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Potential of reduced agricultural lime application rates to increase yield and profitability of maize through microdosing in central Malawi - A short note

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Maize (*Zea mays* L.) is a staple food crop in Malawi, with average yields of 1.8 -2.2 t ha^{-1} compared to potential yields of 5 to 10 t ha^{-1}. In some areas, soil acidity is a serious constraint in crop production. The current recommendation is to apply 2.0 t ha^{-1} of lime as pre-plant broadcast and incorporated into soils with pH$_W$ < 5.5. A pilot study was conducted during 2015/2016 season at Bunda Campus (14° 35 S'; 33° 50 E') to evaluate the response of reduced lime application rates of 0, 100, 250 and 500 kg ha^{-1} applied by point placement or dollop method (mirodosing) in comparison to recommendation pre-plant broadcast application. A uniform fertilizer application of 69:23:0+4S was made on all plots. Gross Margin (GM) analysis, Value Cost Ratio (VCR) and Benefit-Cost Ratio (BCR) were undertaken. A gross Margin analysis was done using prevailing input/out values of 2019 at exchange rate of Malawi Kwacha, MK 745 = 1USD. Results showed that the 'no lime' control (4.01 t ha^{-1}) gave the lowest grain yield and was significantly (P<0.05) out-yielded by the rest of the treatments. The highest yield of 5.75 t ha^{-1} was observed from the 500 kg ha^{-1} application, while the recommended control of 2t/ha yielded 4.90 t ha^{-1}. The BCR was >1.0 for all treatments at two price scenarios of US$0.201 kg^{-1} and US$0.268 kg^{-1} grain, but >2.0 only for 100, 250 and 500 kg ha^{-1} lime application rates. VCR ranged from 4.4 to 10.4, except for 2 t ha^{-1} treatment which had 0.78 and 1.05 at US$0.201 and US$0.268 kg^{-1} grain price, respectively. The results demonstrated that there is potential in reduced lime application rates to increase yield of maize by microdosing of agricultural lime. This study has provided a solid basis for wider evaluation of the concepts for subsequent rolling out to famers.

Key words: Dolomitic lime, soil acidity, microdose applications, aglime profitability.

INTRODUCTION

In Malawi, maize (*Zea mays* L.) is the staple food crop that dominates the cropping systems. Average yields in the period, 2005 to 2012, ranged between 0.81 and 2.65 t ha^{-1} (GoM, 2012). Poor soil fertility is one of the major reasons for low yields (Kumwenda et al., 1997; ICRISAT/ MAI, 2000; Blackie and Mann, 2005; MoAFS, 2012). Other constraints include recurrent droughts, poor management, foliar diseases, stalk borers, termites and

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the parasitic weeds species *Striga* (MoAFS, 2012; Kabambe et al., 2008).

For some parts of the country, especially in high rainfall upland areas, aluminium toxicity due to low pH is a major constraint. Chilimba and Saka (1998) reported that over 40% of the soils in Malawi belong to soil orders Oxisols and Ultisols (US Taxonomy), which are highly weathered and strongly acid with a pH (in water) of < 5.5. Many reports confirm occurrence pH levels below this critical minimum level (Maida, 1985; Chilimba and Nkosi, 2014; Snapp, 1998; Kabambe et al., 2013). There is a current recommendation to apply 2 ha^{-1} agricultural limes as pre-plant broadcast incorporation for soils with pH_w (H_20) < 5.5 (Chilimba, 2005; Chilimba and Nkosi, 2014; Chilimba et al., 2013).

Aluminium toxicity is considered as the most important plant-growth limiting factors in many acid soils, particularly those with pH below 5.0 to 5.5. Tully et al. (2015) reported that up to 24% of Sub-Saharan Africa is under Aluminium toxicity while 8.49 are subject to high P fixation. When acid soil are limed, exchangeable Al^{3+} and hydrohyaluminium cations such as $Al(OH)_2^+$ are converted to insoluble $Al(OH)_3$; resulting in removal of the Al_3^+ from cation exchange competition (Marschner, 2011; McCauley et al., 2009). Availability of P and K are improved with liming. Excess aluminium interferes with cell division in plant roots, fixes phosphorus into less available forms, decreases root respiration, and interferes with uptake, transport, and use of Ca, Mg and P (Fairhurst, 2012; Goulding, 2016). In Cameroon, Yamoah et al. (1996) reported that application of lime and green manure improved stand count, root and stem weights and yields of maize, bean and potato in an acid soil and that high P application was unnecessary when lime was applied. Onwonga et al. (2008) reported that lime application increased soil pH within two months of application and that organic amendments had similar effects in Kenya. The et al. (2012) reported that continuous cultivation of maize resulted in a soil acidity in Cameroon, falling from 4.89 to 4.38 and drops in soil availability of Ca and K. There is potential to reduce the lime requirements and increase yield through microdosing of lime application (The et al., 2012; Kisinyo et al., 2015; One Acre Fund, 2016), including application by point placement or dollop method (One Acre Fund, 2016). Malawi has large deposits of limestone and dolomite. An explorative study was therefore conducted to compare the effectiveness of applying reduced rates of agricultural lime on maize growth and yield at Bunda Campus of Lilongwe University of Agriculture and Natural Resources, central Malawi in 2015-2016 season.

MATERIALS AND METHODS

Experimental design, treatment descriptions and general crop and management

A field trial was conducted utilizing a randomized complete block to evaluate seven treatments and four replicates (Table 1); which were designed to compare the recommended application of lime at 2.0 t ha^{-1} to reduce rates applied as point placements (dollop method), hereafter referred to as microdosing.

The maize variety DK8053, with a maturity period of 140 days, was used in the study. The maize was planted on ridges spaced at 75 cm apart with stations at 60 cm, 2 seeds per station, giving a target plant population of 44,444 plants/ha. Gross plot sizes were 5 ridges x 0.75 cm x 5.3 m long (19.875 m^2), while the net plot comprised three middle ridges excluding end of ridge plants (10.575). The compound fertilizer 23:21:0+4S was applied at 100 kg/ha for basal dressing, one week after planting. The remaining 46 kg/ha N was applied as top dressing at 4 weeks after planting in the form of urea. Ridge preparation, lime application and planting were done in mid-December, 2015. The fields were kept free of weeds by weeding with a hand-hoe. The field preparations and fertilizer, lime application and planting were done in mid-December 2015. Figure 1 shows daily cumulative rainfall (mm) recorded at the site. In general, the season was considered good for maize production.

Study site

A field experiment was conducted at Lilongwe University of Agriculture and Natural Resources – Bunda campus, at the student Crop and Soil Sciences research farm in the 2015/2016 cropping season (November 2015 to April 2016). The farm is 1159 masl at 14°35' S and 33°50' E with an annual rainfall of 1031 mm. The soil types vary from clay loam to sandy loam (Jones and Kanyama, 1977). The specific site for the study had mean pHw of 5.1 (SD 0.22, n=10).

Data recording and analysis

The data recorded in this report were maize plant height, grain yield and stover weight. Grain yield and stover were determined by harvesting all plants from net plot area. For stover, 6 plants were randomly sampled from the net plot area and oven dried to determine percent moisture content of stover, which was used to adjust field weight to dry weight. Grain moisture content was determined using grain moisture meter and yield adjusted to 12.5% storage moisture. Plant height (from base to center of leaf whorl or flag leaf) was determined from an average of 6 plants randomly selected from the net plot. Data were subjected to analysis of variance procedure using Genstat 18th Edition (VSN International, Memel, Hemstead, UK) and mean separation by LSD at ≤ 0.05 probability.

Determination of gross margins (GM), value cost ratio (VCR) and benefit-cost-ratio (BCR)

Gross margins (GM) were determined as gross income from sales minus production costs that vary. The costs that vary mainly consist of labor (land preparation, ridging, planting, fertilizer application, harvesting shelling, cleaning and packaging). These are basic components described by several authors (Dzanja, 2008; Ngulube et al., 2001; Takane, 2008). Dzanja (2008) estimated the total labor requirement to be 139 mandays for maize and these were used in the calculations. However, Takane (2008) estimated labor requirement for maize to be 176 mandays. Another factor considered as a variable cost was packaging, which comprised a new sack for each 50 kg of harvest. Tables 2 and 3 show the total costs for each of the five rates of lime application. The costs of inputs and labor use were those of the October 2019 in Malawi. At this time the exchange rate of the Malawi Kwacha to US $ was 1: 745. The labor was valued based on the minimum wage rate of

Table 1. List of treatments in the lime rate and microdosing study.

Treatment number	Description Kg ha^{-1} lime	Treatment details
1	No lime	$NP_2O_5K_2OS$ 23:21:04. Fertilizer applied by dollop or point placement method one week after emergence. No agri lime application
2	100 as microdose	$NP_2O_5K_2OS$ 23:21:04 applied as in 1. Plus 100 kg lime applied in dollop on one side of maize station
3	250 as microdose	$NP_2O_5K_2OS$ 23:21:04, applied as in 1, plus 250 kg/ha lime applied in dollop on one side of maize station
4	500 as microdose	$NP_2O_5K_2OS$ 23:21:04, applied as in 1, plus 500 kg/ha lime applied in dollop on one side of maize station
5	2000 kg/ha lime, band	$NP_2O_5K_2OS$ 23:21:04, applied as in 1, plus 2000 kg lime applied in band made by opening the ridge to 15cm then covering up

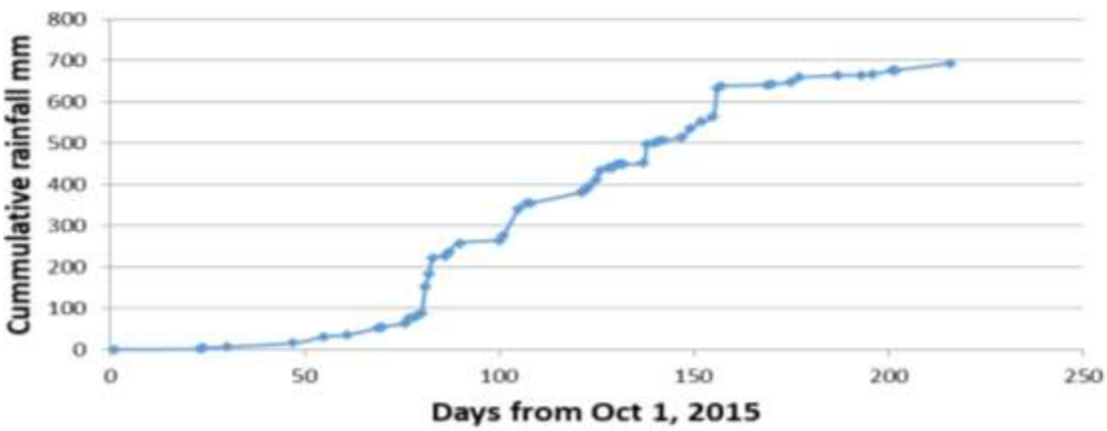

Figure 1. Daily cummulative rainfall (mm) for Bunda College, 2015/2016 season.

Table 2. Variable costs (US $) for the different lime fertilizer rates used in the gross margin calculations for maize (cf 1 US$= Malawi Kwacha, MK, 745).

Input type	Fertilizer package kg ha^{-1} NPKS and inputs costs in MK ha^{-1}				
	69:21:0+4S	69:21:0:4 and 100 kg ha-^{1} lime	23:21:0:4 250 kg ha^{-1} lime	23:21:0:4 500 kg ha^{-1} lime	23:21:0:4 2000 kg ha^{-1} lime
Seed 25 kg/ha	37.58	35.57	35.58	35.58	37.58
Labour at US$1.29manday	356.39	356.39	356.39	356.39	356.39
Fertilizer cost	128.86	128.86	128.86	128.86	128.86
Lime at US $ 8.05 for100 kg +30% transport mark up	0	10.47	26.17	52.34	161.07
Labour Lime application	0	2.58	6.46	12.91	51.65
Bagging	16.10	18.52	19.32	23.15	19.53
Total variable costs*	538.94	554.41	574.79	611.29	755.08

US$ 1.29 for time (October 2019). Calculations were made for two output price scenarios of US$0.201 kg^{-1} and US$ 0.268 kg^{-1} as realistic average prices in the August-October 2019 period. The evaluation also involved calculation of Value Cost Ratio (VCR) and Benefit Cost Ratio (BCR). The VCR was calculated as incremental value of maize divided by treatment/coast associated with implementing the treatment (Kihara et al., 2015). Specifically the costs were those associated with lime purchase and application (Table 2). Benefit–cost ratio was determined by dividing gross income of a treatment by total variable cost. There was no discounting of costs, as the comparison is for one-season data rather than a long- duration project (Ajayi, 2009). The economic calculations are presented in US $ to facilitate 'universal" communication.

Table 3. Effect of lime application rate on maize plant height (cm) 2 to 10 weeks after planting

Treatment	Plant height (cm) x weeks after planting				
	2	4	6	8	10
0 kg/ha lime	18.9	33.6	92.9	130.1[a]*	143.2[a]
100 kg/ha lime, microdose	18.6	34.6	93.8	133.2[a]	148.5[ab]
250 kg/ha lime, microdose	18.1	34.8	96.6	135.3[ab]	155.6[b]
500 kg/ha lime, microdose	18.7	35.1	95.9	151.5[bc]	167.5[c]
2000 kg/ha lime, banding	19.5	34.4	95.5	147.1[c]	160.2[c]
Mean	18.8	34.5	94.9	139.5	155.0
F Prob	0.72	0.84	0.67	<0.001	<0.001

*means denoted by same letter are not significantly different at P≤ 0.05.

Table 4. Effect of treatments on maize grain and stover yield (kg/ha).

	Grain yield kg ha^{-1}	Stover weight kg ha^{-1}
0 kg/ha lime	4012[a]*	7459
100 kg/ha lime, microdose	4601[b]	7884
250 kg/ha lime, microdose	4847[b]	8742
500 kg/ha lime, microdose	5751[c]	9476
2000 kg/ha lime, banding	5064[b]	9080
Mean	4896	8610
F Prob	0.016	0.18

*means denoted by same letter are not significantly different at P≤ 0.05.

RESULTS AND DISCUSSION

Agronomic results

There were no significant treatment differences in plant heights at 2, 4 and 6 weeks after planting. Significant differences were observed at 8 and 10 weeks after planting (Table 3). In both cases 500 kg ha^{-1} microdose treatment gave tallest plants, which were significantly higher than no-lime control and 100 kg ha^{-1} at 8 weeks only but similar to the rest of the treatments including commended 2 t ha^{-1} treatment. For grain yield (Table 4), the 500 kg ha^{-1} lime microdose gave the highest yield which was also significantly higher than all other treatments treatment. There were no significant treatment differences on stover yield.

The increased growth and yield due to lime application are in agreement with local literature (Kabambe et al., 2013; Mtonga, 2013) and regional literature (Kisiyo, 2015; The, 2012) and is agreement with recommendation to apply lime for soils with pHw <5.5 (Chilimba and Nkosi, 2014). It of interest to note the significant yield increase to the lower lime rates as applied by point placement. Rates of 100-250 kg ha^{-1} are substantially lower and would be relatively feasible for smallholder farmers compared to 2 t ha^{-1} currently recommended. The et al. (2012) reported that application of lime at the rate of 250 kg ha^{-1} increased maize grain yield in some varieties of maize, but not others. However, agricultural lime applied at high rates to a large volume of soil has advantage of residual effects which may last for 2-3 seasons. In Malawi, Kabambe et al. (2012) confirmed residual effects of 2 t ha^{-1} after one season with maize and common beans. There are different ways which can be employed in the integrated management of acid soil in order to reduce amount and cost of lime while improving crop productivity. These include use of tolerant varieties (The et al., 2012), amendments with organic inputs including wood ash, compost, and legume rotations (Kabambe et al., 2012; Onyonga et al., 2008; Yamoah, 1996; Goulding, 2016) and agroforestry (De Pauw, 1994). Farmers may also opt for crop species with greater acid resistance (De Pauw, 1994; Goulding, 1989). The yields obtained in this study are higher than average smallholder farmer yields (MoAFS, 2012). On farm yields from research plots with fertilizer application normally fall in the range 2.5-3.5 t ha^{-1} (Ngwira et al., 2012; Kabambe et al., 2013, 2018). The results obtained are explorative in nature and mainly serve to provide a basis for wider on farm verification on the both the rates and method of application before recommendations to farmers.

Gross margins, value cost ration and benefit-cost ratio

The results on Gross Margins (GM) (Table 5) show that all treatments had positive GM, the highest coming at

Table 5. Value cost ratio (VCR).

Treatment	Costs, benefits and VCR in MK at two price scenarios				
	Lime cost, application and bagging	Increment benefit US $ 0.201 kg^{-1}	Increment benefit US $ 0.268 kg^{-1}	VCR US $0.201 kg^{-1}	VCR US $ 0.268 kg^{-1}
No lime	0	-	-	Na	Na
100 kg ha^{-1} lime	15	121	161	7.8	10.4
250 kg ha^{-1} lime	36	161	215	4.5	6.0
500 kg ha^{-1} lime	72	351	470	4.9	6.5
2000 kg ha^{-1} lime	216	170	228	0.78	1.05

500 kg ha^{-1} lime and lowest with the 2 t ha^{-1} lime treatment using both maize product prices. The results are in line with yield results. In a similar GM analysis Kabambe et al. (2018) also reported that GM of maize was positive for yields and prices of 4,000 kg ha^{-1} and US$0.27 kg^{-1} respectively. Recently, Ngwira et al. (2020) reported GMs of US$1000-1800 from on-farm maize trails in Malawi.

Conclusion

The results consistently demonstrate that 500 kg ha^{-1} lime as micro dose resulted in better maize growth and yield compared to no lime treatment and 100 kg ha^{-1} rate. However, both growth and grain yields were similar with the other treatments. The results suggest potential to reduce application rates and increase yield of maize through microdosing of agricultural lime and provide a solid basis for wider evaluation of the concepts for subsequent rolling out to famers. Profitability was clearly related to yield and the associated costs of production. These results are from an explorative study. As the concept of microdosing, as defined here, is the reduction of application rates and the precise point placement. It is recommended that it should be evaluated along with other integrated soil management options that are proven to ameliorate soil acidity and improve yields.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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