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Research Findings

Basmati rice harvesting at Wamumu site, Kenya. Photo by the authors. 2017.

Rice Response to Potassium Fertilization in Mwea, Kenya

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Abstract

In Kenya, the importance of potassium (K) fertilization to enhance crop yields for food security and income generation cannot be disregarded. The present study aimed to evaluate rice responses to different rates of Muriate of Potash (MOP) fertilizer, thus establishing the fertilizer recommendation for maximum rice yields and further identifying the best K fertilizer resource for maximum rice yields. The two most popular rice varieties, Basmati 370 and BW 196, were used. Five different K rates were examined: 0, 40, 80, 120 and 160 kg K_2O ha^{-1}. In addition, three K fertilizers were tested: MOP, Sulphate of Potash (SOP), and NPK-17-17-17 (SSS), all applied at 80 kg K_2O ha^{-1}. Experimental design was a split plot design with fertilizer rates as main plots and rice varieties as the sub-plots in experiment 1, while in experiment 2 fertilizer types were the main plots and varieties were the sub-plots. These experiments were conducted in parallel in four locations in the Mwea Irrigation Scheme: Karaba, Tebere, Thiba, and Wamumu.

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Results revealed significant differences in plant height, tillering, total biomass, grain yield, and harvest index in most instances. These differences were associated with location, cultivar, and K application rates. Generally, grain yields were modest, ranging from 2.0 to 5.5 Mg ha^{-1} for Basmati 370, and from 2.0 to 10.0 Mg ha^{-1} for BW 196. Crop response to K application rate was quite small and limited, in most cases, to 40-80 kg K_2O ha^{-1}. No significant effect was observed for the K fertilizer type. Soil tests indicated severe soil acidity and K shortage at most locations. The restrained yields and relatively poor response to K rates points to fundamental challenges requiring solutions (e.g. soil acidity and water availability) before K fertilization is taken care of. However, splitting K dose during the season may improve K availability when required and crop K uptake, thus supporting better rice yields and income.

Keywords: Basmati 370; BW 196; *Oryza sativa*; soil acidity; paddy soil; potassium.

Introduction

The global population is expanding rapidly and will hit 9.4 billion by 2050 (United Nations Census Bureau, 2012). It is therefore of vital importance to improve crop yield to meet the food demands of future generations, while preserving the environment. However, agricultural production continues to be constrained by a variety of abiotic factors that significantly reduce the quantity and quality of crop production.

In Kenya, rice is the third most important cereal food crop after maize and wheat. Annual consumption is increasing at a rate of 12%, compared to 4% for wheat and 1% for maize, which is the main staple food (Emong'or *et al.*, 2009; Republic of Kenya, 2013). This is attributed to progressive changes in food consumption habits. The current demand for rice in Kenya is estimated at 325,000 Mg per year against the national production of 110,000 Mg per year (Republic of Kenya, 2013). The deficit, about two-thirds of consumption, is met through imports which were valued at KSh 7 billion in 2008. Promotion of rice production will therefore improve food security, increase smallholder farmers' income, contribute to employment creation in rural areas, and reduce the rice import bill.

The productivity of rice is not keeping up with growing demand in Kenya, posing a major threat to national food security. Practices of intensive continuous cropping with no, limited, or imbalanced fertilization has resulted in significant soil nutrient depletion. While efforts have been made to fertilize soils with nitrogen (N) and phosphorus (P), there has been very limited attention to potassium (K).

Potassium is one of the 17 essential nutrients required for plant growth and reproduction (Oborn *et al.*, 2005). It is essential for many physiological processes such as carbon assimilation, photosynthesis, protein synthesis, enzyme activation, stomatal movement, and translocation of organic and inorganic nutrients from soil to plant (Marschner, 2012). Management of K and other essential nutrients is therefore key to achieving a balanced fertility program (Orbon *et al.*, 2005; Zörb *et al.*, 2014). Potassium has a direct influence on the quality of seeds, fruits and vegetables by enhancing size, color, taste, and storage quality (Marschner, 2012; Zörb *et al.*, 2014). Furthermore, plants grown with K fertilizers have also been shown to have increased tolerance to stress factors like drought and frost, and have improved resistance to pests and diseases.

A lack of awareness in Kenya of the importance of K fertilization can be attributed to the general belief that Kenyan soils are well supplied with K (Hinga and Foum, 1972; Muchena, 1974). Nevertheless, evidence has indicated that outflows of major nutrients, including N, P, and K, is greater than inputs, therefore resulting in mining of these nutrients and associated decline in crop yields over time (Kanyanjua *et al.*, 2005). A study conducted several years ago in Mwea Irrigation scheme, revealed a severe K deficiency in 47 sites spread across the five major paddy rice growing sections in the scheme (Gikonyo *et al.*, 2012). Thus, there is growing evidence of increasing K deficiency as a result of: i) sub-optimal or no application of K fertilizers, and; ii) imbalanced use of N and P (Kanyanjua and Buresh, 1999; Gikonyo, 2002; Kanyanjua *et al.*, 2006). Despite these studies, K has not been included in fertilizer recommendations for major food crops in Kenya and its use remains low and limited to high value cash crops like tea, coffee, and some horticultural crops (Kanyanjua *et al.*, 2005). This fact is further confirmed in the recent economic review of agriculture in Kenya (Oseko and Dienya, 2015), showing that fertilizer utilization is still dominated by N and P.

Mwea Irrigation Scheme is a long-term project aimed at providing irrigation water to smallholder farmers in central Kenya (National Irrigation Board, 2017). Rice is the dominant crop in Mwea, and therefore the region has become a target for testing and adoption of the system of rice intensification (SRI), the goals of which are increasing rice yields substantially, saving water, and getting better grain quality (Mati *et al.*, 2015). Mwea Irrigation Scheme is situated between longitudes 37°13'E and 37°30'E and latitudes 0°32'S and 0°46'S. It is in Kirinyaga County, Mwea East and Mwea West sub-Counties (Map 1). The scheme is located at the foothills of Mt. Kenya about 100 km to the northeast of Nairobi. Although only 6,000 ha are under irrigation, the entire scheme covers 12,000 ha and supports a population of more than 50,000 people organized in about 3,242 farm families living in 36 villages. Mwea is the largest scheme in Kenya and is divided into five sections: Tebere, Mwea, Thiba, Wamumu and Karaba, with 820, 770, 750, 710, and 660 ha under irrigation, respectively. The region is classified as tropical, with a semi-arid climate, having an annual mean air temperature of 23-25°C, with about 10°C difference between the minimum (June/July) and the maximum temperatures (October and March). Annual rainfall ranges from 356 to 1,626 mm (average 950 mm), with 2,485 hours of sunshine. The soils in Mwea are classified as Vertisols (Sombroek *et al.*, 1982).

Currently, Mwea Irrigation Scheme accounts for 80% of the country's rice production. Two rice crops are grown annually, the main season occurring between August and December during the short rains, with a long rains crop grown between January and June. Three major rice varieties are grown in the scheme (Basmati 217/370, BW 196, and IR 2793-80-1). Mwea producers suffer from water shortages during the main growing season and often from blast attack during the long rains season, factors that lead to reduced rice yields in both seasons. Other benefits of rice beside income generation for farmers include employment both on farms and in the market. Rice is therefore very important to the livelihoods of Mwea people, with wider economic and food security implications for Kenyans.

In order to promote rice production in Mwea Irrigation scheme and support farmers' livelihood, determining a novel and suitable fertilization policy for rice is focal. Thus, appropriate fertilizer rates must be determined according to soil fertility and crop requirements at each location. Also, there is a need to look at crop performance and costs when identifying suitable fertilizer types. Consequently, the current study aims to sustainably increase rice production through K application. The specific objectives are:

1) To evaluate the response of the two most popular rice varieties in Mwea to different rates of K fertilizer in prospect of establishing a location-suitable K rate required to maximize yields.
2) To test the agronomic efficiency of three K fertilizer types in order to identify the most suitable one.

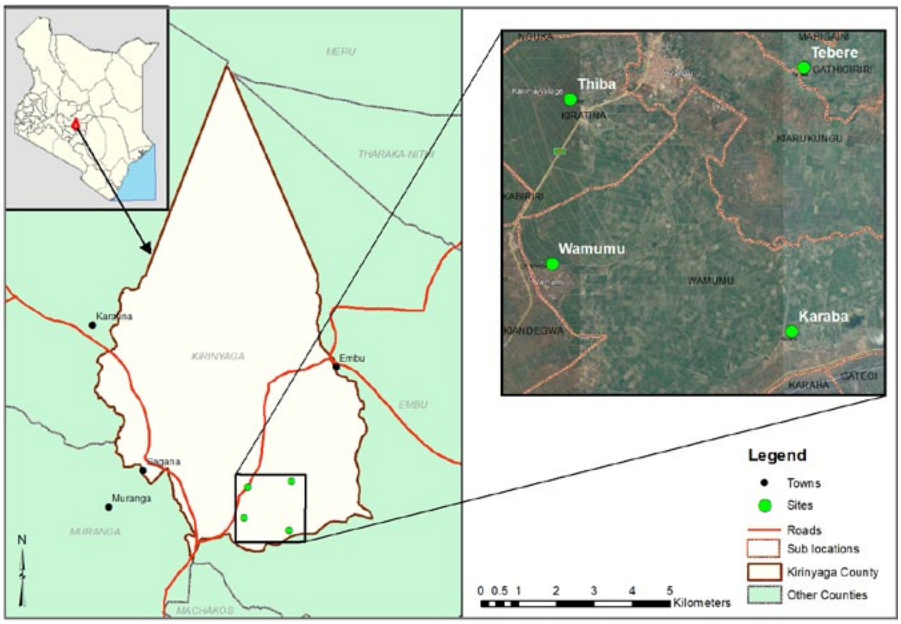
Materials and methods

The trials were conducted in four project sites representing the major rice systems covering the whole scheme. Selected sites were: a) *Thiba*, unit H19 of Ndungi (0º41'26.688 S; 37º20'8.874 E); b) *Wamumu*, unit W7 of Purity Wanjiru (0º43'45.556 S; 37º23'18.54 E); c) *Karaba*, unit K4 of John Ndambiri (0º44'47.176 S; 37º19'53.628 E); d) *Tebere*, unit T18 of James Kiarie (0º40'59.58 S; 37º23'28.638 E) (Map 1).

Composite soil samples were collected in a zig-zag fashion from each trial site. At least 10 samples from each site were combined to make one sample, put in a paper bag and labelled. Collected soil samples, pooled into one sample, were sent to KALRO-Kabete for complete soil fertility analysis. The soils exhibited different characteristics from site to site (Table 1) but generally:

- soils from all the sites were K deficient ($K < 0.24$ meq %) except Tebere top soil;
- all sites were P deficient (Mehlich 1 extractable $P < 35$ ppm) except Wamumu sub-soil;
- all soils had low soil pH (1:1 soil: water ratio), ranging from very strongly acid to strongly acid, except the sub-soils of Wamumu and Tebere;
- N and organic carbon (OC) were at sufficient levels except at Wamumu, where they were deficient;
- calcium and magnesium (not shown) were sufficient in all soils;
- iron (Fe) was very high, particularly in Karaba and Tebere, but was not very high in Wamumu;
- zinc (Zn) levels were adequate in all sites ($Zn > 3.0$ ppm); and
- sodium (Na) was generally high, particularly in Tebere and Wamumu.

Two experiments were carried out. The first, experiment 1, tested rice response to different K rates applied as Muriate of Potash (MOP, KCl). Nitrogen and P were applied according to crop nutrient removal, assuming crop yields of 7 Mg ha^{-1}. Thus, N and P were applied at 150 kg N ha^{-1} and 100 kg P_2O_5 ha^{-1}, respectively.



Map. 1. The locations of the experiment sites in Kirinyaga County, Kenya.
Source: Kenya Soil Survey (KSS).

Table 1. Soil characteristics of the four experiment sites. Bold figures indicate values below critical thresholds.

Location	Thiba		Karaba		Tebere		Wamumu	
Soil depth (cm)	0-20	20-50	0-20	20-50	0-20	20-50	0-20	20-50
Soil pH (soil:water, 1:1)	**4.51**	**4.53**	**5.14**	**4.50**	**5.44**	6.02	**5.12**	6.50
Exch. acidity (meq %)	0.4	0.4	0.3	0.4	0.1	n/a	0.2	n/a
Total nitrogen (%)	0.24	0.28	0.24	0.24	0.40	0.28	0.24	0.19
Total organic C (%)	2.29	2.58	2.26	2.31	3.86	2.72	2.32	1.95
Mehlich P (ppm)	**15**	**25**	**30**	**25**	**30**	**25**	**10**	40
Potassium (meq %)	**0.14**	**0.06**	**0.18**	**0.10**	0.26	**0.14**	**0.14**	**0.06**
Calcium (meq %)	15.0	14.8	15.0	13.8	28.0	25.8	17.8	19.8
Iron (ppm)	70.3	69.4	150	219	234	108	42.4	44.2
Zinc (ppm)	6.60	5.14	4.30	5.00	3.88	3.61	4.85	4.19
Sodium (meq %)	0.34	0.34	0.52	0.36	0.94	0.64	0.70	0.76

Phosphate was applied at planting, while N was applied in three splits: 30, 60, and 60 kg N ha^{-1} (sulphate of ammonia, SA) at transplanting, 24 days after transplanting (DAT), and 45 DAT, respectively. Potassium was applied at 0, 40, 80, 120 and 160 K$_2$O kg ha^{-1} at planting (Table 2). Two varieties of rice, basmati 370 and BW196, were used as test crops.

In experiment 2 (Table 3), rice cultivars Basmati 370 and BW 196 were tested for their response to three K sources: Muriate of Potash (MOP), Sulphate of Potash (SOP), and NPK 17-17-17 (SSS) (a complex commercial fertilizer blend comprising N, P$_2$O$_5$, and K$_2$O at 17% each), all of which were applied at a rate of 80 kg K$_2$O ha^{-1}. Blanket fertilizer rates of N and P similar to those used in experiment 1 were adjusted and applied.

Experiments 1 and 2 were conducted using a split-plot design replicated three times where the main plots were the fertilizer rates (experiment 1) and fertilizer type (experiment 2), and rice varieties were the sub-plots. The main plots were separated by polythene sheets inserted to about 0.2 m below the soil surface to prevent fertilizer seepage from one main plot to the other (Photos 1).

The four farms were planted from 25 July to 2 August 2016. Seedlings were planted at 21-25 days old in all farms except in Tebere, where 14-day rice seedlings were planted. Planting spaces were 25 cm between rows, and 15 cm between plants. Two seedlings were planted per hole. A starter fertilizer of 30 kg N ha^{-1} (SA), triple superphosphate fertilizer, and potash fertilizer (corresponding to the treatment) were applied before planting. No irrigation was applied for the first week to allow the seedlings to establish. Weeding was carried out as deemed necessary.

Data were taken from each plot using 10 plants that were tagged soon after transplanting. Plant height measurements were started two weeks after transplanting and continued at bi-weekly intervals. Basmati 370 was harvested in November, whilst BW 196 was harvested three weeks later, in December.

During harvesting, final tillering was determined. Towards harvest, the two outer rows and two outer seedlings of each plot were removed, leaving the inner area of 4.94 m^2 for harvesting. Harvesting was done manually using sickles, and rice was cut at about 15 cm above the ground. Total biomass weight was determined immediately, and later, after threshing, the grain yield was weighed. The stover and rice paddy were sampled for moisture determination by weighing before and after drying. Data were statistically analyzed using ANOVA. The significance of differences between mean values was evaluated by Duncan's Multiple Range Test. Treatments were declared significantly different if p ≤ 5%.

Table 2. Treatments of the K application rates, experiment 1.

Rice variety	K application rates through MOP (kg K$_2$O ha^{-1})
Basmati 307	0
	40
	80
	120
	160
BW 196	0
	40
	80
	120
	160

Table 3. Treatments of experiment 2, testing different fertilizers as K source for two rice cultivars. All treatments were adjusted at 80 kg K$_2$O ha^{-1}.

Rice variety	Fertilizer type
Basmati 370	MOP
	SOP
	SSS
BW 196	MOP
	SOP
	SSS

Plant height is often used as an indicator of nutrient influence on plant performance, especially at early developmental stages. For both cultivars and in most of the locations, plant height at 28 DAT was greater as K rates increased up to 80 kg

Photos 1. Demarcating sub-plots and main plots receiving different fertilizer rates. Inserting the plastic sheets (left); planting the demarcated plots (right). Photos by the authors.

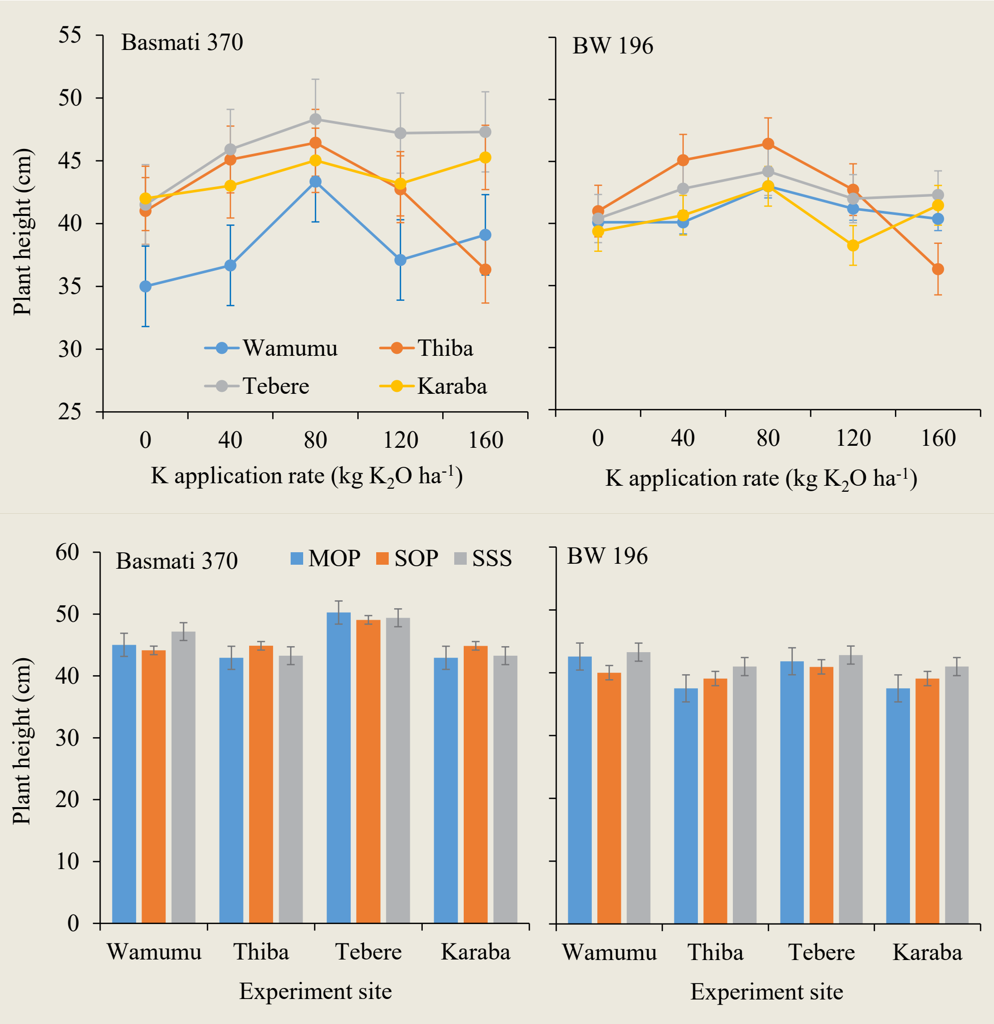


Fig. 1. Effects of K application rate (upper pair), and different K fertilizers at 80 kg K_2O ha^{-1} (lower pair), on plant height of two rice cultivars (Basmati 370 and BW 196) at 28 DAT.

K_2O ha^{-1}. Beyond this K rate, and excluding Basmati 370 at Tebere and Karaba, plant height declined (Fig. 1). Plant height of Basmati 370 differed significantly between experiment sites, with especially low values at Wamumu. The differences in plant height between sites were much less pronounced for cultivar BW 196. In the second experiment, where different K fertilizers were tested at a uniform rate (80 kg K_2O ha^{-1}), no significant differences were observed in plant height at 28 DAT (Fig. 1). There was a slight tendency of Basmati 370 to grow higher, in comparison to BW 196. Also, Basmati 370 was a bit higher at Tebere than the other sites.

The number of tillers per plant can be a good yield predictor. The tillering response to K rates differed substantially between cultivars and sites (Fig. 2). In Tebere, Basmati 370 displayed a consistent rise from 16 to 24 tillers per plant, while being quite constant in Thiba and Karaba (about 20 tillers plant^{-1}), and low in Wamumu (15-17 tillers plant^{-1}). Also BW 196 in Tebere displayed significantly greater tillering capacity, above 25 tillers plant^{-1}, with a clear response to K rate up to 80 kg K_2O ha^{-1}. This response pattern was visible also for BW 196 at Wamumu and Thiba at a lower tillering range. In Thiba, tillering of BW 196 was reduced above 80 kg K_2O ha^{-1}. In Karaba, tillering response was positive at the low and at the high K application rates, but it usually remained at 15-20 tillers plant^{-1} (Fig. 2). The influence of K fertilizer type on rice tillering was minor and inconsistent (Fig. 2). In Wamumu and Thiba, both cultivars tended to grow more tillers under SOP and SSS fertilizers, while this trend disappeared in Tebere and Karaba.

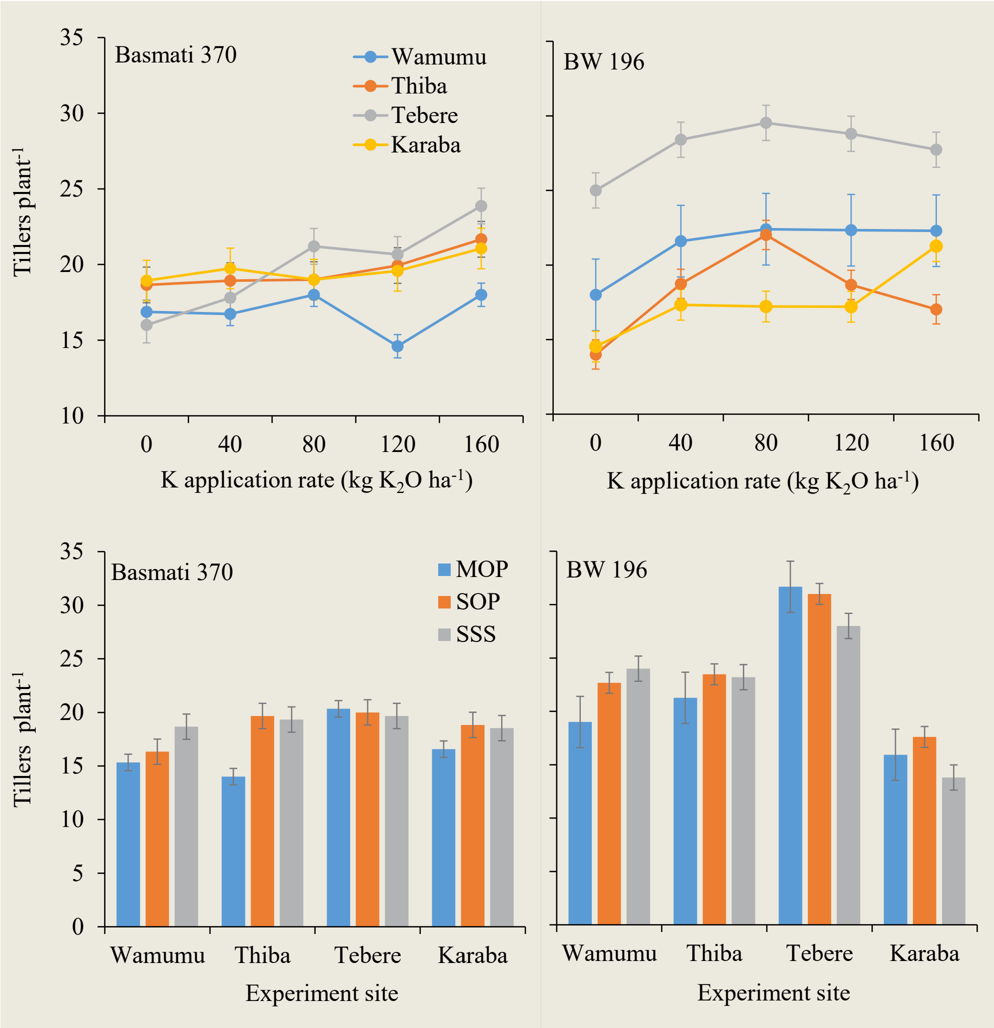


Fig. 2. Effects of K application rate (upper pair), and different K fertilizers at 80 kg K_2O ha^{-1} (lower pair), on the final tillering of two rice cultivars (Basmati 370 and BW 196).

Generally, rice total above-ground biomass at harvest displayed significant response to K application rates (Fig. 3). However, the response patterns were subject to cultivar and site. The greater biomass was produced at Thiba, for both cultivars, where the biomass increased with the rising K rate up to 120 kg K_2O ha^{-1}, and then declined. The smallest biomass was produced at Karaba, where Basmati 370 displayed a significant positive response up to K rate of 80 kg K_2O ha^{-1} but then declined, while BW 196 hardly responded. Similar patterns were observed at Wamumu, although here BW 196 had a more positive response. The two cultivars were significantly different in the biomass response to K rates at Tebere. While Basmati 370 displayed a consistent though small biomass increase with rising K rate, the biomass of BW 196 seemed to decline or remain constant in response to K application. Apart from some local differences, no consistent influence of the K fertilizer type could be observed (Fig. 3).

Paddy grain yield response to K application rates was specific to cultivar and location (Fig. 4). At Wamumu, both cultivars displayed the same pattern of yield response - a significant increase up to 80 kg K_2O ha^{-1}, and a decrease at higher K rates. Also at Karaba, both cultivars shared a similar response pattern, however, yield rise was limited to the first step of K rates from 0 to 40 kg K_2O ha^{-1}, with no further response at higher levels. At Thiba, Basmati 370 grain yield showed no response to K rate, remaining constant at a range of 4.0-4.4 Mg ha^{-1}. On the other hand, BW 196 grain yield increased from 4.3 under no K application, to 6-7 Mg ha^{-1} above 120 kg K_2O ha^{-1}. Interestingly, the grain yields of the two cultivars differed significantly at Tebere, although both cultivars obtained their maximum yields there (Fig. 4). BW 196 yield increased by 100%, from 5 to 10 Mg ha^{-1}, in response to increased K rates from zero to 80 kg K_2O ha^{-1} respectively. The corresponding increase in Basmati 370 yield however stopped at a K rate of 40 kg K_2O ha^{-1} and did not rise further above 5 Mg ha^{-1}. Excluding Tebere, where BW 196 grain yield was significantly low under SOP, K fertilizer type did not affect the grain yields of the two cultivars in both experiment sites (Fig. 4).

With a few exclusions, the harvest index (HI) - the ratio between grain and total aboveground biomass yields - was considerably influenced by the K application rate only at the first step, from 0 to 40 kg K_2O ha^{-1} (Fig. 5). Beyond this range, HI remained constant or even slightly declined. The basal HI was low and subject to

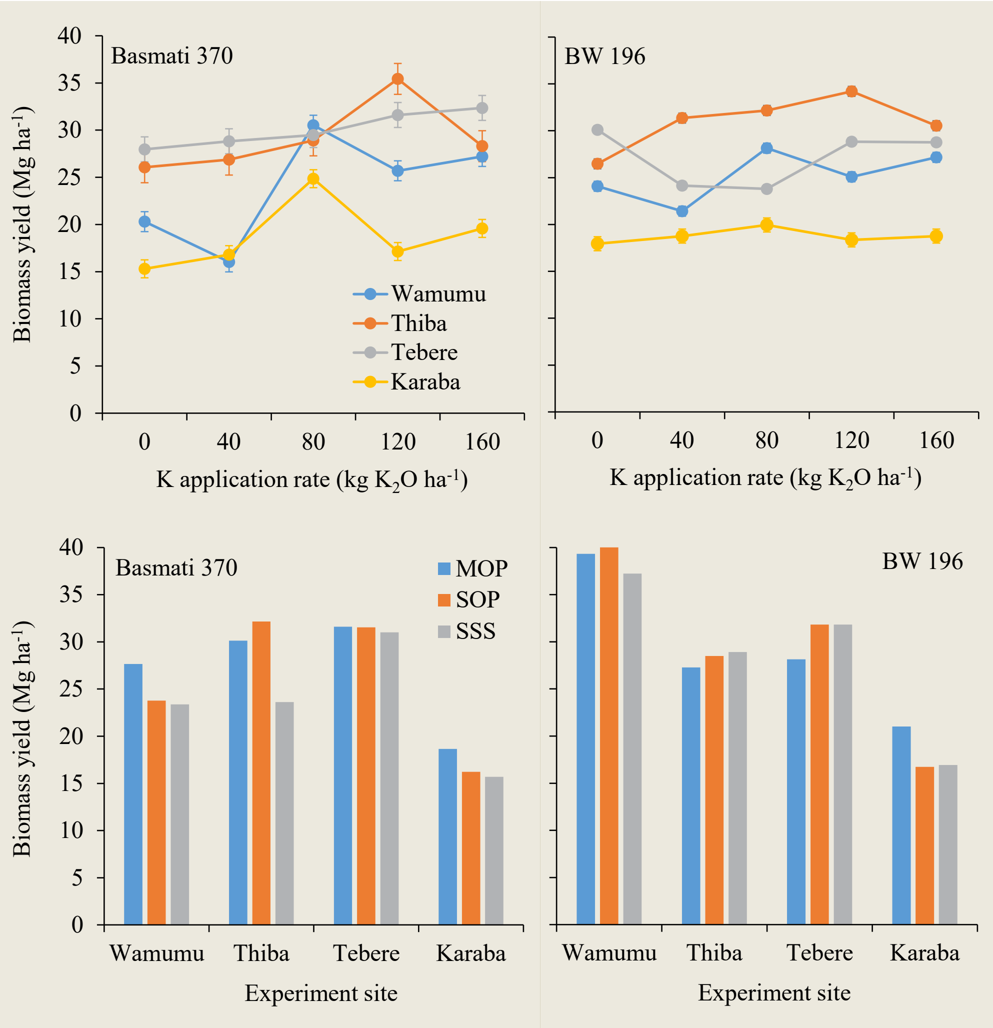


Fig. 3. Effects of K application rate (upper pair), and different K fertilizers at 80 kg K_2O ha^{-1} (lower pair), on the dry aboveground plant biomass of two rice cultivars (Basmati 370 and BW 196).

Photos 2. Data Collection; BW 196 height measurement (left), and BW tillers counting (right). Photos by the authors.

cultivar and location. Basmati 370's HI at Wamumu and Tebere doubled from 9 to 18% in response to K application rate of 40 kg K_2O ha^{-1}, and then declined steadily to 15% with increasing K rates. At Thiba, the initial Basmati 370 HI was the highest, 15%, however, it did not increase, and in one case even declined, in response to elevated K rates. Basmati 370 HI at Karaba displayed a remarkable increase, from 13 to 24%, in response to the K application rate of 40 kg K_2O ha^{-1}, but it fluctuated with the further rise in K application rates. BW 196 HI was a bit more responsive to increasing K application rates (Fig. 5). In Wamumu, it rose from 12 to 21% under 120 kg K_2O ha^{-1}, and then dropped under 160 kg K_2O ha^{-1}. In Thiba it displayed a slight but consistent rise from 17 to 20% along the whole range of K application rates. In Karaba, BW 196's HI pattern was quite similar to that of Basmati 370, but more stable. The most exceptional response was observed at Tebere, where the HI increased from 17% under no K application, to levels greater than 31% under 40 kg K_2O ha^{-1} and above. No considerable differences were observed concerning HI response to K fertilizer types (Fig. 5).

Discussion

In spite of the relative proximity of the four experiment locations (Map 1), large differences occurred between them in the performance of the two rice cultivars and the response of their yield parameters to K application. Significant differences between locations occurred in some critical soil properties (Table 1). Although soil pH was low in all samples, soil acidity in Thiba and Karaba was critically high (pH 4.5-5), while it was less serious in Tebere and Wamumu (pH 5-6). High soil acidity might significantly reduce the cation exchange rate of the soil particles surface, and thus negatively affect soil fertility. Under extreme soil acidity, Fe toxicity might occur in addition to soil structure and texture deterioration, as the mineral composition of the soil particles gradually collapses. In such soils, soil amendment means should be seriously considered in order to raise soil pH and halt processes of soil degradation.

Soils from most locations were poor in P and K (Table 1). Excluding Tebere, where K levels in the upper soil layer seemed on the safe side, soil K concentrations of all other locations were below the minimum threshold considered sufficient for cropping - 0.24 meq% (Gikonyo *et al.*, 2002). Also, differences between locations occurred in respect of water availability during the season, a problem which was especially serious in Karaba. Thus, cultivars' performance and the response to K application should be evaluated in light of these facts.

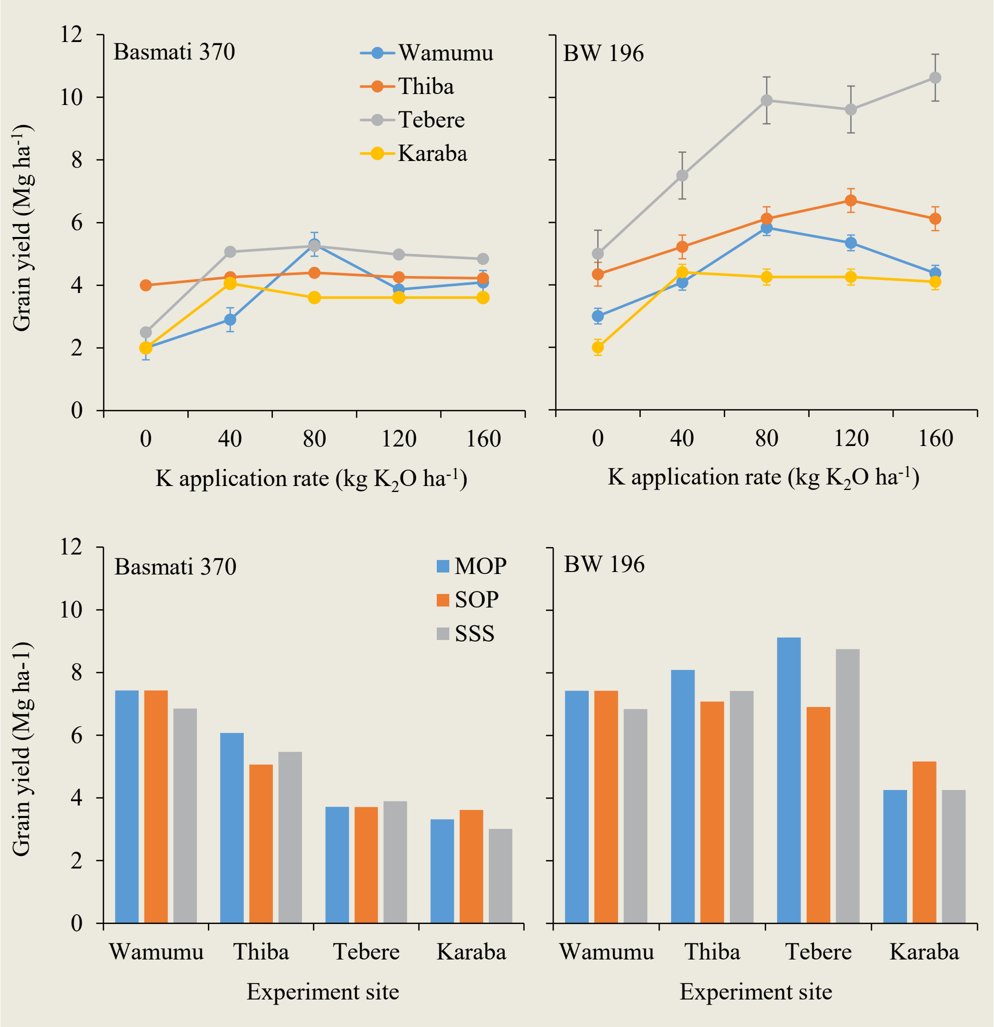


Fig. 4. Effects of K application rate (upper pair), and different K fertilizers at 80 kg K_2O ha^{-1} (lower pair), on the grain yield of two rice cultivars (Basmati 370 and BW 196).

The two cultivars chosen for the study differ significantly. Basmati 370 is a classic tall (about 165 cm), low tillering cultivar, which tends to lodge under high fertility conditions and lose grains. It matures in about 120-130 days with a low average yield (about 4.8 Mg ha^{-1}) but is highly appreciated due to its aromatic flavor and desired cooking qualities (Ashfaq *et al.*, 2014; Ndiiri *et al.*, 2017). In contrast, BW 196 is a long-duration variety (about 160 days) and is considered high tillering, with a relatively high grain yield (7 Mg ha^{-1}). Nevertheless, both cultivars often fail to obtain considerable yields in the Mwea Irrigation Scheme (Ndiiri *et al.*, 2017). Undoubtedly, K deficiency is a major problem restricting rice yields in the region.

Plant height is a good and early indicator of rice K requirements (Wakeel *et al.*, 2017). This is the most direct parameter of rice response to K application, as it is not involved with the complex reproductive process. Thus, four weeks after transplanting, both cultivars in most locations displayed increased plant height, which peaked at the application rate of 80 kg K ha^{-1}, and then decreased or remained stable at higher K rates (Fig. 1). Tillering also takes place quite early in a plant's life, however, this parameter seems much more restricted to the cultivars genetic traits. Possessing a low tillering capacity, Basmati 370 hardly responded to K application, excluding in Tebere where the initial soil K was above the deficiency threshold (Table 1). In BW 196, on the other hand, the number of tillers increased with the rising K rates up to a certain limit, and again, tillering was higher in Tebere (Fig. 2). These results of plant height and tillering suggest that K application has significant advantages if applied at the early stages of crop development.

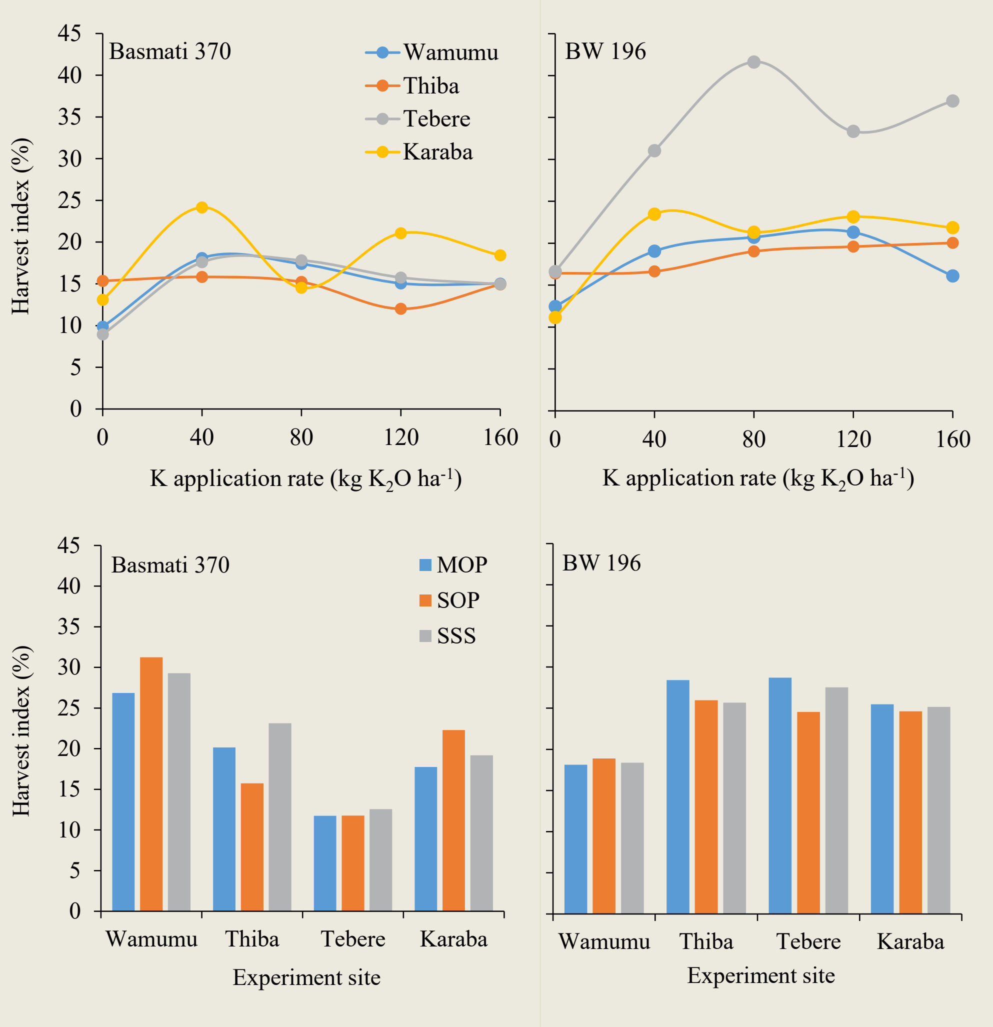


Fig. 5. Effects of K application rate (upper pair), and different K fertilizers at 80 kg K_2O ha^{-1} (lower pair), on the harvest index of two rice cultivars (Basmati 370 and BW 196).

Total rice biomass is expected to increase in response to rising K rates (Pandavuthi, 1977; Dwivedi *et al.*, 2000; Samejima *et al.*, 2005; Wakeel *et al.*, 2017). Nevertheless, in the present study, biomass response was mostly week and not always consistent (Fig. 3). Excluding Thiba, where biomass of both cultivars steadily increased by 25-30% up to a K rate of 120 kg ha^{-1}, and inexplicable fluctuations of Basmati 370 in Wamumu and Karaba, biomass change was very small. This disappointing pattern also occurred with grain yields which were generally quite modest (Fig. 4), when compared to values mentioned in the literature for other countries (FAO, 2016).

The reproductive phase is always complex and more sensitive to nutrient deficiency and abiotic stresses. Potassium is a key nutrient in this process, as it facilitates carbon reallocation and translocation during the grain filling stage (Yang *et al.*, 2004). Thus, K is required quite late, at about 90 to 120 days after transplanting, depending on the cultivar. However, in the practice employed in the present study, K application takes place just once, and early - the whole dose at transplantation. Under these circumstances, rice response to K application would be rate-dependent solely at the very beginning of crop development, but later on, it might correspond to K availability in the rhizosphere. Potassium, especially when applied in the rapidly soluble form of KCl, is highly mobile in wet soils and might be easily leached below the root zone. Furthermore, clay minerals that are extremely poor with K might permanently adsorb the soluble K while the soil dries, thus exhausting any reserve of available K when the soil gets wet again.

When related to unfertilized rice, K application did provide significant increases in grain yields, sometimes by 150% and more (Fig. 4). Yet, even though the range of K application rates that the rice was responsive to was in agreement with earlier studies, 40-120 kg K_2O ha^{-1} (Padmavathi, 1997; Dwivedi *et al.*, 2000; Dong *et al.*, 2010; Kaushik *et al.*, 2012), it would be premature to jump to any conclusions with respect to Mwea, since the absolute yields can be much higher. The improvement in HI, obtained mainly at the lower K rates (Fig. 5), together with the response patterns of plant height and tillering to K, altogether indicate substantially inefficient K fertilization, which requires careful attention.

Several important conclusions arise from the present study. Before any attempts are made to establish K fertilizer recommendations in the region, significant efforts must be made to reduce soil acidity. Severe soil acidity exposes plants to aluminum and Fe toxicity, inhibits root development, and diminishes the availability of most nutrients, leading to extremely poor crop yields (Fageria and Nascente, 2014). Liming should be examined as a suitable solution (Zimdahl, 2015), with soil enrichment using rice straw (Wang *et al.*, 2015). Second, water availability is required to secure normal rice growth and development. In order to evaluate fertilization practices, a stable and continuous water supply should be guaranteed. Unfortunately, water shortages have significantly worsened recently (Kamau, 2017).


Photos 3. Planting Basmati seedlings. Photos by the authors.

Beyond the elementary hurdles of soil acidity and water availability stands the challenge of K fertilization. The soils are depleted of K (Table 1), so the application of this nutrient is essential. However, the inadequate response of the rice yields to substantial K rates (Fig. 4) indicate inefficient application methods. So far, replacing MOP with other K fertilizers did not bring about significant change (Figs. 1-5). Alternatively, it may be postulated that when the K dose is fully applied at transplanting, most of it is diminished before being available at the critical stages of plant development. It is therefore suggested to conduct experiments, in which K doses are split, at least into two applications - at transplanting, and toward bloom. We hypothesize that this way, crop K uptake will significantly improve, K availability will better coincide with crop requirements, and rice yields will rise considerably, even with moderate K rates.

Acknowledgements

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