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Optimising potassium fertilizer rates for sustainable maize (*Zea mays* L.) production on the volcanic soils of Buea, Cameroon

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Abstract

Maize (*Zea mays* L.) production contributes to food security and income generation for many farmers, but productivity is constrained by soil infertility, with potassium (K) deficiency partly accounting for the huge gap between potential and actual yields. This is resolved with K fertilizer input that require appropriate K rates. This study was aimed at determining the optimum K fertilizer rate for maize production on the volcanic soils of Buea in Cameroon. The experiment was setup as randomized complete block design with five K fertilizer rates (0, 30, 60, 90, and 120 kg K ha^{-1}) and four replications. Results reveal increased earthworm abundance at higher K rates (P<0.05). The weight of 1000 maize grains ranged between 320–682 g across K rates, with the lowest in control and highest at 120 kg K ha^{-1} rate (P<0.05). Maize grain yield ranged between 7.5–11.8 tons ha^{-1}, with the lowest in control and highest in 120 kg K ha^{-1} rate (P<0.05). Maize yield increased significantly by 17% from control to 30 kg K ha^{-1}, 16% from 30 to 60 kg K ha^{-1} rates, and only 4% and 6%, respectively, from 60 to 90 and 90 to 120 kg K ha^{-1} rates (P<0.05). The K use efficiency expressed by the agronomic efficiency decreased significantly by 26% from 30 to 60 kg K ha^{-1}, 24% from 60 to 90 kg K ha^{-1}, and 11% from 90 to 120 kg K ha^{-1} rates (P<0.05). Similarly, the partial factor productivity decreased significantly by 41% from 30 to 60 kg K ha^{-1}, 31% from 60 to 90 kg K ha^{-1}, and 20% from 90 to 120 kg K ha^{-1} rates (P<0.05). This decreasing K use efficiency at higher K fertilizer rates is reflected in the decreasing amount of additional maize yield per unit of K fertilizer applied. The income and profitability of K fertilizer input for maize production increased significantly up to 90 kg K ha^{-1} rate that did not differ from the 120 kg K ha^{-1} rate (P<0.05). Overall, K fertilization generated additional income that ranged from US$ 3143–4367 ha^{-1}, with the 90 kg K ha^{-1} rate being the most cost-effective for maize production in the study area.

Keywords: Agronomic efficiency, maize yield, potassium, profitability, soil fertility

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1 Introduction

Maize (*Zea mays* L.) production contributes to food security and income generation for many farmers in sub-Saharan Africa (SSA), but soil nutrient deficiency causes huge gaps between the potential and actual crop yields (Neumann et al., 2010; Abu et al., 2011; Achiri et al., 2018). Maize production is constrained by poor soil fertility that requires fertilizer inputs to supplement crop needs (Ngosong et al., 2019; Tening and Foba-Tendo, 2013). Nanganoa et al. (2020) recently reported significant soil potassium

(K) deficiency across different agro-ecological zones of Cameroon that can have significant effects on maize production. Hence, fertilizers are highly recommended to increase food production per unit area of cultivable land. Despite the need to increase crop production through fertilizer inputs, SSA accounts for only 0.1% of global mineral fertilizer production and less than 10 kg ha^{-1} combine fertilizer use, as compared to about 87 kg ha^{-1} for developed nations (Sanchez, 2002; Bekunda et al., 2010). This partly accounts for the low crop productivity in SSA with over 30% yield gap between the actual crop production and the attainable potential (Sanchez, 2002; Bekunda et al., 2010).

Current farming practices in SSA are not targeted towards effective nutrient management strategies such as precision fertilization. Generally, farmers in SSA lack appropriate information on specific limiting nutrients and often apply composite NPK fertilizers, but site-specific doses of appropriate nutrients are necessary to enhance soil fertility and plant nutrition within the nexus of integrated soil fertility management (Vanlauwe et al., 2010; Gezahegn, 2021). Soil macronutrient deficiency is a major constraint for maize production in Cameroon (Achiri et al., 2018; Nanganoa et al., 2020). Accordingly, optimal nitrogen (Ngosong et al., 2019) and phosphorus (Tening and Foba-Tendo, 2013) fertilizer recommendations have been proposed for the volcanic soils of Buea in Cameroon, but information on optimal K fertilizer rate is limited, and soil potassium deficiency still persists (Nanganoa et al., 2020). This deficiency is partly because K fertilizer lacks proper attention from researchers who have not evaluated K rates, and from farmers who are unaware of the role of K for crop growth and yield.

Despite the importance of K as a primary nutrient for maize production (Pettigrew, 2008; Wang et al., 2007; Mastoi et al., 2013; Ullah, 2017), no study has investigated the appropriate K fertilizer rate for the volcanic soils of Buea in Cameroon. Current K fertilizer rates in this study area are based on recommendations from commercial agents and traditional practices that are unsustainable and not cost-effective. This study was conceived in relation to the need to satisfy the global demand for maize by increasing productivity per unit area of cultivable land using inorganic fertilizer inputs, without jeopardising sustainability. Hence, the study aimed at determining the optimum K fertilizer rate to enhance the yield and income for maize production systems. Thereby achieving macronutrient (NPK) balance by complimenting previous studies and recommendations on the appropriate rate of nitrogen (Ngosong et al., 2019) and phosphorus (Tening and Foba-Tendo, 2013) fertilizers on the volcanic soils of Buea in Cameroon. It was hypothesized that the K use efficiency of maize will increase at higher K fertilizer rates, leading to higher maize yield, income and profitability resulting from the sale of extra crop produce.

2 Materials and Methods

2.1 Experimental site

This experiment was conducted between March and August 2020 at the Teaching and Research farm of the Faculty of Agriculture and Veterinary Medicine, University of Buea, Cameroon. The site is located at the foot of Mount Cameroon in the South West Region of Cameroon, and situated at about 4100 m above sea level, on latitude 04° 8′ 55.1′′ N and longitude 09° 16′ 53.3′′ E. Buea has a mono-modal rainfall with less pronounced dry season from October to May, and rainy season from March to November with heavy rainfall between June and October. The mean annual rainfall ranges from 2085–9086 mm (Fraser et al., 1998). The mean monthly temperature is between 19 and 30 °C and mean annual temperature of 28 °C, and relative humidity between 85–90% with annual sunshine of 900–1200 hours (Fraser et al., 1998).

2.2 Experimental design

The experiment was setup in a Randomized Complete Block Design (RCBD) with five potassium rates (Control – 0, 30, 60, 90, and 120 kg K ha^{-1} rates). The experimental site of 20.5×23 m (471.5 m^2) was cleared using a cutlass and demarcated into four replicate blocks. Each block was partitioned into five plots measuring 3×3 m each. The blocks were separated from each other by 1.5 m buffer while plots within blocks were separated by 1 m, and 2 m buffer zone surrounded the entire experimental site. The plots were tilled manually to produce raised beds of about 30 cm high.

2.3 Crop cultivation

The Cameroon maize selection (CMS 8704) purchased from an agro-shop in Buea was sown manually at 5–10 cm soil depth and 75×50 cm spacing, with three seeds per stand that was thinned after germination to two vigorous plants per stand, giving a total density of 53,333 plants per hectare. K fertilizer was applied as muriate of potash at planting, at the rate of 0, 60, 120, 180 and 240 kg ha^{-1}, which corresponds to 0, 30, 60, 90 and 120 kg K ha^{-1}, respectively. In order to achieve macro-nutrient balance in all plots, phosphorus was added at planting as single superphosphate at the rate of 60 kg ha^{-1} (Ngosong et al., 2019), while 90 kg ha^{-1} of nitrogen (Tening and Foba-Tendo, 2013) was applied as two split doses of urea with the first dose of 45 kg ha^{-1} applied during planting and the second dose of 45 kg ha^{-1} applied at six weeks after germination according to recommendations from previous studies (Ngosong et al., 2019; Tening and Foba-Tendo, 2013). All fertilizers were applied by ringing at about 5 cm from the plants. A pyrethroid insecticide (Cigogne 360 EC; SCPA SIVEX International® France; comprising Cypermetrine 360 g/L as active ingredient) was applied using a knapsack sprayer at the rate of 40 mL 30 L^{-1} water to control maize pests on all plots at four, six, and eight weeks after planting. The experimental site was regularly monitored for the emergence of weeds and manual weeding was done when necessary. Soil moisture during the experiment period depended on the local rainfall regime.

2.4 Data collection

2.4.1 Soil chemical properties

An auger was used to randomly collect soil samples at 0–15 cm depth. Pre-planting soil was sampled using the Z–form for the entire experimental site after clearing and laying out but before tillage, while post-planting soil was sampled for each plot at harvest. All soil samples were air-dried at room temperature and stored in polybags prior to analysis. The soil samples were crushed and sieved through a 2-mm sieve for the determination of soil physical and chemical properties. The soil particle size was determined using the pipette method with sodium hexametaphosphate as a dispersing agent (Kalra and Maynard, 1991). The soil pH was determined potentiometrically in water (H_2O) and 1N potassium chloride (KCl) solutions after 24 hours in soil suspension (soil/liquid 1:2.5 w/v) using glass electrode pH meter. The exchangeable bases (Ca_2^+, Mg_2^+, K^+, and Na^+) were extracted using 1 N ammonium acetate (NH_4OAc) solution at pH 7. Calcium (Ca) and magnesium (Mg) were determined by the titration method using Eriochrome Black T (EBT or Erio T) as indicator while potassium (K) and sodium (Na) were determined using the flame photometer (Benton and Jones, 2001). Exchange acidity was extracted with 1 N KCl and determined by titrating the extract with 0.01 N NaOH, using phenolphthalein indicator (Benton and Jones, 2001). Effective cation exchange capacity (ECEC) was determined by the summation of exchangeable bases and exchange acidity. The total soil nitrogen (N) was determined by macro Kjeldahl digestion method (Bremner, 2016). The soil available phosphorus (P) was determined by the Bray II method (Benton and Jones, 2001), and organic carbon was determined by the wet oxidation method (Walkley and Black, 1934).

2.4.2 Maize growth and yield parameters

Data on plant height, number of leaves and leave area index (LAI) were collected from five randomly selected plants at the middle rows of each plot at 8 weeks after planting. Plant height was measured using a graduated tape from the ground level to the upper leaf collar with the developed leaf sheath. The LAI was measured using a meter rule to record the length and width of the 2nd leaf below that of the main ear (e.g., leaf on 2nd node below that of the main ear) and calculated as follows (Amanullah et al., 2016):

$$\mathrm{LAI} = \mathrm{L} \times \mathrm{W} \times k \tag{1}$$

where L = length of leaf, W = width of leaf, and k = constant (0.75).

After harvesting (11th August 2020), data (number of cobs, length of cob, number of lines per cob, number of grains per line, number of grains per cob, 1000-grain weight, and dry grain yield) on maize yield components were collected. The number of cobs per plant were visually observed and counted. Cobs were dehusked before measuring their length and circumference, grains per line, and the number of lines per cob. Maize grains were oven-dried at 60oC for three days before weighing on a balance and reported in tons ha^{-1}. Ten grains were randomly selected and their sizes measured for each cob per sampled plant using a vernier caliper. The dry weight (g) of one thousand randomly selected maize grains was recorded using a balance.

2.4.3 Potassium use efficiency

The potassium use efficiency of maize plants was assessed through the partial factor productivity (PFP) that infers on the level productivity of the crop¬ping system in comparison to its nutrient input, and agronomic efficiency (AE) that infers on the level of productivity improvement gained by using different K fertilizer rates (Niaz et al., 2016; Dobermann, 2007):

$$\mathrm{AE} = \frac{\mathrm{Y} - \mathrm{Y}_0}{\mathrm{F}} \tag{2}$$

$$\mathrm{PFP} = \frac{\mathrm{Y}}{\mathrm{F}} \tag{3}$$

where Y = grain yield of fertilized plots, Y_0 = grain of unfertilized plots, and F = amount of fertilize applied.

2.4.4 Profitability of potassium fertilization

A cost-benefit analysis was calculated to determine the profitability of K fertilization for maize production. Gross income from the sale of maize was determined in relation to local market prices recorded from twenty maize retailers at three markets in the study area, which revealed an average cost of US$ 0.62 per kg (310 FCFA local currency). All farm expenditures (e.g., clearing, weeding, tillage, planting, thinning, fertilization, pest control, harvesting, drying, and shelling) were calculated for each treatment to determine the total production cost. Net income (NI) and profitability index (benefit/cost ratio – BCR, where values greater than one [>1] indicate profitability) were calculated as follows (Ngosong et al., 2018; Pal et al., 2020):

$$NI = GI - PC \tag{4}$$

$$BCR = \frac{GI}{PC} \tag{5}$$

where GI = income from total sales, and PC = total production cost.

2.5 Data analysis

Statistical analyses were done for all data sets using SPSS (Ver. 23). Data were analyzed for normality and homogeneity of variance using the Kolmogorov-Smirnov and Levene's tests, respectively. Data for earthworms, soil chemical properties, plant growth (e.g., plant height, number of leaves, leaf area index) and yield (e.g., number of cobs per plant, length of cob, circumference of cob, number of grains per cob, grain yield, and the weight of 1000 grains), potassium use efficiency (e.g., agronomic efficiency and partial factor productivity), income and profitability were subjected to one-way analysis of variance (ANOVA). Significant means were separated using the Turkey's HSD test ($P<0.05$).

3 Results

3.1 Soil properties and earthworms

The soil analysis of the experimental site revealed a pre-planting soil composition of 23.64% silt, 38.03% clay and 38.33% sand for this experimental site. The post-planting soil exchangeable K ranged between 1.56–2.35 cmol kg^{-1} with the highest at 90 and 120 kg K ha^{-1} rates that differed significantly from the lowest in the control ($P<0.05$; Table 1). Soil available phosphorus ranged between 13.84–23.11 mg kg^{-1} soil and increased at higher K fertilizer rates with the highest at 120 kg K ha^{-1} rate that differed significantly from the control ($P<0.05$; Table 1). Total soil nitrogen ranged between 0.26–0.27% and differed significantly across K fertilizer rates with the highest at 90 and 120 kg K ha^{-1} rates, as compared to the other treatments ($P<0.05$; Table 1). The soil C/N ratio ranged between 8.09–8.38 and differed significantly across K fertilizer rates with the highest in the control that decreased with increasing K rates ($P<0.05$; Table 1). The soil pH (KCl) ranged between 4.43–4.63 and varied across K fertilizer rates with the highest at 120 kg K ha^{-1} rate that differed significantly from the control ($P<0.05$; Table 1). The abundance of earthworms ranged between 19–41 individuals m2, with the lowest in the control and 30 kg K ha^{-1}, which differed significantly from 60, 90 and 120 kg K ha^{-1} rates ($P<0.05$; Fig. 1).

3.2 Maize yield and K use efficiency

The height of maize plants ranged between 172–234 cm and differed significantly across K fertilizer rates with the lowest in the control and the highest at 120 kg K ha^{-1} that did not differ from 90 and 60 kg K ha^{-1} rates ($P<0.05$; Table 2). Maize cob length ranged from 14.9–22.6 cm per cob across the different K rates, with the highest at 90 and 120 kg K ha^{-1}, followed by 60 and 30 kg K ha^{-1} rates as compared to the lowest in the control ($P<0.05$; Table 2). The circumference of maize cobs ranged between 15.5–17.4 cm with the lowest in the control and the highest at 120 kg K ha^{-1} that did not differ significantly from 90 and 60 kg K ha^{-1} rates ($P<0.05$; Table 2). The number of cobs ranged from 1–2 per maize plant, with the lowest in the control and 30 kg K ha^{-1} rate, as compared to the highest in 60, 90 and 120 kg K ha^{-1} rates ($P<0.05$; Table 2). The number of maize grains ranged between 381.2–1288 per cob, with the lowest in the control and the highest at 120 kg K ha^{-1} that did not differ from 90 and 60 kg K ha^{-1} rates ($P<0.05$; Table 2). Maize grain size ranged from 0.8–1.0 cm with the lowest in control and the highest at 120 kg K ha^{-1} that did not differ from 90 and 60 kg K ha^{-1} rates ($P<0.05$; Table 2).

The 1000-maize grain weight ranged between 320–682 g across K fertilizer rates, with the lowest in control and the highest at 120 kg K ha^{-1} rate ($P<0.05$; Table 2). The maize grain yield ranged between 7.5–11.8 tons ha^{-1}, with the lowest in control and the highest at 120 kg K ha^{-1} that did not differ from 90 and 60 kg K ha^{-1} rates ($P<0.05$; Fig. 2). Overall, maize yield increased by 17% (1.5 tons) from the control to 30 kg K ha^{-1}, and 16% (1.7 tons) from 30 to 60 kg K ha^{-1} rates, but only increased by 4% (0.4 tons) and 6% (0.7 tons), respectively, from 60 to 90 and 90 to 120 kg K ha^{-1} rates ($P<0.05$; Fig. 2).

The K use efficiency of maize was expressed by the agronomic efficiency that decreased significantly by 26% from 30 to 60 kg K ha^{-1}, 24% from 60 to 90 kg K ha^{-1}, and 11% from 90 to 120 kg K ha^{-1} rates ($P<0.05$; Fig. 3). In addition, the partial factor productivity decreased by 41% from 30 to 60 kg K ha^{-1}, 31% from 60 to 90 kg K ha^{-1}, and 20% from 90 to 120 kg K ha^{-1} rates ($P<0.05$; Fig. 4). This decreasing K use efficiency at higher K fertilizer rates is reflected in the decreasing amount of additional maize yield per unit of K fertilizer applied.

3.3 Profitability of K fertilization

The total production cost of maize increased with K fertilizer application but this was compensated by the additional crop yield, which significantly increased

Table 1. Effect of potassium fertilizer rates on post-planting soil chemical properties

Parameter	Potassium fertilizer rates (kg ha^{-1})				
	0	30	60	90	120
pH (water)	5.36 ± 0.05a	5.32 ± 0.07ab	5.22 ± 0.03b	5.22 ± 0.04b	5.19 ± 0.05c
pH (KCl)	4.46 ± 0.05b	4.53 ± 0.03ab	4.50 ± 0.08b	4.43 ± 0.03b	4.63 ± 0.03a
Total N (%)	0.26 ± 0.004b	0.26 ± 0.002ab	0.27 ± 0.002a	0.26 ± 0.002ab	0.27 ± 0.001a
Organic C (%)	2.14 ± 0.01a	2.16 ± 0.01a	2.16 ± 0.01a	2.16 ± 0.06a	2.19 ± 0.05a
C/N ratio	8.38 ± 0.02a	8.25 ± 0.01b	8.26 ± 0.01b	8.09 ± 0.04c	8.09 ± 0.04c
Bray P (mg kg^{-1})	14.12 ± 0.10d	20.51 ± 0.24b	13.84 ± 0.07e	16.52 ± 0.02c	23.11 ± 0.09a
Ca (cmol kg^{-1})	6.78 ± 0.07c	8.26 ± 0.03a	7.52 ± 0.09b	6.41 ± 0.16d	8.41 ± 0.16a
Mg (cmol kg^{-1})	1.89 ± 0.07bc	2.01 ± 0.25ac	2.13 ± 0.12a	1.76 ± 0.21bc	2.11 ± 0.09a
K (cmol kg^{-1})	1.99 ± 0.09ab	1.56 ± 0.21c	1.76 ± 0.17bc	2.35 ± 0.27a	2.12 ± 0.36ab
Na (cmol kg^{-1})	0.07 ± 0.01a	0.06 ± 0.01a	0.09 ± 0.02a	0.07 ± 0.01a	0.07 ± 0.01a
Ex. acidity (cmol kg^{-1})	0.30 ± 0.02b	0.35 ± 0.01a	0.29 ± 0.02bc	0.26 ± 0.01c	0.15 ± 0.01d
ECEC (cmol kg^{-1})	11.03 ± 0.02c	12.78 ± 0.02a	11.79 ± 0.03b	10.85 ± 0.03d	12.79 ± 0.01a
Base saturation (%)	97.28 ± 0.02d	97.26 ± 0.02d	97.58 ± 0.02c	97.60 ± 0.01c	98.83 ± 0.01a

Values are Mean ± SD; Values within columns with different letters are significantly different (P<0.05).

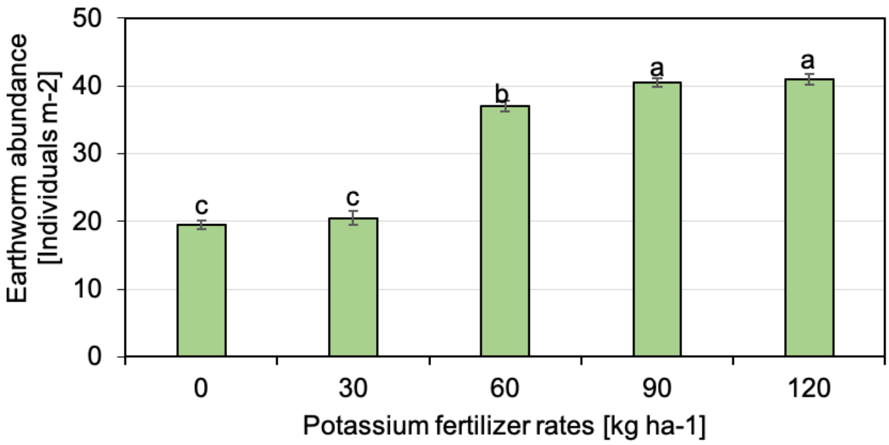

Figure 1. Effect of potassium fertilizer rates on abundance of earthworm (Individuals m^{-2}). Values with different letters are significantly different (P<0.05).

Table 2. Impact of potassium fertilizer rates on maize performance

Parameter	Potassium fertilizer rates (kg ha^{-1})				
	0	30	60	90	120
Plant height (cm)	172 ± 24c	182 ± 26bc	206 ± 9abc	222 ± 18ab	234 ± 25a
Number of leaves	15 ± 1a	15 ± 2a	16 ± 1a	16 ± 1a	16 ± 1a
Leaf area index	1013 ± 61a	1026 ± 76a	1057 ± 59a	1063 ± 54a	1066 ± 52a
Length of cobs (cm)	14.9 ± 0.4d	19.3 ± 0.3c	20.9 ± 0.9bc	22.0 ± 1.1ab	22.6 ± 0.9a
Cob circumference (cm)	15.5 ± 0.2b	15.8 ± 0.3b	17.5 ± 0.7a	17.5 ± 0.3a	17.4 ± 0.2a
Cobs per plant	1 ± 0.0c	1 ± 1.0bc	2 ± 1.2ab	2 ± 1.0ab	2 ± 1.0a
Lines per cob	12 ± 1b	13 ± 1b	16 ± 1a	17 ± 1a	16 ± 1a
Grains per line	33 ± 1b	36 ± 1b	40 ± 1a	41 ± 2a	42 ± 1a
Grains per plant	381 ± 43b	594 ± 296b	1158 ± 92a	1261 ± 179a	1288 ± 140a
1000-grain weight (g)	320.8 ± 37.0c	420.9 ± 8.7b	651.4 ± 40.0a	671.8 ± 27.7a	682.0 ± 46.6a
Grain size (cm)	0.80 ± 0.1c	0.83 ± 0.1bc	0.95 ± 0.1ab	0.98 ± 0.1a	1.03 ± 0.1a

Values are Mean ± SD; Values within columns with different letters are significantly different (P<0.05).

the net income and profitability of maize production as compared to the control without addition of K fertilizer (Table 3; P<0.05). Moreover, the net income increased at higher K fertilizer rates, with the highest income of $4,700 obtained at the 120 kg K ha^{-1} that did not differ significantly from 90 and 60 kg K ha^{-1} rates, with $4,360 and $4,180, respectiviely, but differed from the 30 kg K ha^{-1} rate and the control (Table 3; P<0.05). Correspondingly, the profitability index for K fertilization increased at higher K fertilizer rates, with the highest at 120 kg K ha^{-1} that did not differ significantly from the 90 and 60 kg K ha^{-1} rates, but differed from the 30 kg K ha^{-1} rate and the control (Table 3; P<0.05).

4 Discussion

4.1 Soil fertility and maize performance

The observed influence of K fertilizer on the soil fertility dynamics is consistent with the guidelines for tropical soils by Landon (Landon, 1991), which is in line with other studies (Kemal and Abera, 2015; Tening and Foba-Tendo, 2013). The decrease in soil pH into the acidic range at higher K fertilizer rates demonstrates the potential for soil acidification that may jeopardize soil health and productivity. This decrease in soil pH may not affect crop yield in the short-term, but could have long-term effects on soil properties that may eventually affect productivity. Hence, it is important to consider the potential long-term effects of higher K fertilizer rates on soil properties that may eventually affect crop performance and jeopardise agricultural sustainability. The increase in earthworms as soil engineers engaged in nutrient mineralization that enhance soil fertility and plant nutrition (Postma-Blaauw et al., 2006; Sheehan et al., 2006) is reflected in the yield of maize. In sum, the increase in soil fertility and maize yield following K fertilizer application corroborates the recent report by Ngosong et al. (2019) who highlighted nutrient deficiency, including soil K as a major constraint for crop production across different agro-ecological zones of Cameroon. The decreased agronomic efficiency at 90 and 120 kg K ha^{-1} rates supports the fact that plants can only absorb soil nutrients up to a maximum level based on its physiological needs, after which any additional nutrient input does not cause significant growth and productivity (Tena and Beyene, 2010; Alemayehu and Shewarega, 2015). Overall, the results support the hypothesis that maize yield will increase with K fertilization at the study site.

The increase in soil exchangeable K content for the respective treatments is commensurate with the additional K fertilizer input and consistent with other reports (Gezahegn, 2021). This can influence the natural abundance of earthworms through litter availability and fertilizer dynamics (Smith et al., 2008; Ngosong et al., 2020). Additionally, environmental factors (e.g., temperature and moisture) and food (e.g., quality and quantity) can influence cocoon production, hatching and growth of earthworms (Kanianska et al., 2016; S, 2018; Spiegel et al., 2018). The increase in earthworm abundance at higher K fertilizer rates could be due to variations in soil parameters with increased root exudates and plant biomass that served as food for earthworms (Subin et al., 2015; Singh et al., 2020). The increase in maize growth and yield parameters is in line with the role of potassium in the nutrient uptake ability of plants and cell enlargement for better crop growth (Aslam et al., 2013; Waqas et al., 2018). The increase in maize yield components with potassium fertilizer application is consistent with other studies that reported similar findings at higher potassium fertilizer application rates (Wakeel et al., 2002; Maqsood et al., 2013; Amanullah et al., 2016; Ullah, 2017). This increase in maize grain weight and yield at higher K fertilizer rates could be due to a combination of increased metabolism, carbon dioxide assimilation, photosynthetic and enzyme activities responsible for accumulation and translocation of photosynthates from the leaves to final productive units, resulting in best seed filling and heavier grains (Ullah, 2017; Waqas et al., 2018; Bojtor et al., 2021). The low K use efficiency of maize at higher K fertilizer rates could be due to the effect of increasing soil acidification or attainment of soil K saturation for optimal uptake by the maize plants, and the additional K fertilizer did not cause significant increase on maize yield. Thereby, highlighting the need for optimal K fertilizer rate based on soil K status and the agronomic efficiency of maize as previously reported for N and P (Ngosong et al., 2019; Tening and Foba-Tendo, 2013). This result does not support the hypothesis that K use efficiency will increase at higher K fertilizer application rates, and highlights the importance of understanding the critical nutrient uptake threshold of plants.

4.2 Profitability of K fertilizer

The Economist (2011) advocate precision farming as a sustainable strategy to increase crop yield and income, which is a major aim of the present study to achieve appropriate site-specific K fertilization rate to boost maize productivity without jeopardising sustainability. This is consistent with the higher maize yield and profitability up to a maximum K fertilizer rate (Gezahegn, 2021; Waqas et al., 2018), and in line with reports on the importance of fertilizer inputs for better crop yields in Cameroon (Nanganoa et al., 2020; Yengoh, 2012). The increased maize yield is reflected in the income and profitability (Achiri et al., 2018; Jjagwe et al., 2020), which would encourage resource-poor farmers in SSA to invest in K fertilizer inputs, especially given that their opportunity cost with little access to financial capital is often 100% (Tiffen, 2003).

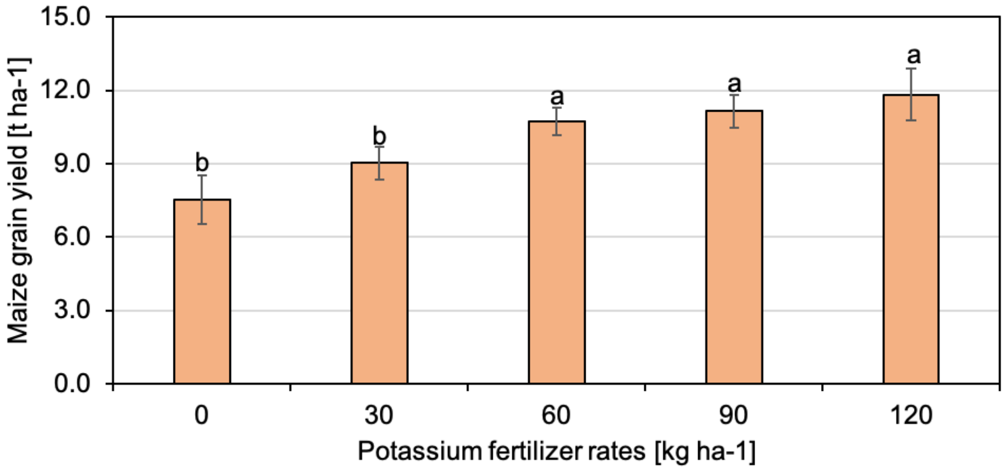

Figure 2. Impact of potassium fertilizer rates on maize grain yield. Values with different letters are significantly different (P<0.05).

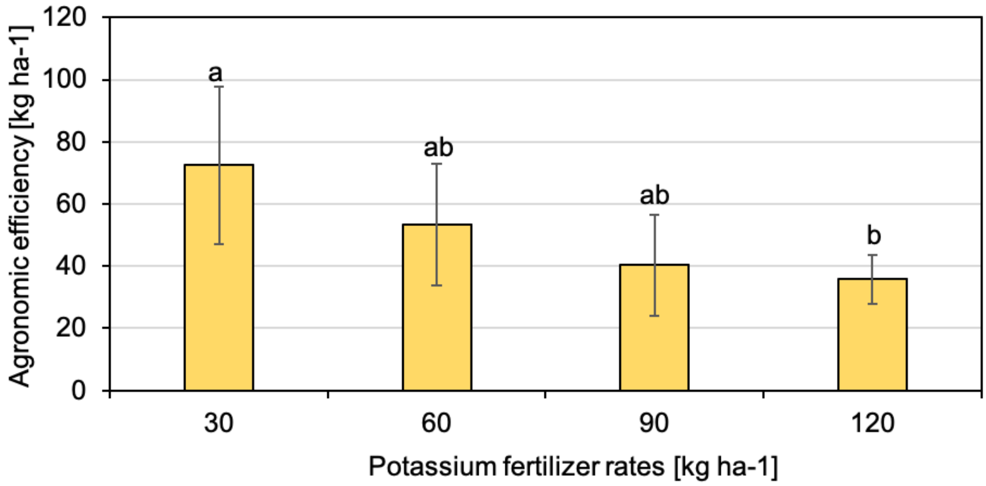

Figure 3. Agronomic efficiency of maize across different potassium fertilizer rates. Values with different letters are significantly different (P<0.05).

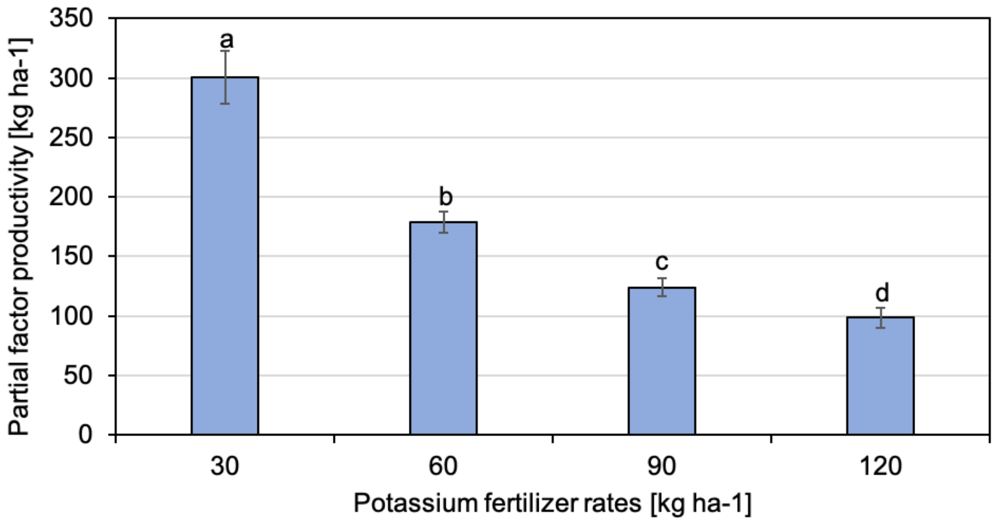

Figure 4. Partial factor productivity of maize across different potassium fertilizer rates. Values with different letters are significantly different (P<0.05).

Table 3. Impact of potassium fertilizer rates on income and profitability of maize production

K fertilizer rates (kg ha-1)	Gross income (USD ha-1)	Net income (USD ha-1)	Profitability index
0	4,700d	2,300d	2.0c
30	5,580c	3,140c	2.0b
60	6,640b	4,180b	2.6a
90	6,940b	4,360b	2.7a
120	7,300a	4,700a	2.8a

Values within columns with different letters are significantly different (P<0.05).

Similarly, Ngosong et al. (2018) reported increased crop yields and profitability following the application of inorganic fertilizer on the volcanic soils of Buea in Cameroon. In sum, these results support the hypothesis that high K fertilizer application rate will increase the income and profitability of maize production systems on the volcanic soils of this study site up to a maximum amount where additional K fertilizer input did not have any significant effect. Therefore, resource-poor small-scale subsistence maize farmers could consider K fertilization as a means of improving their maize productivity and income.

5 Conclusion

The increased maize yield and income for the different K fertilizer rates highlights the importance of K fertilization rate for better performance. The best yield and profitability of maize production was obtained at K fertilizer rates up to 90 kg ha^{-1}, which is recommended as the most cost-effective K fertilizer rate for maize production in the study area. The decrease in K use efficiency expressed by the agronomic efficiency and partial factor productivity of maize at higher K fertilizer rates is consistent with the attainment of critical nutrient uptake and productivity levels by the maize plants, for which any additional K fertilizer input did not cause significant increase in maize yield.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

Abu GA, Djomo-Choumbou RF, Okpachu SA. 2011. Evaluating the constraints and opportunities of maize production in the west region of cameroon for sustainable development. JSDA 13:189–96.

Achiri D, Mbaatoh M, Njualem D. 2018. Agronomic and yield parameters of CHC202 maize (zea mays l) variety influenced by different doses of chemical fertilizer (NPK) in bali nyonga, north west region cameroon. Asian Journal of Soil Science and Plant Nutrition 2:1–9. doi: 10.9734/ajsspn/2017/39583.

Alemayehu Y, Shewarega M. 2015. Growth and yield responses of maize (zea mays l.) to different nitrogen rates under rain-fed condition in dilla area, southern ethiopia. Journal of Natural Science Research 5.

Amanullah, Iqbal A, Irfanullah, Hidayat Z. 2016. Potassium management for improving growth and grain yield of maize (zea mays l.) under moisture stress condition. Scientific Reports 6. doi: 10.1038/srep34627.

Aslam M, Ibni Zamir MS, Afzal I, Yaseen M. 2013. Morphological and physiological response of maize hybrids to potassium application under drought stress. Journal of Agricultural Research (03681157) 51.

Bekunda M, Sanginga N, Woomer PL. 2010. Restoring soil fertility in sub-sahara africa. In: Advances in Agronomy. Elsevier. p. 183–236. doi: 10.1016/s0065-2113(10)08004-1.

Benton J, Jones J. 2001. Laboratory guide for conducting soil tests and plant analysis. CRC Press, Boca Raton, London, UK, New York, Washington, D.C, USA.

Bojtor C, Illés Á, Mousavi SMN, Széles A, Tóth B, Nagy J, Marton CL. 2021. Evaluation of the nutrient composition of maize in different NPK fertilizer levels based on multivariate method analysis. International Journal of Agronomy 2021:1–13. doi: 10.1155/2021/5537549.

Bremner JM. 2016. Total nitrogen. In: Agronomy Monographs. American Society of Agronomy, Soil Science Society of America. p. 1149–1178. doi: 10.2134/agronmonogr9.2.c32.

Dobermann A. 2007. Nutrient use efficiency - measurement and management. In: Proceedings of the International Fertilizer Industry Association (IFA) Workshop on Fertilizer Best Management Practices, 7-9 March 2007, Brussels-Belgium, 1-28.

Fraser P, Hall J, Healing J. 1998. Climate of the Mount Cameroon Region, long and medium term rainfall, temperature and sunshine data. SAFS, University of Wales Bangor, MCPLBG. Limbe. 56.

Gezahegn AM. 2021. Role of integrated nutrient management for sustainable maize production. International Journal of Agronomy 2021:1–7. doi: 10.1155/2021/9982884.

Jjagwe J, Chelimo K, Karungi J, Komakech AJ, Lederer J. 2020. Comparative performance of organic fertilizers in maize (zea mays l.) growth, yield, and economic results. Agronomy 10:69. doi: 10.3390/agronomy10010069.

Kalra Y, Maynard D. 1991. Methods manual for forest soil and plant analysis. Northwest Region, Technical Report, Information Report NOR-X319.

Kanianska R, Jad'ud'ová J, Makovníková J, Kizeková M. 2016. Assessment of relationships between earthworms and soil abiotic and biotic factors as a tool in sustainable agricultural. Sustainability 8:906. doi: 10.3390/su8090906.

Kemal YO, Abera M. 2015. Contribution of integrated nutrient management practices for sustainable crop productivity, nutrient uptake and soil nutrient status in maize based cropping systems. Journal of Nutrients 2:1–10. doi: 10.18488/journal.87/2015.2.1/87.1.1.10.

Landon J. 1991. Tropical Soil Manual. Longman Scientific and Technical Essex, UK.

Maqsood M, Shehzad MA, Wahid A, Butt AA. 2013. Improving drought tolerance in maize (zea mays) with potassium application in furrow irrigation systems. International Journal of Agriculture & Biology 15.

Mastoi GS, Zia-ul hassan RI, Shah AN, Qureshi SA. 2013. Response of field grown hybrid maize to integrated use of inorganic and organic potassium fertilizers. Agricultural Veterinary Science 29:126–136.

Nanganoa LT, Ngome FA, Suh C, Basga SD. 2020. Assessing soil nutrients variability and adequacy for the cultivation of maize, cassava, and sorghum in selected agroecological zones of cameroon. International Journal of Agronomy 2020:1–20. doi: 10.1155/2020/8887318.

Neumann K, Verburg PH, Stehfest E, Müller C. 2010. The yield gap of global grain production: A spatial analysis. Agricultural Systems 103:316–326. doi: 10.1016/j.agsy.2010.02.004.

Ngosong C, Bongkisheri V, Tanyi CB, Nanganoa LT, Tening AS. 2019. Optimizing nitrogen fertilization regimes for sustainable maize (zea mays l.) production on the volcanic soils of buea cameroon. Advances in Agriculture 2019:1–8. doi: 10.1155/2019/4681825.

Ngosong C, Nfor I, Tanyi C, Olougou M, Sone K, Agbor D, Ndakwe A, Nanganoa L, Tening A. 2020. Effect of poultry manure and inorganic fertilizer on earthworm population and soil fertility: implication on root nodulation and yield of climbing bean (phaseolus vulgaris). Fundamental and Applied Agriculture :1doi: 10.5455/faa.76612.

Ngosong C, Nkiambuo BN, Tanyi CB, Nkongho RN, Okolle JN, Egbe AE, Tening AS. 2018. Comparative study of soil and foliar NPK fertilizers on the yield and income of cucumber (cucumis sativus l.). Asian Journal of Advances in Agricultural Research 8:1–9. doi: 10.9734/ajaar/2018/45721.

Niaz A, Yaseen M, Shakar M, Sultana S, Ehsan M, Nazarat A, et al. 2016. Maize production and nitrogen use efficiency in response to nitrogen application with and without humic acid. Journal of Animal and Plant Sciences 26:1641–1651.

Pal S, Sana M, Banerjee H, Lhungdim L. 2020. Effectiveness of nitrogen and bio-fertilizer choice for improving growth and yield of hybrid rice (oryza sativa l.) during dry season. Oryza-An International Journal on Rice 57:302–309. doi: 10.35709/ory.2020.57.4.6.

Pettigrew WT. 2008. Potassium influences on yield and quality production for maize, wheat, soybean and cotton. Physiologia Plantarum 133:670–681. doi: 10.1111/j.1399-3054.2008.01073.x.

Postma-Blaauw MB, Bloem J, Faber JH, van Groenigen JW, de Goede RG, Brussaard L. 2006. Earthworm species composition affects the soil bacterial community and net nitrogen mineralization. Pedobiologia 50:243–256. doi: 10.1016/j.pedobi.2006.02.001.

S A. 2018. Life cycle of vermicomposting earthworms eisenia fetida and eudrilus eugeniae under laboratory controlled condition. Biomedical Journal of Scientific & Technical Research 10. doi: 10.26717/bjstr.2018.10.002015.

Sanchez PA. 2002. Soil fertility and hunger in africa. Science 295:2019–2020. doi: 10.1126/science.1065256.

Sheehan C, Kirwan L, Connolly J, Bolger T. 2006. The effects of earthworm functional group diversity on nitrogen dynamics in soils. Soil Biology and Biochemistry 38:2629–2636. doi: 10.1016/j.soilbio.2006.04.015.

Singh S, Singh J, Vig AP. 2020. Diversity and abundance of earthworms in different landuse patterns: Relation with soil properties. Asian Journal of Biological and Life Sciences 9:111–118. doi: 10.5530/ajbls.2020.9.18.

Smith R, McSwiney C, Grandy A, Suwanwaree P, Snider R, Robertson G. 2008. Diversity and abundance of earthworms across an agricultural land-use intensity gradient. Soil and Tillage Research 100:83–88. doi: 10.1016/j.still.2008.04.009.

Spiegel H, Mosleitner T, Sandén T, Zaller JG. 2018. Effects of two decades of organic and mineral fertilization of arable crops on earthworms and standardized litter decomposition. Die Bodenkultur: Journal of Land Management, Food and Environment 69:17–28. doi: 10.2478/boku-2018-0003.

Subin K, Madan K, Udhab RK. 2015. Earthworm population in relation to different land use and soil characteristics. Journal of Ecology and The Natural Environment 7:124–131. doi: 10.5897/jene2015.0511.

Tena W, Beyene S. 2010. Identification of growth limiting nutrient(s) in alfisols: Soil physico-chemical properties, nutrient concentrations and biomass yield of maize. American Journal of Plant Nutrition and Fertilization Technology 1:23–35. doi: 10.3923/ajpnft.2011.23.35.

Tening A, Foba-Tendo J. 2013. Phosphorus fixing capacity of a volcanic soil on the slope of mount cameroon. Agriculture and Biology Journal of North America 4:166–174. doi: 10.5251/abjna.2013.4.3.166.174.

The Economist. 2011. The 9 billion-people question: A special report on feeding the world. February 26, 2011.

Tiffen M. 2003. Transition in sub-saharan africa: Agriculture, urbanization and income growth. World Development 31:1343–1366. doi: 10.1016/s0305-750x(03)00088-3.

Ullah I. 2017. Yield and yield attributes of maize (zea mays l.) as affected by detasseling and potassium fertilization. Pure and Applied Biology 6. doi: 10.19045/bspab.2017.600101.

Vanlauwe B, Bationo A, Chianu J, Giller K, Merckx R, Mokwunye U, Ohiokpehai O, Pypers P, Tabo R, Shepherd K, Smaling E, Woomer P, Sanginga N. 2010. Integrated soil fertility management. Outlook on Agriculture 39:17–24. doi: 10.5367/000000010791169998.

Wakeel A, Hassan A, Aziz T, Iqbal M. 2002. Effect of different potassium levels and soil texture on growth and nutrient uptake of maize. Pakistan Journal of Agricultural Sciences 39:99–103.

Walkley A, Black IA. 1934. An examination of the degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37:29–38. doi: 10.1097/00010694-193401000-00003.

Wang X, Cai D, Hoogmoed WB, Perdok UD, Oenema O. 2007. Crop residue, manure and fertilizer in dryland maize under reduced tillage in northern china: I grain yields and nutrient use efficiencies. Nutrient Cycling in Agroecosystems 79:1–16. doi: 10.1007/s10705-007-9113-7.

Waqas L, Jan MF, Ahmad H, Khan EH, Khan N, Rehan W, et al. 2018. Impact of mineral potassium on phenology, growth and yield of maize hybrid. International Journal of Environmental Sciences & Natural Resources 8:168–171.

Yengoh GT. 2012. Determinants of yield differences in small-scale food crop farming systems in cameroon. Agriculture & Food Security 1. doi: 10.1186/2048-7010-1-19.

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