Research Findings

Photo 1. Maize fields at Bungoma County, Kenya. Photo by S. Kimani.

Potassium Application Enhances Maize Productivity in Kenya

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Abstract

Many soils in western Kenya are acidic and potassium (K) deficient. Subsequently, maize (*Zea mays*) productivity is far below crop potential for the region. While the use of nitrogen (N) and phosphorus (P) fertilizers has been widely accepted among local farmers, K application is still ignored.

The present study aims to sustainably increase maize yields through the application of K under balanced fertilization. The specific objectives were to study maize response to K application rate, with and without lime; to test possible benefits of applying slow-release N fertilizer compared with top-dressed N; and to evaluate the effects of three types of K fertilizers on maize yield. Experiments took place in 2018 in five locations: Ndengelwa and Mabanga (Bungoma County), and Kamidi, Wepukhulu and Githanga (Trans Nzoia County). Two experiments were conducted at each location. The first experiment evaluated eight fertilizer treatments, with lime (2 Mg ha^{-1}) and without lime. The treatments included six pre-planting K rates of 0, 40, 80, 120, 160,

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and 200 kg K_2O ha^{-1}, slow-release N applied with 80 kg K_2O ha^{-1}, and an unfertilized control (UFC).

All treatments except UFC received pre-planting N and P through the application of di-ammonium phosphate and side dressing with urea to bring the levels up to 150 kg N and 100 kg P_2O_5 per ha. In the second experiment, three types of K fertilizer - muriate of potash (MOP), sulphate of potash (SOP), and NPK-17-17-17 (SSS) were compared at 80 kg K_2O ha^{-1}, with and without liming.

Application of N and P at different K levels increased maize yields from 2 and 3 Mg ha^{-1} under UFC, to 6 and 12 Mg ha^{-1}, in Bungoma and Trans Nzoia County, respectively.

Water availability significantly restricted the duration of the cropping season and, consequently, reduced yields. Beyond this obstacle, liming displayed insignificant and inconsistent impacts on maize yields. K application displayed a significant potential to increase yields, although adverse effects were evident at rates higher than 40 kg K_2O ha^{-1}. In conclusion, K application should be divided into separate doses and delivered throughout the season or through slow-release fertilizers. Moreover, the amount and type of K fertilizer, as well as liming requirements, should be evaluated in each location according to the local soil properties and in consideration of the economic benefits.

Keywords: Liming; relative yield; slow release; soil acidity; *Zea mays*.

Introduction

Maize (*Zea mays*) is the most important staple crop in Kenya, and is grown across a wide range of agro-ecological zones, accounting for about 40% of daily calories (Kibaara, 2005). Approximately 3.5 million small-scale farmers are involved in maize production in Kenya, constituting 75% of the total maize crop, while about 1,000 large-scale farmers produce the remaining 25%. Annual *per capita* maize consumption in Kenya is estimated at 98 kg. Over the years, production has fallen behind the national demand for maize, and the deficits have had to be met through import. In 2017, for example, the shortage of maize led to an increase in maize flour prices - from 55 to 75 KES kg^{-1}, forcing the government to subsidize maize flour prices through imports of 100,000 Mg (ton), thus lowering prices to 45 KES kg^{-1} (KIPPRA, 2017).

The national average maize yields are estimated at 1.8 Mg ha^{-1}. These yields are about one fifth of those attained among world-leading maize producing countries, such as Argentina. In the early 1980s, maize yields began to increase following adoption of hybrid maize varieties and accompanying high fertilizer use to the extent that by 1986, the average national yields were over 2 Mg ha^{-1} (Nyoro, 2002). However, this growth has not been sustained, due to various biophysical and socio-economic factors, including declining soil fertility, high input costs, lack of suitable seeds, pest and diseases, lack of access to credit, inadequate extension services, and unfavorable markets (Republic of Kenya, 1997; 2004; 2010). Poor weather has also affected the output of maize in some years.

As mentioned above, a major constraint of maize production in Kenya is low and declining soil fertility. Nutrient input and output studies on farmlands across Kenya and sub-Saharan Africa (SSA) show an alarming negative balance leading to widespread land degradation. Soil nitrogen (N), phosphorus (P), and potassium (K) balances, established for 13 countries in SSA, show consistent negative trends (Smalling *et al.*, 1993). About 200 million ha of cropland lost 660 kg N ha^{-1}, 75 kg P ha^{-1} and 450 kg K ha^{-1} during the 30 years between 1960 and 1990, with particularly high to very high depletion rates in East and Central Africa. As a result, the originally fertile lands that had yielded 2-4 Mg ha^{-1} of cereal grains in the past became infertile, obtaining very poor cereal crop yields (below 1 Mg ha^{-1}) during 1990-2000 (Sanchez *et al.*, 2002). Furthermore, the practice of intensive continuous cropping, with limited or imbalanced fertilizer management, or no nutrient replenishment at all, has resulted in further nutrient depletions.

The cost of production has increased tremendously over the last decade, as prices of farm inputs have correspondingly escalated (KIPPRA-MoA Report, 2007). 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 declining soil fertility is exacerbated in recent years by climate change, manifested by growing weather variability, increasingly shorter cropping seasons, and droughts.

Most soil fertility efforts have focused on N and P application, two of the most limiting nutrients in crop production in Kenya (Okalebo *et al.*, 1997). In maize production, N and P are usually applied in compound forms, mainly as di-ammonium phosphate, or through other combinations. The nutrients are applied at planting in the compound form, and N is further supplemented with top-dressing during the early vegetative growth stage of the crop. Considering the heavy rainstorms in most seasons, this practice opens up opportunities for N losses through leaching. Applying slow-release N fertilizers - such as coated N formulas - at planting, might reduce N leaching and ensure a better synchronization of N release with crop requirements.

While efforts have been made to fertilize soils with N and P, there has been very limited focus on K fertilization. In the 1970s and 1980s, it was generally assumed that K was not important for Kenyan soils, and there were no specific recommendations for K application. Studies by Mangale (1995) did not show clear responses to K, however, Kanyanjua *et al.* (2006) recommended application of 25 kg potassium oxide (K_2O) ha^{-1}. In recent years, Kenyanya *et al.* (2013) found that in western Kenya, maize crop development and yield parameters (plant height, stem thickness, ear dimensions, and grain yield) rose steadily with increasing K doses. Optimum output, with grain yields of 3.3 Mg ha^{-1}, were reached at K rates of 150 kg K_2O ha^{-1}, nevertheless, the content of other macronutrients diverged out of their optimum ranges (Kenyanya, 2015). These studies indicate that further research is essential to determine accurate K application recommendations.

The decline of soil fertility is largely associated with another confounding limitation to maize productivity in Kenya - 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, such as di-ammonium phosphate and calcium ammonium nitrate. These soils have high aluminum (Al) levels (above 2 cmol Al kg^{-1} soil, and above 20% Al saturation), and are low in soil available P (less than 5 mg potassium oxide (P_2O_5) kg^{-1} soil) due to moderate-high P sorption (107-402 mg P kg^{-1} soil). Therefore, the recovery of P fertilizers in these soils is quite limited. Application of lime, P fertilizer and organic manure increases soil pH and available P, and reduces Al toxicity on Kenyan acid soils. The application of lime, P fertilizer and organic manure has been found to increase maize grain yield by 5-75, 18-93 and 70-100%, respectively, on Kenyan acid soils.

Nevertheless, soil acidity also largely affects soil K status and K availability. High soil acidity means high proton (H^+) concentration in the soil solution. With their higher electrical affinity to the negative charge of the soil particle surface, the protons displace other positively charged ions, such as K^+. Thus, K ions that cannot adhere to the soil particles remain in the soil solution. Under rainy conditions, these ions can be leached away with the water or down below the rhizosphere. This very short and transient availability might be the fate of any soluble K fertilizer, unless soil acidity is reduced. The process of liming can decrease soil acidity by enriching the soil with hydroxide ions (OH^-). In addition, the considerable supply of calcium ions (Ca^{2+}) through liming improves the balance between positively and negatively charged nutrients, altogether providing better access of K^+ to the solid soil phase.

The present study aims to sustainably increase maize yields through K application under balanced fertilization for enhanced food security in western Kenya. The specific objectives were to study maize response to K application rate, with and without lime; to test the possible benefits of applying coated N fertilizer compared with top-dressed N; and to evaluate the effects of three types of K fertilizers on maize yield.

Materials and methods

Field experiments were conducted at Bungoma and Trans Nzoia Counties (Fig. 1) in western Kenya, which is considered the breadbasket region for the country. Bungoma and Trans Nzoia Counties cover about 3,032 and 2,496 km^2, respectively. In both locations, the mean annual temperature is 18.9°C. March is the warmest month, with an average temperature of 20°C, and July is the coldest month, with an average temperature of 17.9°C. Precipitation averages at 1,262 mm $year^{-1}$. The lowest monthly precipitation is 25 mm (January), and the highest is 175 mm (May). Soils are clay loams, with high acidity.

In Trans Nzoia County, experiments took place at three farm sites: Githanga, Kamidi, and Wepukhulu. In Bungoma County, experiments were carried out at Mabanga Agricultural Training Centre (ATC) and at Ndengelwa.

Two different experiments were conducted. Experiment 1 was set up to evaluate maize response to different rates of potash fertilizer (0-200 kg K_2O ha^{-1}) in order to establish the optimum K requirement for maximum crop yield. Generally, soils in the maize-growing areas are acidic, and hence liming is a common practice. To evaluate the advantage of using lime, the experiment included liming as a second primary factor (no lime vs. lime). The lime was applied to the designated plots at 2,000 kg ha^{-1}. All treatments except the unfertilized control (UFC) received pre-planting N and P through the application of di-ammonium phosphate and side dressing with urea to bring the levels up to 150 kg N and 100 kg P_2O_5 per ha. Potassium was applied pre-planting at 0, 40, 80, 120, 160 and 200 kg K_2O ha^{-1}, giving rise to treatments K_0, K_{40}, K_{80}, K_{120}, K_{160}, and K_{200}, respectively. One additional treatment, a slow-release N fertilizer (Agromaster®

Photo 2. Protus Makokha (left), Crops Officer at Mabanga ATC, instructs students and a farm worker about plot layout and the importance of liming. Photo by S. Kimani.

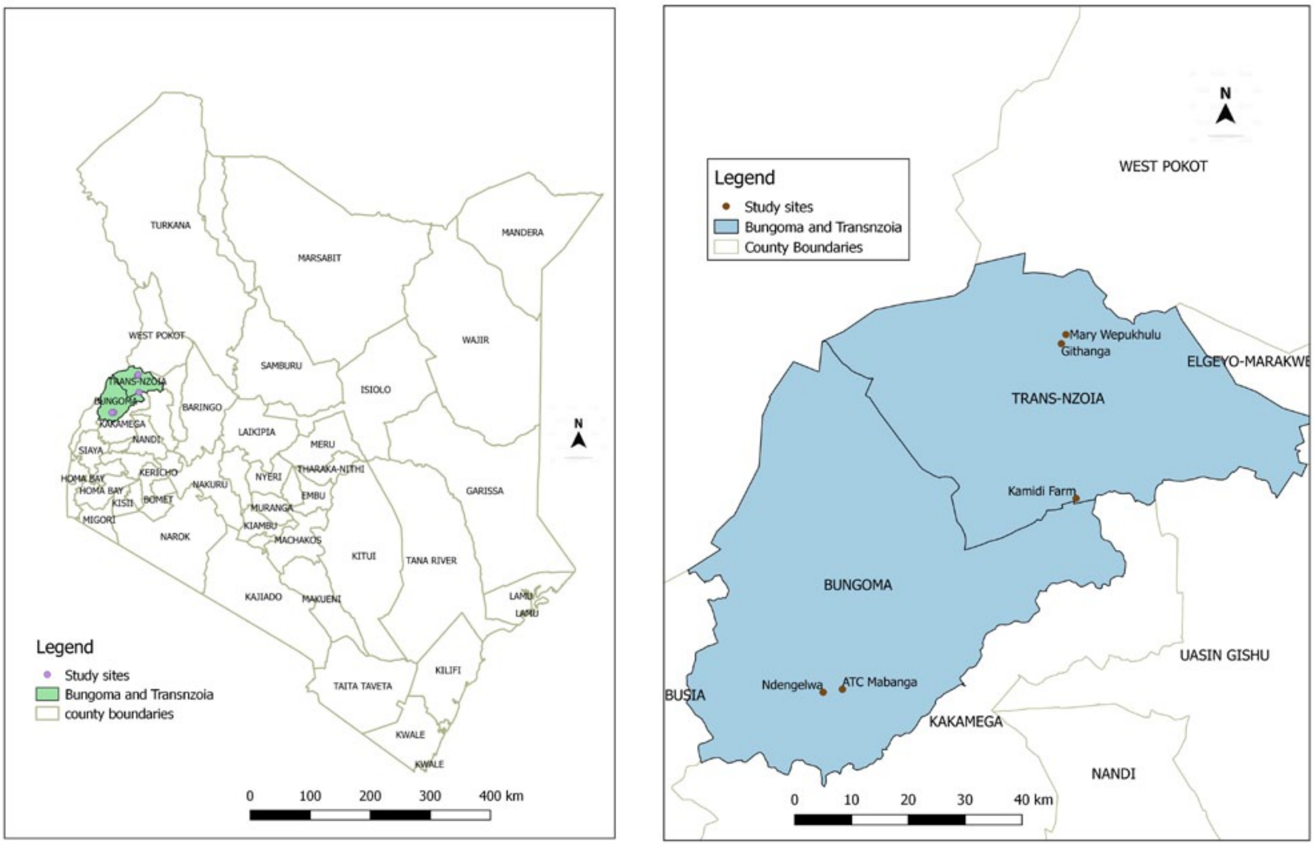

Fig. 1. Maps of the experiment locations; Bungoma and Trans Nzoia Counties in Kenya (left), and the specific sites in each county (right).

NP, ICL Specialty Fertilizers) combined with K_{80} (SRN K_{80}), was applied at planting. This replaced the standard N and P application, and was designed to evaluate the contribution of slow-release N to crop performance. The SRN K_{80} treatment was compared with the K_{80} treatment alone. The plan for experiment 1 is summarized in detail in Table 1.

Experiment 2 aimed to evaluate maize response to different potash fertilizers. The three fertilizers tested were sulphate of potash (SOP), muriate of potash (MOP), and NPK-17-17-17 (SSS). MOP is the most common potash fertilizer, while SSS is a common compound fertilizer. Potassium was applied at 80 kg K_2O ha^{-1}, while N and P_2O_5 were applied at 150 and 100 kg ha^{-1} at planting, respectively. The treatments were applied with and without liming at pre-planting.

Table 1. A detailed description of experiment 1. Nitrogen and P were applied through di-ammonium phosphate (DAP) at planting, with two additional side dressings of urea, to complete doses of 150 kg N ha^{-1} and 100 kg P_2O_5 ha^{-1}. In treatment SRN K_{80}, this practice was replaced with a pre-plant application of Agromaster® NP. UFC - unfertilized control.

K rate	No lime		Lime	
	Treatment code	Fertilizers	Treatment code	Fertilizers
kg K_2O ha^{-1}			---------------2,000 *kg ha^{-1}*---------------	
0	K_0	DAP+urea	K_0	DAP+urea
40	K_{40}	DAP+MOP+urea	K_{40}	DAP+MOP+urea
80	K_{80}	DAP+MOP+urea	K_{80}	DAP+MOP+urea
120	K_{120}	DAP+MOP+urea	K_{120}	DAP+MOP+urea
160	K_{160}	DAP+MOP+urea	K_{160}	DAP+MOP+urea
200	K_{200}	DAP+MOP+urea	K_{200}	DAP+MOP+urea
0	UFC	-	UFC	-
80	SRN K_{80}	Agromaster NP	SRN K_{80}	Agromaster NPK

Both experiments were designed in split plots using four randomized complete blocks (RCBD). Liming and no liming were assigned the main plots, while K rates (Exp. 1) and K fertilizer type (Exp. 2) were assigned the sub-plots. Sub-plots were 6 x 4 m in size with 0.5 m paths between each and 1 m paths between blocks. At all sites, the land was prepared using a hand hoe and furrows were made. Seeds cultivars 'H520' and 'H6213' were sown on 23 March 2018 at Bungoma and Trans Nzoia Counties, respectively. The seeds were positioned at a 5 cm depth within the soil and at a density of 44,444 plants ha^{-1}. Precipitation rates during crop development were much higher at Trans Nzoia than at Bungoma County - 637 and 381 mm, respectively (Fig. 2). Consequently, crop development at Trans Nzoia continued until late September, whereas it ceased as early as July at Bungoma. As a result, harvests took place on 3 August and on 5 October 2018, 133 and 190 days after sowing, at Bungoma and Trans Nzoia Counties, respectively. At harvest, grain and stover yields were determined and the harvest index was calculated.

Results

Absolute grain and stover yields varied considerably among locations. In Bungoma County, grain yields were much higher at Ndengelwa, ranging from 4-7 Mg ha^{-1} with considerable variability, compared to Mabanga where grain yields ranged from 2.5-4.5 Mg ha^{-1}. The differences between the two neighboring locations were even greater in regard to the stover yields that ranged from 5-7 and 2-5.5 Mg ha^{-1} at Ndengelwa and Mabanga, respectively. At both locations, harvest indices varied widely from 0.40 to 0.55, with slightly higher values at Mabanga (Fig. 3). Although some significant differences occurred sporadically, liming effects were inconsistent at both locations.

Significant differences in crop performance also occurred between the experiment sites in Trans Nzoia County (Fig. 4). Grain yields were much higher at Wepukhulu, ranging from 5.5-11, compared to 4.5-8 Mg ha^{-1} at Kamidi and Githanga. Stover yields were lower at Kamidi, ranging from 6-10, compared to 8-14 Mg ha^{-1} at Wepukhulu and Githanga. Harvest indices ranged from 0.39-0.51 at Kamidi and Wepukhulu, but tended to be lower at Githanga (0.30-0.44). Liming tended to increase grain yields in most cases, and a similar effect was observed for stover at Kamidi and Wepukhulu but not at Githanga. The impact of liming on harvest index fluctuated inconsistently (Fig. 4).

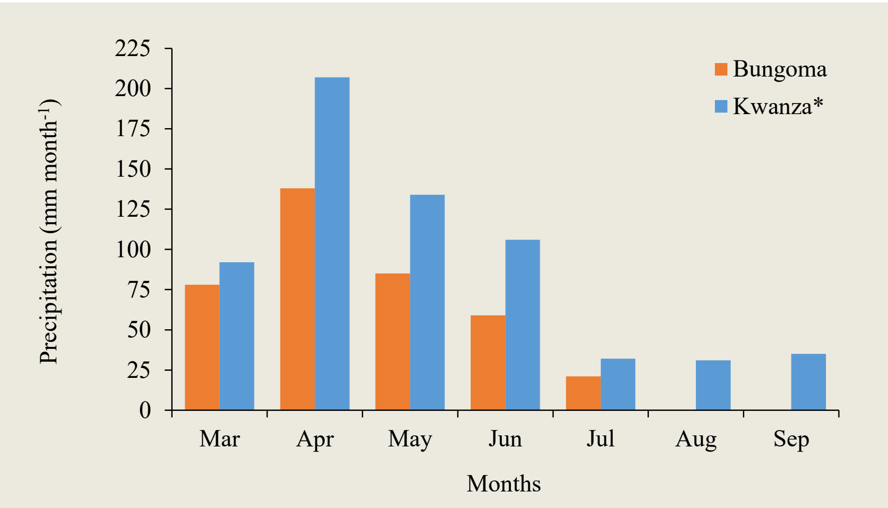

Fig. 2. Monthly precipitation rates at Bungoma and Kwanza (Trans Nzoia, near Wepukhulu and Githanga), Kenya, during the 2018 maize cropping season. *Source:* https://www.meteoblue.com/en/weather/forecast/archive/.

Table 2. General effect of K application rate on maize grain yields at five experiment sites in Kenya. At each site and K rate, liming sub-treatments were pooled together. Where the same letter appears next to the values, this indicates no significant differences (p<0.05) between K rates within each site.

K rate	Ndengelwa	Mabanga	Kamidi	Wepukhulu	Githanga
kg K_2O ha^{-1}			*Mg ha^{-1}*		
0	4.909 bcd	2.739 d	5.497 d	9.874 a	6.609 b
40	5.998 a	4.234 a	7.251 a	10.071 a	7.222 a
80	4.583 cd	3.334 bc	6.643 ab	8.417 b	5.125 c
120	4.459 cd	3.472 b	6.255 bc	7.316 bc	5.317 c
160	5.180 abc	2.961 cd	5.799 cd	8.076 b	5.219 c
200	5.151 ab	3.204 bc	5.435 d	6.125 c	4.897 c

Since liming had inconsistent and non-significant influences on crop performance in most cases, the major variable, namely K application rate, was analyzed at each site, pooling together the lime and no lime sub-treatments (Table 2). The highest grain yields were obtained under the lower K rate of 40 kg K_2O ha^{-1} at all sites. Yields obtained under this treatment were significantly higher than for the K_0 treatment, excluding at Wepukhulu. Under K rates higher than 40 kg K_2O ha^{-1}, grain yields tended to decline significantly; however, the pattern of that decline was not similar among sites (Table 2).

Pooling together the general effects of K application rates at all sites confirmed the significant increase in grain yields in response to the lower rate of 40 kg K_2O ha^{-1} - about a 25% increase on average - as well as the decline in grain yield levels in response to further rising K rates (Fig. 5A). Interestingly, harvest indices climbed from about 0.40 under K_0 to 0.48 under K_{40}, but slightly decreased under further rising K rates, remaining at the intermediate range of 0.40-0.44 (Fig. 5B).

The experiments at each site included two additional treatments - UFC and SRN K_{80}. In Fig. 5, these two treatments are compared with their corresponding K_0 and K_{80} treatments, and with and without liming, to analyze their effects on grain yield. At Ndengelwa, grain yield significantly increased under the K_0 treatment as compared to the UFC

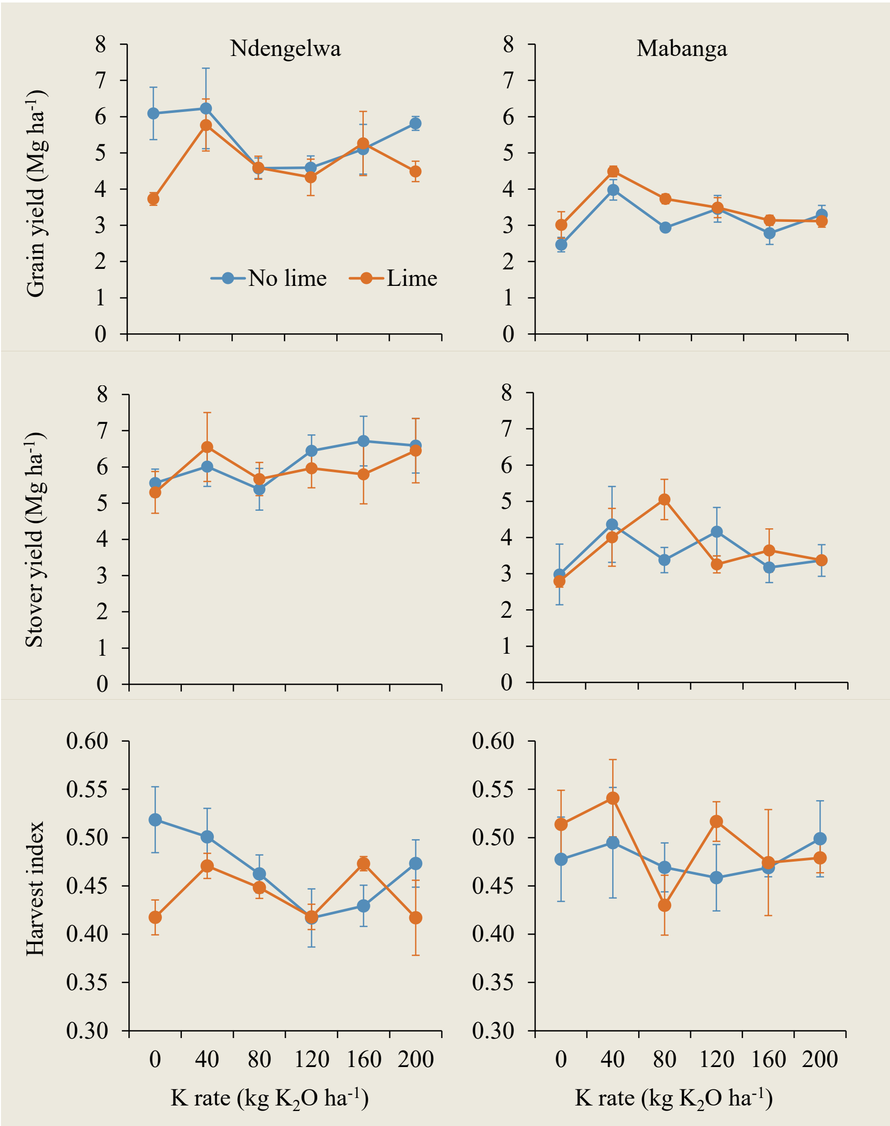

Fig. 3. Effects of K application rate on grain and stover yields and on the harvest index of maize at Ndengelwa and Mabanga in Bungoma County, Kenya. Bars indicate SE.

Photo 3. Maize top-dressing at Mary Wepukhulu farm, Kwanza, Trans Nzoia. Photo by S. Kimani.

Photo 4. Liming the plots. Photo by S. Kimani.

treatment, but liming had a considerable adverse effect on yield. At Mabanga, yields were significantly lower and their response to the elementary N and P fertilizer applied under K_0 was very poor, with liming providing only a slight advantage to the treatment. At the Trans Nzoia County sites, grain yields up-surged significantly under K_0 as compared to the UFC treatment. Liming also showed positive impacts on yields at Kamidi and Githanga. The most significant response to K_0 was observed at Wepukhulu, where grain yield rose from 3.5 under UFC to 10 Mg ha^{-1} under K_0, but there was no obvious effect of liming on yield (Fig. 6).

Potassium applied at 80 kg K_2O ha^{-1} (K_{80}) did not give rise to overall significant changes in grain yields. Grain yields remained at the levels achieved under the UFC treatment at Ndengelwa, slightly increased at Mabanga and Kamidi, and declined significantly at Wepukhulu and Githanga, compared to the corresponding yields of K_0 (Fig. 6). On the other hand, the combination of K_{80} with SRN brought about significant yield increases in most cases (Fig. 6). The general pattern of grain yield responses to these different fertilizer combinations is demonstrated by the relative yield parameter in Fig. 7, where data from all experiment sites were normalized to the UFC grain yield. It is clearly shown, that liming does not have any significant contribution to maize yield; under the terms of the present study, it even had a slight but consistent tendency to reduce yields. On the contrary, the various fertilizer practices did have significant effects on yield, with increases against UFC yields of 81, 76, and 130% gained by treatments K_0, K_{80} and SRN K_{80}, respectively (Fig. 7).

In Experiment 2, the differences in absolute grain yields between sites remained stable, keeping the order of Wepukhulu > Kamidi ≥ Ndengelwa ≥ Githanga > Mabanga. The effect of different K fertilizer types was sporadic or site-specific, with hardly or no significant differences (Fig. 8). Liming

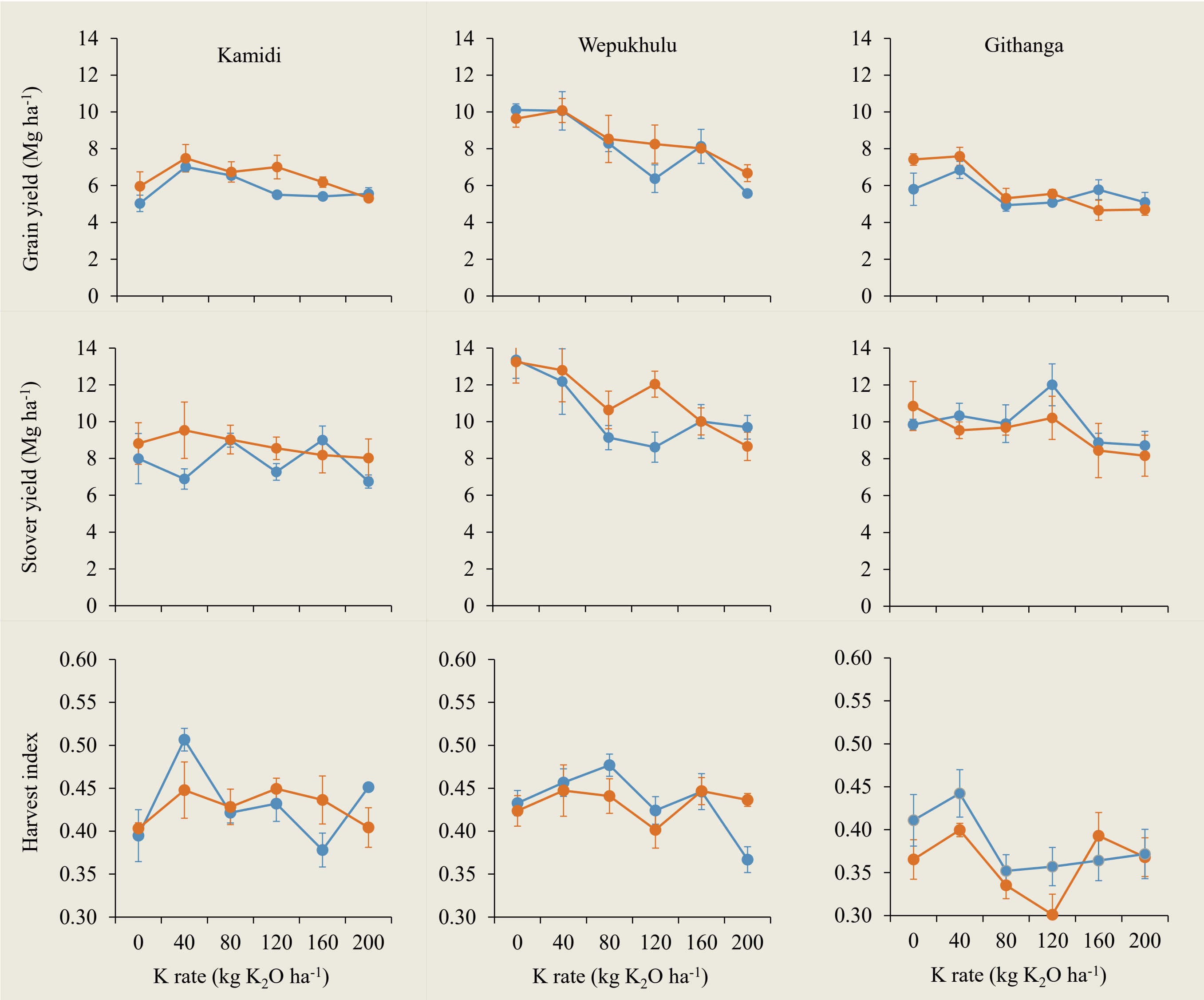

Fig. 4. Effects of K application rate on stover and grain yields and on the harvest indices of maize crop at Kamidi, Wepukhulu, and Githanga in Trans Nzoia County, Kenya. Bars indicate SE.

tended to slightly reduce yields, where SOP or SSS were applied, compared to MOP, which increased yields under lime application.

Discussion

Although the major staple food crop in Kenya, local maize yields are regularly much lower than that of world-leading maize producing countries. This chronic problem can be attributed to many factors, among which, high soil acidity, poor soil fertility and unreliable water availability are dominant and interchangeable.

Photos 5. Weighing and sorting cobs and stover samples at Mabanga ATC. Photo by S. Kimani.

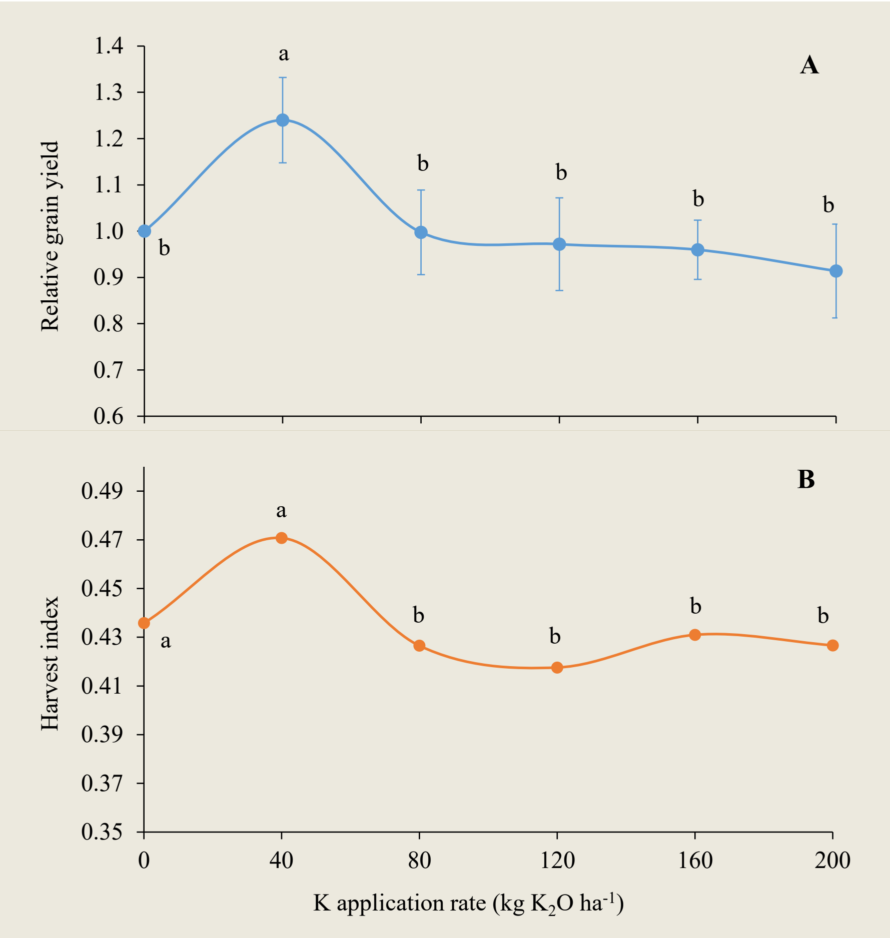

Fig. 5. Patterns of the relative grain yield (A) and harvest index (B) responses to K application rate at five maize experiment sites in Kenya (pooled data). Relative yields: yields of the different treatments were normalized to that of K_0 at each location. Similar letters indicate no significant differences ($p<0.05$).

Many studies have been carried out to address the problem of soil acidity in Kenya (Kanyanjua *et al*., 2002; Kanyanjua *et al*., 2006; Okalebo *et al*., 1997; Kisinyo *et al*., 2013), which can be partially reduced and overcome through liming (Oates, 2008). On one hand, a lack of knowledge on the importance of lime, as well as its limited availability in many agro-dealer outlets, significantly restricts and slows the dissemination of this solution in Kenya. On the other hand, liming should not be considered as a miracle cure. As recently suggested by Opala *et al.* (2018) and confirmed in the present study, the effects of liming are site-dependent and largely influenced by agricultural input factors such as fertilizer type and rate. In general, the liming effect on grain and stover yields was insignificant and inconsistent throughout the study, and in some cases, even interfered with the effects of the second major factor - K application rates.

A considerable step towards enhanced maize yields is the application of N and P fertilizers, the contribution of which was clearly demonstrated in most experiments in this study when compared to the rates achieved under the UFC (Figs. 6 and 7). Another important step is the splitting of the N dose into several applications during the cropping season. Alternatively, and even better, is the use of a slow-release N fertilizer, which gave rise to higher yields when compared to splitting of the N dose (Figs. 6 and 7). However, this result might vary under different environmental or practical conditions and, therefore, would require further research.

Considering the serious degradation in soil fertility, particularly in soil K status and availability (Smalling *et al*., 1993; Sanchez *et al*., 2002; Kenyana *et al*., 2013), the effect of K application on maize yields in Kenya is currently presumed to be highly significant and, furthermore, rate dependent. These assumptions have been partially met in the present study. While significant yield increases occurred at all experiment sites, this effect was limited to the lowest K application rate (40 kg K_2O ha^{-1}) in most of the cases (Figs. 3-5; Table 2). Moreover, higher K application rates even reduced grain yields, as clearly shown at Mabanga, Kamidi, Wepukhulu, and Githanga, and partially at Ndengelwa (Table 2). The latter phenomenon may indicate a wrong methodology of K application, especially under the Kenyan conditions. When a high K dose is delivered as a single application, concentrated in the vicinity of the germinating seed, a strong adverse effect of salinity might occur, diminishing the nutritional effect, which might significantly restrict crop growth and development. In addition, during the early stages of crop development and under heavy precipitation rates (as often is the case in western Kenya, Fig. 2), the highly soluble K fertilizer might be leached rapidly away from a poorly developed root system. During the rest of the season, the crop would then develop under K deficient conditions. This scenario, which can explain the reduction in crop performance under the higher K application rates, can be easily avoided. As already practiced with N, splitting the seasonal K dose into several applications during crop development may result in a completely different range of yield responses to K application rate. Alternatively, supplying slow-release K fertilizers may appear very useful in stabilizing soil K availability, as demonstrated for N. A combination of the

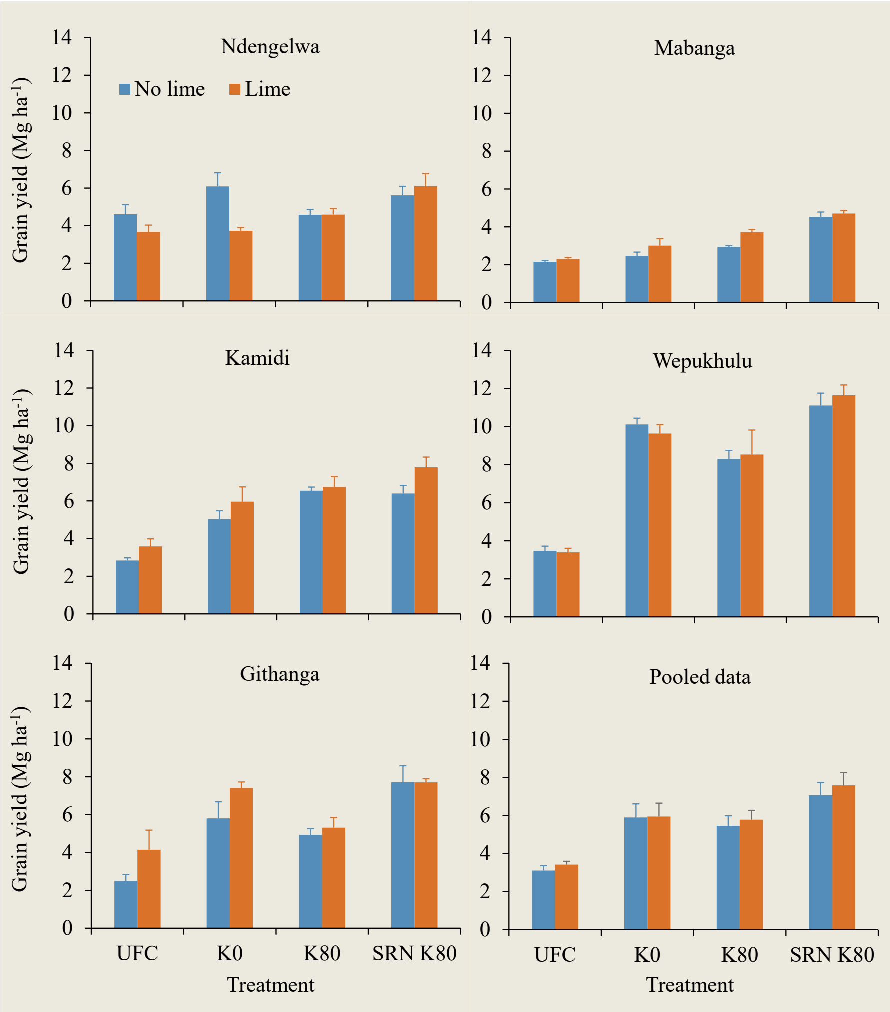

Fig. 6. Local as well as general (pooled) effects of UFC, K_0, K_{80} and SNR K_{80} fertilizer treatments, and liming/no liming, on maize grain yield at the five experiment sites in Kenya.

two approaches might lead to enhanced precision when supplying K according to crop requirements at each developmental stage (Leigh and Wyn-Jones, 1984; Setiyono *et al.*, 2010).

The impact of K fertilizer type on maize performance remains unclear. The limited conditions under which this question has been studied in the present research means that no substantial conclusions can be made. Nevertheless, the significant site-specific responses achieved from this study (Fig. 8) indicate that further attention is required when considering the nature of the local soil and environment, the timing of K fertilizer application, and the crop requirements at a given stage of development.

Large variation occurred in crop performance, including time of harvest and grain and stover yields, between the experiment sites. Naturally, such differences may emerge from local soil properties, practices, and cultivars. Further, the different precipitation patterns seemed also to have a significant role, dictating the duration of the season, and consequently, the yield properties. In 2018, Bungoma County experienced much lower rainfall compared to Trans Nzoia (Fig. 2). Critically low precipitation rates in July - which were significantly less than

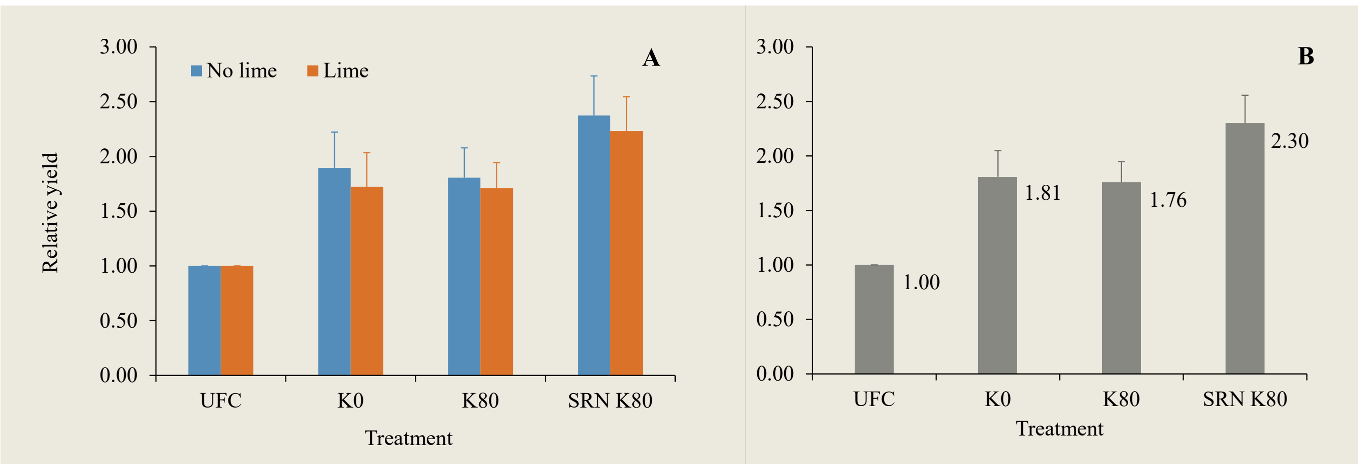

Fig. 7. The general impact of UFC, K_0, K_{80} and SNR K_{80} fertilizer treatments, and liming/no liming, on the relative maize grain yields at the five experiment sites in Kenya. The treatments: with and without liming (A), and pooled together (B). Relative yields: yields of the different treatments were normalized to that of UFC at each location. Bars indicate SE.

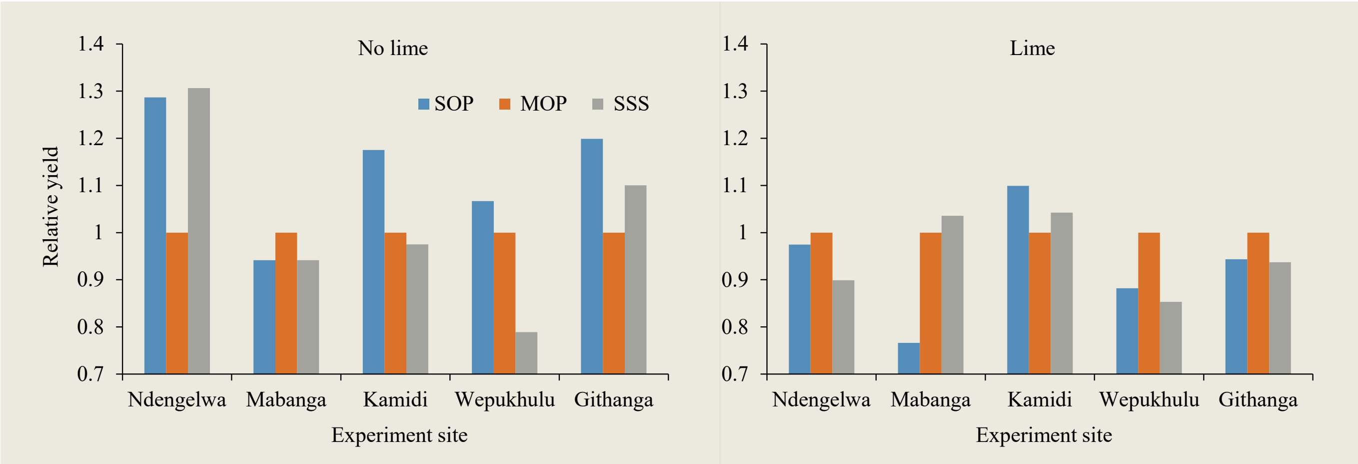

Fig. 8. Effects of different K fertilizer types, and liming/no liming, on the relative yield of maize grown at the five experiment sites in Kenya. Grain yields under SOP and SSS were normalized to the corresponding yields under MOP application.

the normal crop water requirements during the grain filling stage (Akinmutimi, 2015) - probably shortened the growing season by as much as 60 days in Bungoma compared to Trans Nzoia, leading to much lower yields (at least at Mabanga).

Matching water availability to crop requirement is a major challenge (Mwesigwa *et al.*, 2017), sometimes greater than providing the required mineral nutrition. Freedom from a dependency on precipitation can be obtained via various irrigation technologies and can substantially enhance maize as well as other crop production. Furthermore, it will materialize the synergy of fertigation.

Conclusions

The potential of maize production in Kenya, which the present study only partly reveals, is much greater than the currently achieved yield levels (Kabaara and Kavoi, 2012). The application of N and P, along with varying K doses, increased maize yields from 2-6 Mg ha^{-1} in Bungoma County and from 3-12 Mg ha^{-1} in Trans Nzoia County. Poor water availability can significantly restrict the duration of the cropping season and, consequently, reduce yields. Beyond this obstacle, K application can be a very useful means to achieve significantly higher yields. However, K dose should be better split and delivered over the duration of the season or through slow-release fertilizers, as demonstrated by the SRN application. The accurate K dose, type of K fertilizer, as well as the liming requirements must be evaluated separately for each location according to the local soil properties, and in consideration of the economic benefits.

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The paper "Potassium Application Enhances Maize Productivity in Kenya" also appears on the IPI website.