments	GFB (\$)	TVC (\$)	NFB (\$)	MRR (%)	Treatments	GFB (\$)	TVC (\$)	NFB (\$)	MRR (%)	Treatments	GFB (\$)	TVC (\$)	NFB (\$)	MRR (%)
Control	126.05	8.96	117.08		Control	233.59	16.66	216.93		Control	322.43	23.98	298.45	
0.77 tons L ha ⁻¹	158.22	65.20	93.03	D	0.77tons L ha ⁻¹	274.27	73.66	200.61	D	0.77tons L ha ⁻¹	379.69	82.47	297.23	D
13 kg P/ha	252.62	104.75	147.87	32	1.55 tons L ha ⁻¹	308.42	130.92	177.51	D	1.55 tons L ha ⁻¹	467.31	143.92	323.38	21
1.55 tons L ha ⁻¹	170.45	120.95	49.50	D	13 kg P ha ⁻¹	442.95	183.18	259.77	26	13 kg P L ha ⁻¹	650.83	273.13	377.70	32
37.5 kg N +13 kg L ha ⁻¹	534.23	150.24	383.99	519	13 kg P + 0.77 tons L ha ⁻¹	534.22	243.37	290.86	52	13 kg P + 0.77 tons L ha ⁻¹	766.85	334.79	432.06	88
13 kg P + 0.77 tons L ha ⁻¹	311.39	162.85	148.54	D	37.5 kg N + 0.77 tons L ha ⁻¹	852.89	302.61	550.28	438	13 kg P + 1.55 tons L ha ⁻¹	899.21	400.48	498.73	101
37.5 kg N/ha + 0.77 tons L ha ⁻¹	498.33	198.39	299.94	D	13 kg P + 1.55 tons L/ha	599.27	303.03	296.24	D	37.5 kg N + 0.77 tons L ha ⁻¹	1309.49	419.41	890.08	2068
13 kg P + 1.55 tons L ha ⁻¹	348.09	220.36	127.73	D	37.5 kg N+13 kg P ha ⁻¹	938.50	322.79	615.71	324	37.5 kg N ha ⁻¹	1182.61	440.20	742.41	D
37.5 kg N/ha	443.29	224.17	219.12	D	37.5 kg N ha ⁻¹	776.49	326.92	449.58	D	37.5 kg N +1.55 tons L ha ⁻¹	1383.50	480.26	903.24	22
37.5 kg N+1.55 tons L ha ⁻¹	524.66	254.92	269.73	D	37.5 kg N + 1.55 tons L ha ⁻¹	905.87	361.20	544.67	D	37.5 kg N+13 kg P ha ⁻¹	1475.53	519.41	956.12	135
37.5kg N + 13kg +0.77 tons L ha ⁻¹	579.97	290.89	289.08	D	37.5 kg N/ha + 13kg P/ha+0.77 tons L/ha	1020.90	466.04	554.86	D	37.5 kg N + 13kg P +0.77 tons L ha ⁻¹	1591.34	665.16	926.18	D
37.5 kg N +13 kg P +1.55 tons L ha ⁻¹	630.76	349.17	281.58	D	37.5 kg N +13 kg P +1.55 tons L ha ⁻¹	1111.57	527.11	584.46	D	37.5 kg N +13 kg P +1.55 tons L ha ⁻¹	1721.61	729.60	992.01	17

189 L = lime containing 21% calcium oxide

4. CONCLUSION

The average grain yield increment during the cropping period were 148 and 40 % due to 50% of the recommended N and P fertilizer rates, respectively and 5 - 17% due to 25 -50% of the lime requirement. The majority of production costs (57-75%) were due to inorganic inputs (lime, N and P fertilizers). However some micro-dosing treatments produced economically viable returns during the cropping period. Only treatments with 50% of both the recommended N and P rates, respectively produced economically viable returns throughout the cropping period with NFBs of USD 383.99, 615.71 and 956.12 during the first, second and third seasons, respectively. A combination of 50 and 25% of the recommended P fertilizer and lime rates, respectively and 50 and 25% of the recommended N and lime rates, respectively produced economically viable returns during the second and third cropping seasons only. The NFBs for the 50 and 25% of the recommended P and lime, respectively were USD 290.86 and 432.6 during the second and third seasons, respectively. For 50 and 25% of the recommended N and lime, respectively the NFBs were USD 550.28 and 899.21 during the second and third seasons, respectively. A combination of 50% of both the recommended N and lime, respectively only produce economically viable return with NFB of USD 498.73 during the third cropping season. Smallholder farmers cultivating P and N deficient acid soils can realize economically viable returns by micro-dosing of N, P fertilizers and lime. Researchers need to develop economically viable micro-doses of inorganic inputs suitable for adoption by SHF to increase maize production in the Kenyan N and P deficient acid soils.

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