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Maize yield response to potassium and lime application at Bungoma and Trans Nzoia Counties, Western Kenya

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Abstract

Maize is the most important staple food in Kenya, and is grown across a wide range of agro-ecological zones, accounting for about 40 present of daily calories. A major constraint in maize production in Kenya is low and declining soil fertility. Nutrient input and output studies on farmlands across Kenya and sub-Saharan Africa show an alarming negative balance leading to widespread land degradation. This study sought to increase maize yield through application of potassium (K) and lime in western Kenya. The studies were conducted at Bungoma and Trans Nzoia counties, considered as the breadbasket region for the country. The objectives were to establish maize responses to K fertilization and lime application. The field studies evaluated maize response to different rates of potash fertilizer (0 - 200 K_2Okg/ha) in order to establish the K requirement for maximum/optimum crop yields. Experimental design was a split plot arranged in randomized complete block design (RCBD) replicated four times. The lime and no lime were assigned to the main plots while the K levels were assigned to the sub-plots. There were three farms in Trans Nzoia county, and two farms in Bungoma county. At Bungoma, liming increased maize stover yields by 70% from 2.4 to 4.3 tons/ha. Bungoma, maize grain yields ranged from 2.2 to 4.5 tons/ha in Mabanga and 3.6-6.2 tons/ha. The optimal response to K at 40kg K_2O/ha at Ndengelwa and 80kg/ha at Mabanga sites. In Trans Nzoia, liming treatment stratum was significantly different at 5% level and increased stover yields by 17%. At the 40 K_2Okg/ha application, liming increased stover yields by 50% (6.3-9.5 tons/ha), whilst under no liming, 40kg K_2O /ha application increased the stover yields by 30% (5.4-6.9 tons/ha). Our work confirms that soils in western Kenya are acidic and have low levels of K. These soils therefore require liming and NPK fertilization for optimal maize production and food security.

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Introduction

Maize is the most important staple food in Kenya, and is grown across a wide range of agro-ecological zones, accounting for about 40 percent of daily calories (Kibaara, 2005) and accounts for 80% of Kenya cereal production (WFP, 2022). Approximately 3.5 million small-scale farmers are involved in maize production accounting for 75% of the total maize crop while 1,000 large-scale farmers produce the remaining 25% of the production. Annual per capita consumption of maize in Kenya is estimated at 98 kilograms which translates to between 30 and 40 million bags of maize annually. Over the years, production has fallen behind the national demand for maize, and the deficits have had to be met through imports. Estimated maize production declined from 40.7 million bags in 2013 to 35.4 million bags in 2017 (GOK, 2018). During the same period, maize imports increased more than eight-fold (GOK, 2018). In recent years, for instance in 2020-2021 the amount produced decreased by an estimated 550,000 metric tons (MT) as a result of variables such as higher fertilizer prices, which led to reduced application rates, and the most severe drought in 40 years, amongst other challenges. This in turn led to a price increase of 30-65% for 1-kg of maize flour in 2022 and the release of all national maize reserves in May 2022 (WFP, 2022).

Poor weather is blamed for the low output of maize in some years. The national average maize yields are estimated at 1.8 tons per hectare, equivalent to twenty (20) 90-kg bags (GOK 2018). These yields are about one fifth of those attained internationally in countries such as Argentina (Merlos *et al.*, 2015). In the early 80s, the maize yields started to increase following adoption of hybrid maize varieties and the accompanying fertilizer use to the extent that by 1986, the average national yields were over 2 tons per hectare (Nyoro, 2002). However, this growth has not been sustained, due to various biophysical and socio-economic factors, some of which include soil fertility decline coupled with high input costs, lack of clean seed, pest and diseases, lack of access to credit and inadequate extension services and unfavorable markets (Republic of Kenya, 1997; 2004; 2010).

A major constraint in maize production in Kenya is low and declining soil fertility. Nutrient input and output studies on farmlands across Kenya and sub-Saharan Africa show an alarming negative balance leading to widespread land degradation. According to Smalling *et al.* (1993), Nitrogen (N), Phosphorus (P), and Potassium (K) balances for 13 countries in SSA showed negative trends with about 200 million ha of cropland having lost 660kg N ha^{-1}, 75kg P ha^{-1} and 450kg K ha^{-1} in the last 30 years, with high to very high depletion rates in East and Central Africa. As a result, the originally fertile lands that yielded 2 - 4 t ha^{-1} of cereal grains have been turned into infertile ones where cereal crop yields of < 1 t ha^{-1} are common (Sanchez 2002). Furthermore, the practice of intensive continuous cropping with limited, no replenishment or imbalanced fertilization of nutrients has resulted in high nutrient depletions. The cost of production has increased tremendously since the last decade, as prices of farm inputs have correspondingly escalated (KIPPRA, 2017; WFP 2022). Consequently, food insecurity is rampant in the region with up to 90% of households having to buy food to supplement their harvest. The problem of soil fertility decline is exacerbated by climate change and variability with the region experiencing increasingly shorter cropping seasons and droughts in recent years.

Most soil fertility work has focused on nitrogen (N) and phosphorus (P), two of the most limiting nutrient elements in crop production in Kenya (Okalebo *et al.*, 1997). In maize production, the N and P are usually applied in compound form mainly as diammonium phosphate and other combinations. The fertilizer is applied at planting in the compound form, and N is supplemented as top-dressing during maize early vegetative growth stage. There are therefore possibilities of N losses due to leaching, both for the applied N at planting time and top-dressing, considering the heavy rainstorms in most seasons associated to climate change. Applying coated N at planting would therefore ensure a more synchronized N release for plant growth and minimize leaching, and this may also be associated with K effects on maize yields. While efforts have been made to fertilize soils with N and P, there has been very limited focus on potassium (K).

In the 70's and 80's it was generally assumed that K was not a problem in Kenyan soils, and there were no specific recommendations for K application. Results on crop response to K in Kenya have been variable. For instance, studies by Mangale (1995) did not show clear responses to K, but others by Kanyanjua *et al.* (2002) recommended application of 25kg K per ha. In recent years, Omanga *et al.* (2013) working in western Kenya found that maize growth parameters of plant height and stem girth and its yield parameters of ear weight, ear length, ear girth and grain yields increased steadily as potassium doses were increased and reached their optimum values at potassium doses of 155.84 and 144.76kg/ha suggesting the need for more studies which would lead to formulation of K application recommendations.

Apart from soil fertility decline, another confounding limitation to maize productivity in Kenya is soil acidity. In Kenya acid soils occupy 13% of the total land area, and the acidity is mainly a result of parent materials of acid origin, leaching of base cations and use of acid forming fertilizers for instance di-ammonium phosphate and calcium ammonium nitrate (Kanyanjua *et al.*, 2002). These soils have high levels of Al (>2 cmol Al/kg and > 20% Al saturation) and low in soil available P (<5mg P/kg soil) due to moderate-high (107-402 mg P/kg) P sorption, hence limiting recovery of nutrients such as P fertilizer. Application of lime, P fertilizer and organic matter increases soil pH, available P and reduces Al toxicity on Kenyan acid soils. Soil acidity has also been found to influence K availability. As the soil pH is reduced (increasing soil acidity) the availability of K is often reduced. Where there is a significant imbalance between available K and the other major cations (Primarily Calcium, Magnesium, and sometimes Hydrogen, Aluminum, and Sodium), it may affect the availability of K to the crop.

Lime, P fertilizers and OMs have increased maize grain yield by 5-75, 18-93 and 70-100%, respectively on Kenyan acid soils. Similarly, deployment of crop cultivars tolerant to Al toxicity and/or low soil available P increases crop yields. However, lack of knowledge on the importance of lime, unavailability of lime in many agro-dealer outlets, and inadequate soil organic matter limits crop yield on Kenyan acid soils.

This study therefore sought to increase maize yield through application of potassium and lime in Trans Nzoia and Bungoma Counties, western Kenya.

Materials and methods

Study area

The field experiments were conducted at Bungoma and Trans Nzoia counties in western Kenya, considered the cereal grain breadbasket region for the country. Soils are mostly Acrisols and Ferralsols.

Bungoma County

The county covers an area of about 3,032km². It is located on the southern slopes of Mt. Elgon, and borders the Republic of Uganda to the northwest, Trans-Nzoia County to the northeast, Kakamega County to the east and southeast and Busia County to the west and southwest. The temperature here averages 18.9 °C, with the hottest month being March, at an average temperature of 20.0 °C. July, with an average temperature is 17.9 °C is the coldest month. Precipitation here averages 1262mm. Precipitation is the lowest in January, with an average of 25mm. Most precipitation falls in May, with an average of 175mm.

Trans Nzoia County

Trans Nzoia County covers an area of 2,495.6km² and it is located in the North rift Region. The county borders Uganda to the West, Bungoma and Kakamega Counties to the South, West Pokot County to the North, Elgeyo Marakwet and Uasin Gishu Counties to the South East. The temperature averages 18.9 °C and precipitation averages 1262mm.

Field sites

Four study sites were established in Trans Nzoia County at Kwanza Sub County at Mary Wepukhulu, and Githanga farms and Kiminini Sub County (Kamidi's farm). In Bungoma County, two farms at Kanduyi Sub County included Mabanga Agricultural Training Centre (ATC) and Ndengelwa.

The field studies evaluated maize response to different rates of potash fertilizer (0 - 200 K_2Okg/ha) in order to establish the K requirement for maximum/optimum crop yields. Generally, soils in the maize growing areas, are acidic and therefore to improve the fertilizer use efficiency, liming was included in the treatment combinations. Thus, to demonstrate the benefits of lime, the treatments were to include the different potash fertilizer rates plus nitrogen, phosphorus with or without lime. The lime was applied at 2 tonnes per ha, equivalent to sixteen 50-kg bags per acre. In all the treatments with an exception of Nil plots, N and P were applied at 150 Nkg/ha (in three splits) and 100 P_2O_5kg/ha at planting. Potassium was applied at 0, 40, 80, 120, 160 and 200 K_2Okg/ha. The treatments for the maize trials are shown in Table 1.

Table 1. Treatment combinations

Treatment	Liming	Potassium rates (K_2Okg/ha) of MOP	Combined Treatments	Treatment designation	Applied fertilizer
1	No lime	Nil	Unfertilised Control	Nil	None
2	No lime	0	N+P+K0	K-0	Diamonnium phosphate (DAP)
3	No lime	40	N+P +K40	K-40	DAP +Muriate of potash (MOP)
4	No lime	80	N+P+K80	K-80	DAP +Muriate of potash (MOP)
5	No lime	120	N+P +K120	K-120	DAP +Muriate of potash (MOP)
6	No lime	160	N+P+K160	K-160	DAP +Muriate of potash (MOP)
7	No lime	200	N+P+K200	K-200	DAP +Muriate of potash (MOP)
8	Lime (L)	Nil	L+ Unfertilised Control	L-Nil	DAP +
9	Lime (L)	0	L+N+P+K0	L-K-0	DAP +
10	Lime (L)	40	L+N+P+K40	L-K-40	DAP +Muriate of potash (MOP)
11	Lime (L)	80	L+ N+P+K80	L-K-80	DAP +Muriate of potash (MOP)
12	Lime (L)	120	L+N+ P+K120	L-K-120	DAP +Muriate of potash (MOP)
13	Lime (L)	160	L+N+P+K160	L-K-160	DAP +Muriate of potash (MOP)
14	Lime (L)	200	L+N+ P+K200	L-K-200	DAP +Muriate of potash (MOP)

NB: L- Lime, K- Potassium, N- Nitrogen, P- Phosphorus

Experimental Design

Experimental design was a split plot arranged in randomized complete block design (RCBD) replicated four times. The lime and no lime were assigned to the main plots while the K levels were assigned to the sub-plots. Maize plot sizes were 6 x 4 m^2 plots with 0.5 m paths between plots and 1 m paths between blocks. In all sites, land was prepared using a hand hoe. Furrows were then made and seed was sown at 5 cm depth at spacings of 75 between rows and 30 cm between plants. Planting density at all sites 44,444 plants per Ha, while planting dates and varieties used are shown in Table 2 below.

Table 2. Maize varieties used at the four sites, sowing and harvest dates in 2018.

Site	Kwanza	Kiminini	Ndengelwa	Mabanga
Variety	H6213	H6213	H520	H520
Sowing date	23 March	24 March	22 March	21 March
Harvest date	6 October	4 October	2 August	3 August

Soil Sampling and Analysis

Before experiment establishment, soils in the participating farms were sampled at 0-30 cm depths using an auger. The soils were then air-dried and ground to pass through a 2mm sieve, after which they were characterized for pH (in water), total C (Walkley Black), total N (Kjeldahl), total P, Ca, Mg, K, and Zn, extracted in NH_4OAC. Details of the analytical methods were described by Hinga *et al.* (1980). Data collected included plant heights at the early vegetative stage, and above-ground biomass which included grain yield at harvest. Harvesting was done at 133 and 190 days after sowing respectively for Bungoma and Trans Nzoia counties. Data analysis was done using GENSTAT 15th Edition (Payne *et al.*, 2012).

Results

Soil parameters

Table 3 shows the chemical analytical results. The soil pH ranged from 4.9 to 6.2 across the four farms. Two farms, Mabanga ATC in Bungoma and Kamidi farm in Kiminini had acid soils which required liming.

The exchangeable acidity for the two farms was also below critical levels. Phosphorus, total nitrogen and organic carbon were low in all the four farms, a common feature for most smallholder farms in Kenya. Potassium levels were low mainly in two farms, Mabanga and Kamidi, marginal at Ndengelwa farm and adequate in Wepukhulu and Githanga farms.

Table 3. Soil chemical Analytical results.

Parameter and depth (cm)	Bungoma				Trans Nzoia					
	Ndengelwa		Mabanga		Kamidi		Wepukhulu		Githanga	
Soil Depth (cm)	0-20	20-50	0-20	20-50	0-20	20-50	0-20	20-50	0-20	20-50
Soil pH (Water)	6.19	5.5	4.9	5	4.95	5.09	5.75	5.74	5.5	5.4
Exch. Acidity (me%)	n/a	n/a	0.2	0.2	0.3	0.3	n/a	n/a	n/a	n/a
Total Nitrogen (%)	0.12	0.12	0.12	0.09	0.13	0.11	0.13	0.12	0.1	0.09
Total Org. Carbon (%)	1.11	1.11	1.15	0.68	1.35	0.98	1.43	1.09	1.23	1.11
Mehlich Phosphorus (ppm)	15	15	10	10	5	25	15	15	14	14
Potassium (me%)	0.21	0.26	0.09	0.1	0.21	0.15	0.42	0.26	0.4	0.2
Calcium (me%)	4.2	4	1.4	1.3	1	0.8	4.2	4.4	3.9	4
0.1M HCl Zinc (ppm)	2.41	3.23	2.79	2.04	2.26	1.35	2.66	4.06	2.51	3.06

NB: underline denotes below the critical level (deficient for nutrients), acidic for pH.

Maize Response to Potassium

Bungoma County

Liming effect was significant for the treatments at 5% level at Mabanga but there was no effect at Ndengelwa. At Mabanga, liming significantly ($P<0.05$) increased stover yields by 70% from 2.4-4.3 t/ha. In Bungoma, maize grain yields ranged from 2.2-4.5 t/ha in Mabanga and 3.6-6.2 in Ndengelwa, with optimal response to K at 40kg/ha at Ndengelwa and 80kg/ha at Mabanga (Fig 1). Potassium rate at 40kg/ha resulted in a 50% stover yield increase at Ndengelwa with yields ranging from 4-6 t/ha (Fig. 2). In Mabanga, liming was significantly different at 10%, and when combined with K at 40kg/ha increased maize grain yields by 70% from 3-5 t/ha, whilst application of K at 40kg/ha under no liming regime increased maize grain yields by 60% (2.5-4 t/ha). Total dry matter yield followed similar trends to the grain, with significant liming treatment differences at Mabanga, and no effect at Ndengelwa (Fig. 3).

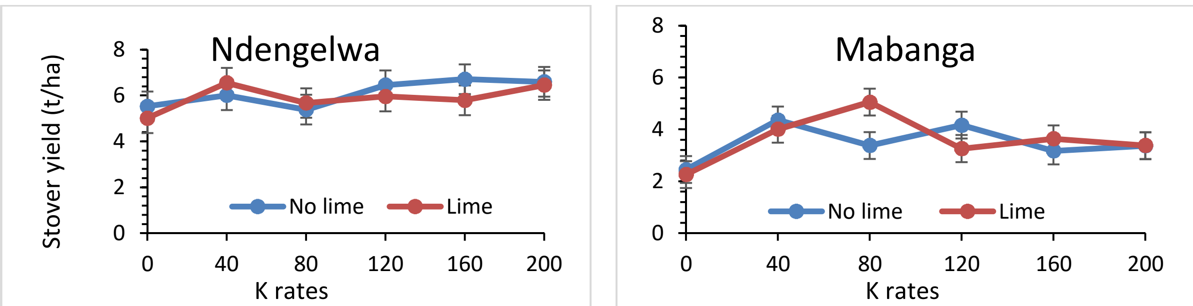

Fig. 1. Stover yield response to K fertilization at Ndengelwa and Mabanga farms in Bungoma County.

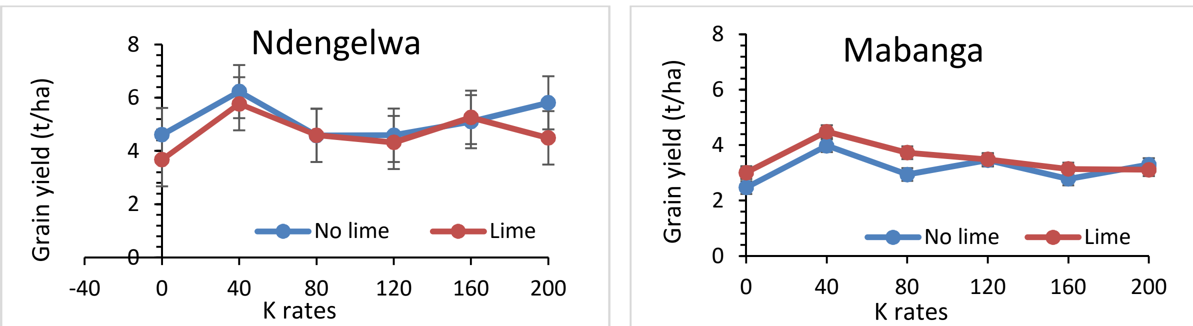

Fig. 2. Grain yield response to K fertilization at Ndengelwa and Mabanga farms in Bungoma County.

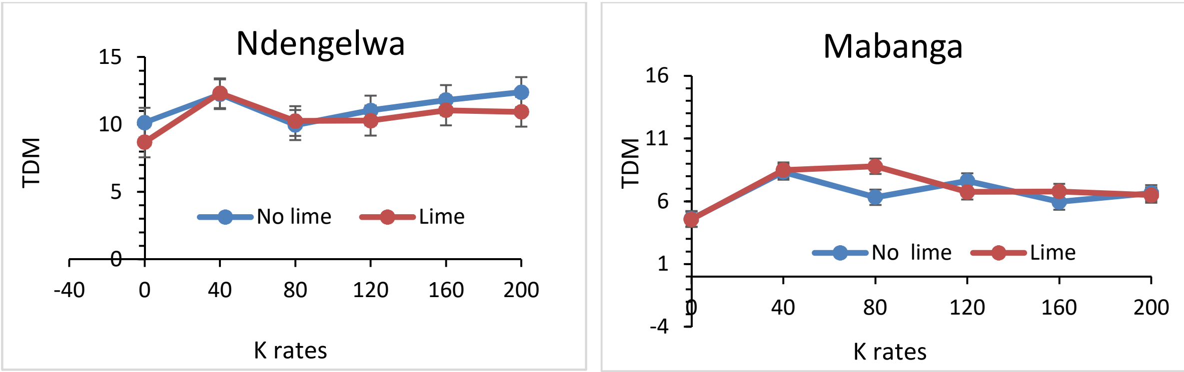

Fig. 3. Total above ground dry matter (TDM) yield response to K fertilization at Ndengelwa and Mabanga farms in Bungoma County.

Trans Nzoia County

Liming treatment stratum was significantly different at 5% level at Kamidi farm. Overall, liming increased stover yields by 17%. At 40kg/ha K_2O application, liming increased stover yields by 50% (6.3-9.5 t/ha), whilst under no liming, 40kg/ha K_2O application increased stover yields by 30% at 5.4-6.9 t/ha (Fig. 4.). At Wepukhulu farm, liming had no effects on maize stover yields. The stover yields ranged from 5-13 t/ha. At this farm maize yields ranged from 4-10 t/ha, while total dry matter ranged from 14-20 t/ha (Fig. 4.). At Githanga farm, liming, though not statistically significant, increased overall maize yields by 10%. Treatments were significantly different at 1% level, and yields declined at K rates above 40kg/ha (Fig. 5.). Although maize stover yields response to K was variable across farms, optimal maize grain response to K occurred at 40kg K_2O in all farms. Total dry matter across the farms followed similar trends to grain and stover yields with the highest amounts obtained at Wepukhulu farm (Fig. 6.).

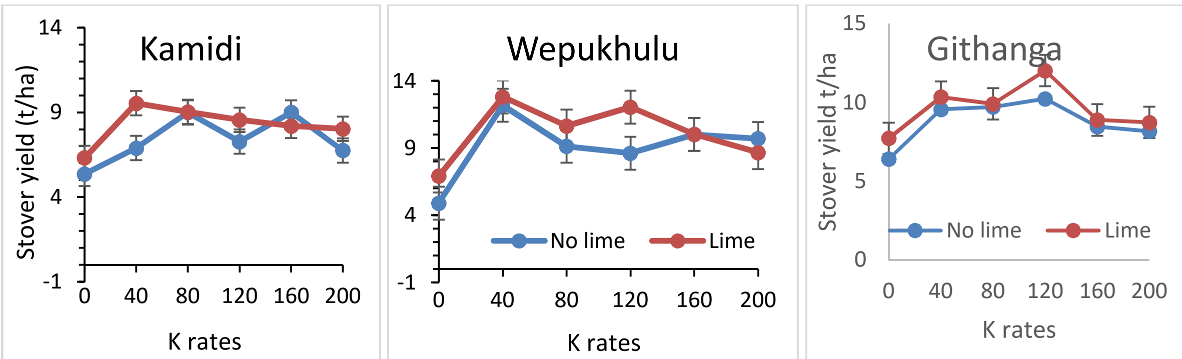

Fig. 4. Stover yield at Kamidi, Wepukhulu and Githanga farms in Trans Nzoia County.

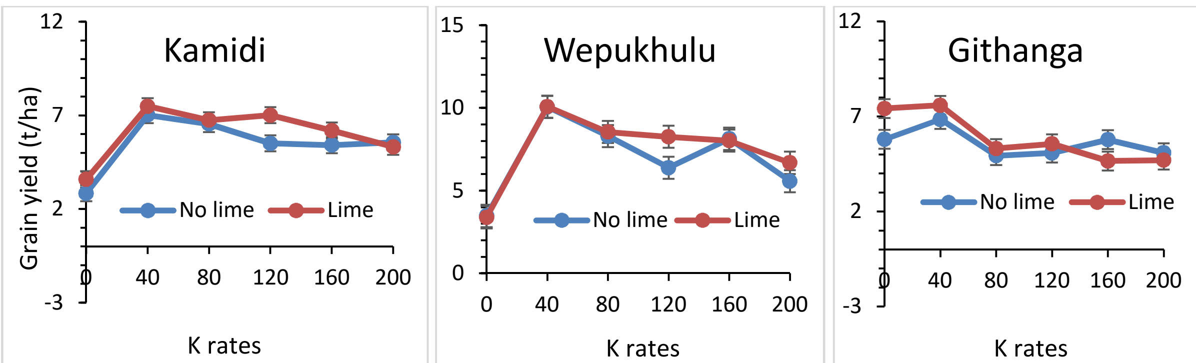

Fig. 5. Grain yield response to K fertilization at Kamidi, Wepukhulu and Githanga farms in Trans Nzoia County.

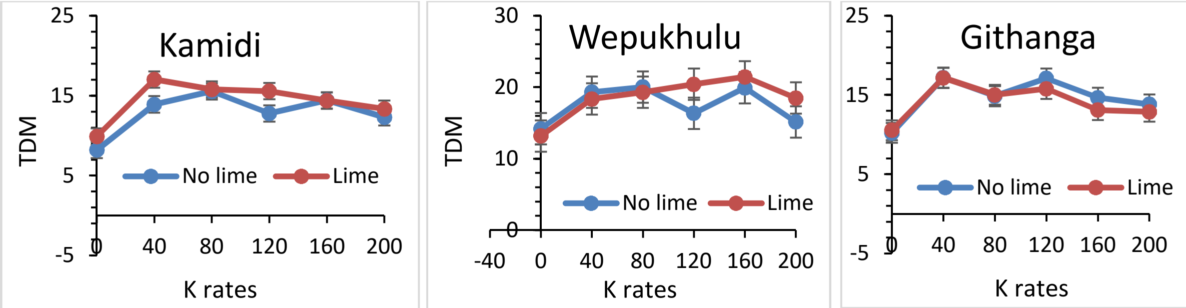

Fig. 6. Total above ground dry matter yield response to K fertilization at Kamidi, Wepukhulu and Githanga farms in Trans Nzoia County.

Discussion

Maize production in Kenya has continued to fall below the national demand. In 2012, the deficit was at 341,000 metric tonnes, and by 2016 the deficit had grown to 953,000 metric tonnes (KIPPRA 2017). There is therefore an ever increasing need to increase the production of this staple food. The government policy in the maize sub-sub-sector has been to provide incentives for increased production to ensure food self-sufficiency and security, while providing appropriate support to local farmers to get good returns so that they can remain in maize production. Despite these reforms, however, food security and self-sufficiency have remained elusive, because maize yields achieved by the Kenyan farmers across the major agro-ecological zones are much lower than the yield potential. In our study, application of N and P at different K levels increased maize from 2 to 6 t/ha in Bungoma County and from 3 to 12 t/ha in Trans Nzoia County.

In both Bungoma and Trans Nzoia counties, optimal K rates for grain production was 40kg K_2O while yield increment beyond this rate was inconsistent and, in most cases, negative. The initial soil analysis in this site showed low and inadequate levels mainly in two farms, Mabanga (Bungoma County) and Kamidi (Trans Nzoia County) and marginal to adequate levels in the other 3 farms. Due to adequate K levels in most Kenyan soils, several authors have reported low response to K. For instance, Ndung'u –Magiroi, *et al.* (2017) and Kaizzi *et al.* (2012) reported higher responses to K at rates lower than 5kg K_2O /ha in maize monocrops. The just concluded KCEP project in Nandi and Trans Nzoia Counties showed that K is adequate in most soils and only maintenance application is required for optimal maize production (Koech *et al.*, 2018). High rates of K especially when applied as KCL (muriate of potash) increases the salt concentration (chloride) and scotching of seed in crops with low chloride tolerance, which reduces the plant population and yields (Senkoro *et al.*, 2018, Koech *et al.*, 2018). Potassium fertilizer is an expensive nutrient source whose application should be based on evidence of nutrient deficiency and crop response.

Maize yield response to lime application was variable, significant liming effect is an indication of high soil acidity in the farms which require correction. Soil acidity is one of the causes of low maize yields and many studies have been carried out to address the problem (Kanyanjua *et al.*, 2002; Kanyanjua *et al.*, 2006; Okalebo *et al.*, 1997 and Kisinyo *et al.*, 2013). Soil acidity affects availability of other nutrients while it restricts nutrient uptake due to interference with rooting system. This study showed higher yield increases with application of agricultural lime irrespective of K application. The variable response to liming in this study suggests further work on liming and K response in the study areas.

Conclusion

Based on initial soil analysis, our work confirms that soils in western Kenya are acidic and have low levels of K. This requires liming and NPK fertilization. Our results indicate responses to K fertilization, indicating the need to incorporate K in maize fertilization in the study areas. Potassium applied at 40kg K_2O was found to be the optimal rate that optimize maize production in the study area. Any rate beyond this will result to decline in yield and economic benefit.

Liming was effective in reducing soil acidity which translated to increased maize yield in Bungoma County but not in Trans Nzoia County which was attributed to variation in soil acidity levels. K efficiency was however enhanced by application of lime in acidic soils. This study recommends that K should be included into fertilizer formulation where K is limiting. In areas with adequate levels, probably a small dose to maintain the K levels in soil should be considered.

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