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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 farm 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: SHF 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 reduce its grain yield by about 16, 28, and 30%, respectively [5]. Therefore, yield of maize, which is the staple food in tropical Africa, Kenya include, are very low, averaging less than 1 ton ha^{-1} against a potential of 4 tons 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, in Kenya the recommended N and P fertilizer rates for maize production are 75 kg N and 26 kg P ha^{-1}, respectively [9]. In addition to inorganic fertilizers, use of lime is highly recommended for the management of acid soils in Kenya [2, 3]. However, these approaches have several drawbacks which have hindered their adoption by smallholder farmers (SHF). Use of organic inputs is labour intensive, they are of often low in nutrient content and not available in sufficient quantities on SHF fields. Inorganic fertilizers, on the other hand, are expensive and most SHF cannot afford [6, 8], yet use of fertilizers remains the key to increasing food production in Africa [10]. The main problem with most of the fertilizer management recommendations is that they target maximization of yields or profits without consideration of the resource constraints faced by many 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].

Therefore there has been therefore growing interest to find alternative interventions that promote efficient and sustainable use of fertilizer tailored to smallholder farmers' socio-economic conditions [12]. One such technology is the use of precision technique referred to as micro-dosing, which involves the application of small, affordable quantities of inorganic inputs at the time of planting or as top dressing. 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. Other research however suggests that farmers can increase their average yield by 50-100% by applying as little as 10 kg N ha^{-1} [10]. In addition, fertilizer use efficiency could be improved by liming

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the acid soils to eliminate Al toxicity [2] thereby resulting in a reduction in the amount of fertilizer required to achieve a target yield. Much of the work on micro-dosing of fertilizers has been conducted in semi-arid regions of Zimbabwe 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 on: - i) maize grain yield and ii) economic benefits on nutrient deficient acid soil in Busia County, Kenya.

2. MATERIAL AND METHODS

2.1 Site Description

The study was carried out in Busia County, Kenya, 1300 m asl, (0°19'N & 34°12'E) with mean annual rainfall of 1600 mm which is distributed over two main cropping seasons, the long rainy season which is from March to July and the short rainy season 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 laid out in randomized complete block design with N in the main plot, P in the sub-plot and lime in sub-sub plot. Two N rates, 0 representing a practice where farmers apply no fertilizer and 37.5 kg N ha^{-1}, which is 50% the recommended N fertilizer rate for the area [9]. P was also applied at 0 and 13 P kg ha^{-1} for similar reasons as N. Liming material containing 21% calcium oxide (CaO) was obtained from Homa Lime Company in Kisumu County, Kenya and was applied at 0, 0.77 and 1.55 tons ha^{-1}. The 0.77 and 1.55 tons ha^{-1} are 25 and 50% of the actual lime requirements, respectively for the site [15].

Plots measuring 3.5 m by 3 m were demarcated after being ploughed to an appropriate tilth during the long rain in the year 2008. Each plot was separated from the next by a spacing of 1 m. Lime was applied only once during the long rain in the year 2008 by evenly broadcast and thoroughly mixing it with the soil 30 days prior to planting. This was to allow for adequate time for it to react with the soil. Phosphate fertilizer as triple superphosphate (TSP) and N as calcium ammonium nitrate (CAN) were spot applied into the planting holes and thoroughly mixed with soil at the time of planting during the long and short rains in the year 2008 and also during the long rain in the year 2009. Nitrogen was split-applied with 30% at planting and the rest as a top-dress at six weeks later. Two maize seeds (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. Maize was managed using the recommended agronomic practices for the area and the grain harvested at physiological maturity.

2.3 Determination of Crop Response to Treatment

The grain yield was computed using the following formulae:-

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

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

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

All the maize yield data were 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) whenever treatment effects were significant at $p \leq 0.05$.

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

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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:-

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

where Y x 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
Labour costs			
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:-

$$MRR\ (\%) = \frac{\text{Change in NFB } (NFB_b - NFB_a)}{\text{Change in TCV } (TCV_b - TCV_a)} \times 100 \quad (4)$$

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.

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3. RESULTS AND DISCUSSION

3.1 Effect of Treatments on Grain Yield

The maize grain yield data is presented in Table 2. All the treatments had significant effect ($p \leq 0.05$) on maize grain yield. The mean maize yield increments during the cropping period above the control were 148 and 40% due to 50% of both the recommended rates of N and P fertilizers, respectively 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. A combination of N and P fertilizers produced higher yield than any of them due to their synergism.

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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	
	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	0.737
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	
	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	2.039
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				

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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

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

L = lime containing 21% calcium oxide

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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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