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Research Application Summary

Effects of inorganic fertilizer applications on grain yield, nutrient use efficiency and economic benefits of maize in Western Kenya

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Abstract

Declining soil fertility levels due the application of low rates and unbalanced nutrients is the main cause of low yields in western Kenya. We therefore designed a randomized complete block nutrient omission trial with six replications to determine the effects of inorganic fertilizers on grain yield, nutrient use efficiency and economic benefits of maize in the region. The treatments were NK, NP, PK, NPK and NPK+CaMgZnBS. The results showed that application of PK fertilizer regime resulted in slow crop growth rate (CGR) and relative growth rate (RGR) and low biomass compared to other treatments. Application of a wider range of nutrients (NPK+CaMgZnBS treatment) improved maize growth and yield compared to other treatments. In terms of grain response, N application recorded the highest yield (1800 kg/ha) followed by P (1300 kg/ha) then K (1100 kg/ha) and least by a combined application of secondary macronutrients and micronutrients (ZnBMgCaS = 400 kg/ha). Highest agronomic efficiency of 32.5 kg grain /kg nutrient applied was recorded due to P followed by K (27.5 kg grain /kg nutrient) and least by N (15 kg grain /kg nutrient).. Economic analysis showed higher total production cost, gross revenue and net revenue due to application of NPK+ZnBMgCaS fertilizer than other treatments. However, the lowest (1.60) and highest (2.12) benefit to cost ratio values were recorded due to the application of PK and NPK fertilizer regimes, respectively. Based on this study, inclusion of Zn, B, Mg and Ca nutrients increased yield but it was not economical, indicating that farmers could be encouraged to apply a combination of N, P and K fertilizers.

Key words: Agronomic efficiency, economic analysis, fertilizer application, growth rates, maize, nutrient response

Résumé

La baisse des niveaux de fertilité du sol due à l'application de faibles taux et de nutriments déséquilibrés est la principale cause des faibles rendements dans l'ouest du Kenya. Nous avons donc conçu un essai randomisé complet sur les omissions d'éléments nutritifs en bloc avec six répétitions pour déterminer les effets des engrais inorganiques sur le rendement en grains, l'efficacité de l'utilisation des éléments nutritifs et les avantages économiques du maïs dans la région. Les traitements étaient NK, NP, PK, NPK et NPK + CaMgZnBS. Les résultats ont montré que l'application du régime d'engrais PK entraînait un taux de croissance des cultures lent (TCC) et un taux de croissance relatif (TCR) et une faible biomasse par rapport à d'autres traitements. L'application d'une plus large gamme de nutriments (traitement NPK + CaMgZnBS) a amélioré la croissance et le rendement du maïs par rapport aux autres traitements. En termes de réponse des céréales, l'application de N a enregistré le rendement le plus élevé (1800 kg/ha) suivi de P (1300 kg/ha) puis de K (1100 kg/ha) et le moins par une application combinée de macronutriments secondaires et de micronutriments (ZnBMgCaS = 400 kg/ha). La plus grande efficacité agronomique de 32,5 kg de céréales / kg de nutriments appliqués a été enregistrée en raison de P suivi de K (27,5 kg de céréales / kg de nutriments) et le moins de N (15 kg de céréales / kg de nutriments). L'analyse économique a montré un coût de production total plus élevé, brut revenus et revenus nets dus à l'application d'engrais NPK + ZnBMgCaS par rapport aux autres traitements. Cependant, les valeurs les plus faibles (1,60) et les plus élevées (2,12) du rapport avantages / coûts ont été enregistrées en raison de l'application des régimes d'engrais PK et NPK, respectivement. Sur la base de cette étude, l'inclusion de nutriments Zn, B, Mg et Ca a augmenté le rendement mais ce n'était pas économique, ce qui indique que les agriculteurs pourraient être encouragés à appliquer une combinaison d'engrais N, P et K.

Mots clés: efficacité agronomique, analyse économique, application d'engrais, taux de croissance, maïs, réponse nutritive

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Introduction

Maize is a staple food for over 90% of Kenyans with an average consumption per capita of 103 kg/year (Pingali, 2001). Other than being an important source of food, the crop is a key source of income to the smallholder farmers and a source of animal feed and raw material in the oil sector (Shiferaw *et al.,* 2011). It is estimated that smallholder farmers account for about 80% of the total maize produced in Kenya (Kamindi *et al*., 1999). Despite the importance of maize, smallholder farmers still record low yields - average of 1.66 t/ha (FAOSTAT, 2014) - compared to the potential yield of 6 – 10 t/ha in Western Kenya (Smalling and Jansen, 1993; Makokha *et al.,* 2001). Such low yield in the region is partly due to high soil infertility caused by soil nutrient depletion as reported by Sanchez (1997). According to Mwangi and others (1998), small scale farmers have poor nutrient management strategies as they do not apply adequate fertilizers to replenish the lost nutrients. Such low use of fertility inputs in the region could be attributed to low access and limited financial strength to acquire these inputs which are expensive in the region. Also, poor agricultural extension services characterized by very low extension officer to farmers ratio – currently at 1: 1000 compared to the FAO-recommended ratio of 1: 400 - and dissemination of blanket and obsolete fertilizer recommendations have significantly contributed to the current low fertilizer use and the subsequent current low maize yield. For instance, in Western Kenya, National Farmers Information Service (NAFIS) promotes application of 36 and 40 kg of DAP and urea per acre, respectively (www.nafis.

go.ke), despite the growing demand for increased yields and high nutrient losses. If not well managed, such low rates being promoted cannot adequately supply nutrients for improved maize productivity while at the same time adjusting for inefficiencies caused by leaching, erosion, adsorption and volatilization processes. The growing need for primary macronutrients is evident. For example, Kihara and Njoroge (2013) reported that inability of farmers to supply N and P nutrients could result in, respectively, 43 and 50% of yield reduction in western Kenya. Further, there is inadequate research on the effects of applying secondary (e.g. Ca, Ma and S) and micro (e.g. B and Zn) nutrients on maize production in western Kenya. This is despite their reported significant contribution to growth and yield of maize (Abunyewa *et al.,* 2004; Kanwal *et al.,* 2008; Vanlauwe *et al.,* 2015). Therefore, a study was carried out to determine the effects of inorganic fertilizers on grain yield, nutrient use efficiency and economic benefits of maize in Western Kenya.

Materials and Methods

Site description. The trial was set up at Alupe region in Busia County; located on 340 07' 28.6'' E and 00 0 30' 10.1'' N with annual rainfall range of 1100 to 1450 mm and daily mean temperatures of 24 0C. The soils had pH of 4.75, 1.29% soil organic carbon, 0.14% N, 1.04 me% K, 26.2 ppm P, 0.32 me% Ca, 3.28 me% Mg and 4.3 ppm Zn. The soils were ferralsols type (Jaetzold et al., 2006). The area has a bi-modal rainfall pattern, wet seasons from March to May (long rain season) and October to December (short rain season).

Experimental design and treatments. The experiment was arranged in a randomized complete block design with six replicates each measuring 8 m by 10 m. The fertilizer regimes were NK, NP, PK, NPK and NPK+CaMgZnBS. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), boron (B) and sulphur (S) nutrients were applied at rates of 120, 40, 40, 10, 10, 5 and 26.3 kg/ha, respectively, using urea, triple superphosphate (TSP), muriate of potash (MOP), calcium sulphate, magnesium sulphate, zinc sulphate and borax nutrient, respectively. Maize variety DK 8031 was used for the trials.

Agronomic practices. During 2013/2014 short rains season, DK 8031 maize variety was planted to deplete nutrients from the field. During 2014 long rains season, tilling of land was done a week before the onset of the rains using conventional hoes. Planting of maize was done at the onset of the effective long rains at row spacing of 75 cm and within row spacing of 25 cm. Nitrogen was applied in three equal splits (at planting, V4 and V10 stages of maize vegetative growth) while the rest of the nutrients were applied at planting. The V4 and V10 are vegetative (V) growth phases of maize when the crop has 4 and 10 visible leaf collars, respectively (Ciganda *et al.,* 2009). The 1st and 2nd weed control activity was done at V4 and V10, respectively, of maize growth stages using hoes. All the plots were harvested at the fourth month after emergence - the maturity stage.

Data collection. Crop growth rate (CGR): The CGR was measured at 30 days interval and computed as described by Hunt (1978) using the formula: CGR (gm 2day 1) = (W2 W1)/A(T2 T1), where W1 is total dry weight at time T1, W2 is the total dry weight at time T2 and A is plant area.

Relative growth rate (RGR): This was computed from the dry biomass collected at defined 30 days interval using Hunt *et al*. (2002) formula: RGR (gkg^{-1} DM d^{-1}) = (1/W)* (W2-W1)/ (T2-T1).

Grain yield: Number of plants and cobs per net plot (15 m^2) were counted manually and recorded. Total fresh weights of stover and cobs were taken per net plot. The yields were recorded from each plot and expressed in tons per hectare after adjusting for grain moisture to 14^0C.

Yield response and agronomic efficiency (AE): Maize agronomic efficiencies for nitrogen, phosphorus and potassium were calculated from yields based on subtraction equation:
[Yield in fertilized plot (kg/ha) – yield in non-fertilized plot (kg/ha)]/ Quantity of nutrients applied (kg/ha).

Economic analysis: Economic performance was assessed through a partial budget analysis using labour data and prices of all applied inputs (CIMMYT, 1988). Total variable cost (TVC) was given by the sum total of all the costs incurred during the production period while gross benefits (GB) as the monetary value of harvested grains. Net benefit (NB) was given as the difference between TVC and GB while benefit to cost ratio (BCR) was computed as the ratio of GB to TCV.

Statistical analysis. Collected data were subjected to analysis of variance (ANOVA) using Genstat statistical computer software, 15th version. Where F test was significant, means were compared using Fisher's protected least significant difference (L.S.D.) procedure at p 0.05 (Gomez and Gomez, 1984). Net benefits and benefits to cost ratio were computed to determine the profitability of various fertilizer combinations.

Results

Crop growth rate (CGR): Fertilizer application significantly influenced CGR ($P< 0.001$). The lowest values were recorded as a result of PK fertilizer regime application. The NPK+CaMgZnBS and NPK fertilizer regimes recorded similar CGR at all growth intervals. Across fertilizer regimes, maize CGRs were observed to increase and peaked at 60 to 90 DAE then declined towards 90 to 120 DAE (Figure 1).

Relative growth rate (RGR): Significantly lower and higher maize RGR values were recorded under the application of PK and NPK+CaMgZnBS fertilizer regime, respectively, than under other treatments at all growth period intervals. The highest RGR values were recorded at 0 to 30 DAE intervals, followed by a decline across the intervals and reached the lowest values at 90 to 120 DAE (Figure 2).

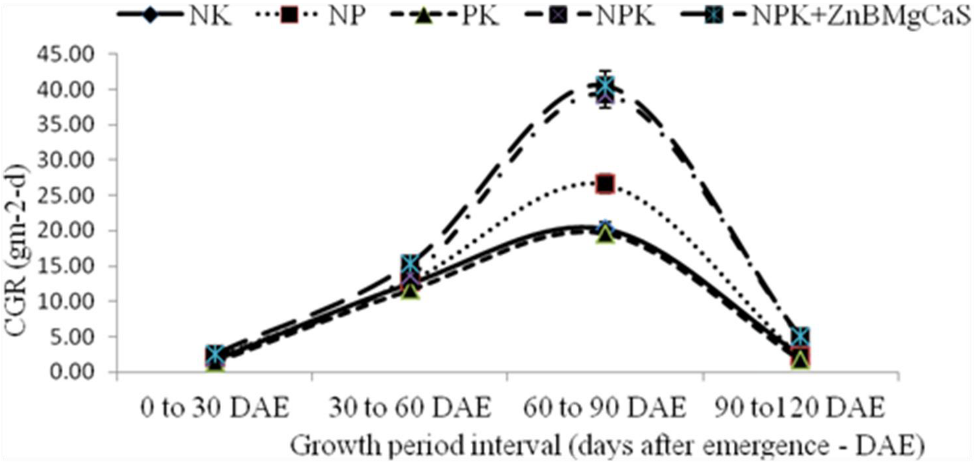

Figure 1. Maize growth rates as affected by various fertilizer regimes at different growth period intervals during the 2014 long rains growing season at Alupe in Busia County

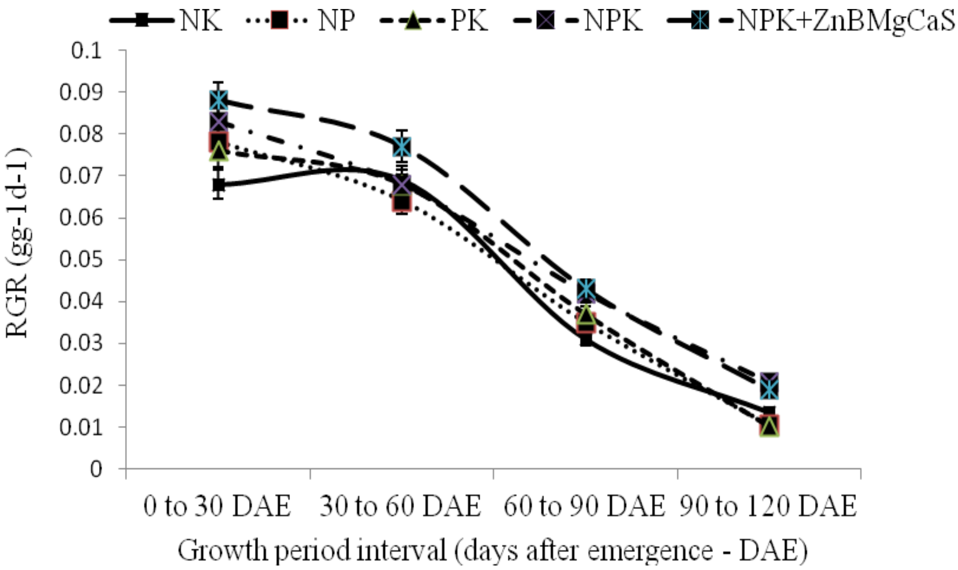

Figure 2. Maize relative growth rates as affected by various fertilizer regimes at different growth period intervals during the 2014 long rains growing season at Alupe in Busia County

Grain production and yield response: Grains were significantly influenced ($p< 0.01$) by the fertilizer regimes. The PK fertilizer regime treatment recorded lower yield (2.3 t/ha) than all other treatments. The NPK+CaMgZnBS treatment out-yielded NPK, NP, NK and PK treatments by 700, 1500, 1700 and 2200 kg/ha, respectively (Figure 3).

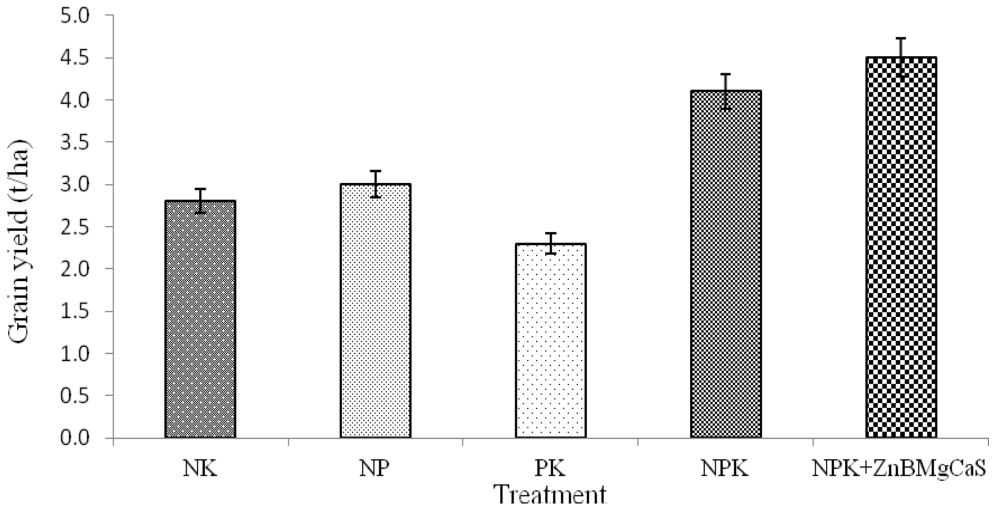

Figure 3. Maize grain yields as affected by various fertilizer regimes during the 2014 long rains growing season at Alupe in Busia County

In terms of nutrient response, N application recorded the highest yield response (1800 kg/ha) followed by P (1300 kg/ha) then K (1100 kg/ha) and least by combined application of secondary macronutrients and micronutrients (ZnBMgCaS = 400 kg/ha) (Figure 4).

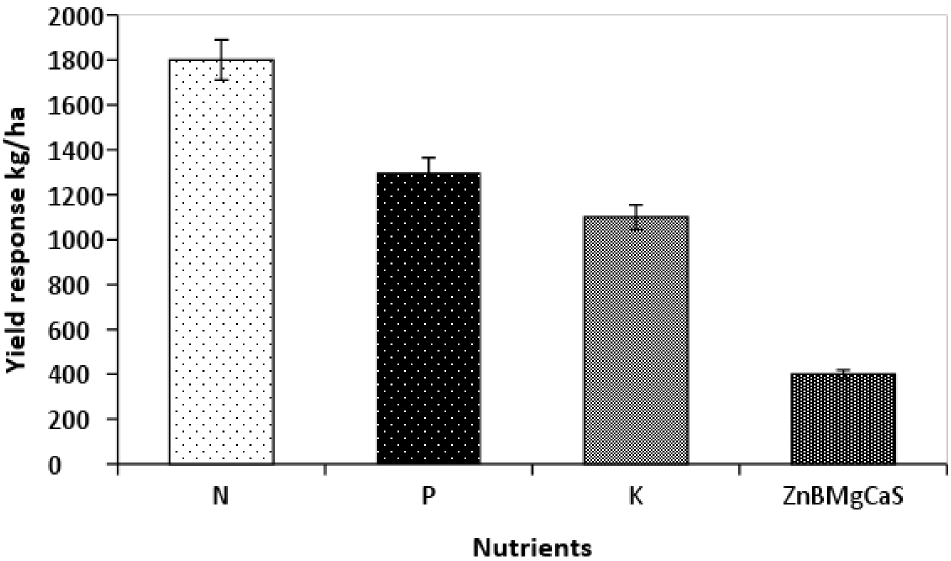

Figure 4. Maize yield responses due to the application of N, P, K and CaMgZnBS nutrients during the 2014 long rains growing season at Alupe in Busia County. The secondary macro and trace nutrients were applied together

Agronomic efficiencies (AE) of N, P and K: The agronomic efficiency of N, P and K nutrients on biomass was low at 30 DAE (N = 1.3 kg biomass /kg nutrient, P = 2.5 kg biomass /kg nutrient and K = 0.5 kg biomass /kg nutrient) (Figure 5). This was observed to increase through 60 DAE and reached the peak at 90 DAE (N = 50 kg biomass/ kg nutrient, P = 124.5 kg biomass/ kg nutrient and K = 107.3 kg biomass/ kg nutrient) before decreasing towards 120 DAE (Figure 5). At all growth periods, except at 90 DAE, application of P nutrient recorded highest agronomic efficiencies followed by the application of N nutrient and then K nutrient. In terms of grain production, application of P nutrient resulted in the highest agronomic efficiency of 32.5 kg grain /kg nutrient. This was followed by the application of K (27.5 kg grain /kg nutrient) and least by application N of (15 kg grain /kg nutrient).

Economics of fertilizer application: The economic analysis showed highest total variable costs of $1088.17/ha due to the application of NPK+ZnBMgCaS fertilizer regime (Table 1). This was followed by $963.96/ha due to the application of NPK fertilizer regime. The least total variable cost ($748.59/ha) was recorded due to the application of PK fertilizer regime. This trend was also observed with gross and net revenues (Table 1). The net revenue realized due to the application of NPK+ZnBMgCaS fertilizer regime was $512.50, $456.45, $705.24 and $81.85/ha more than net revenue realized due to the application of NK, NP, PK and NPK fertilizer regimes, respectively. The lowest (1.60) and highest (2.12) benefit to cost ratio values were recorded due to the application of PK and NPK fertilizer regimes, respectively (Table 1). The NK and NP regimes recorded similar benefit to cost ratio.

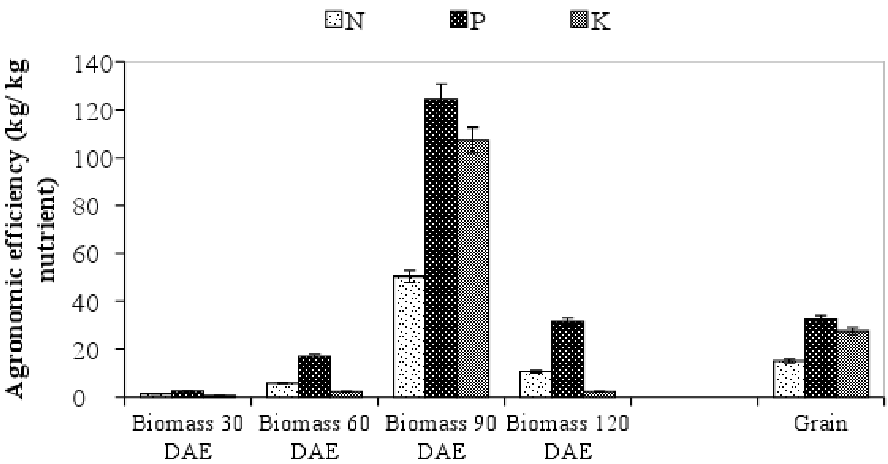

Figure 5. Agronomic efficiencies of N, P and K nutrients on biomass and grain yield production during the 2014 long rains growing season Alupe in Busia County. Biomass production was considered at 30, 60, 90 and 120 days after emergence (DAE)

Table 1. Economic analysis of maize production under various fertilizer regimes during the 2014 long rains growing season at Alupe in Busia County

	Total variable cost ($/ha)	Gross revenue ($/ha)	Net revenue ($/ha)	Benefit to cost ratio
Fertilizer regimes				
NK	781.29	1426.73	645.43	1.83
NP	841.54	1543.02	701.48	1.83
PK	748.59	1201.28	452.69	1.60
NPK	963.96	2040.04	1076.08	2.12
NPK+ZnBMgCaS	1088.17	2246.10	1157.93	2.06

Discussion

Application of a wide range o
f nutrients (NPK+ZnBMgCaS and NPK regimes) seemed to have boosted maize growth which translated directly into high yield performance compared to a narrow range of nutrients (NP, NK and PK regimes). However, the yields attained were lower than the potential yields of between 6 and 10 t/ha of maize reported by Makokha *et al*. (2001) in Western region. This could be due to generally high soil acidity (pH = 4.75) reported during this trial. Other researchers have confirmed this and reported high soil acidity, pH<5.5 that cause nutrient unavailability, to be one of the major constraints to crop production in Western Kenya (Liao *et al.,* 2006; Nziguheba *et al.,* 2016; Otieno *et al.,* 2018).

Omission of either of the primary macronutrients resulted in poor growth and loss of yields: Omission of N (PK fertilizer regime) resulted in shorter plants, smaller leaves, slower crop growth and relative growth rates, and lower biomass production and grain yields than other treatments. This could have been due to the crucial role of N during growth and reproduction that was impaired under low supply - N is heavily involved in vital metabolic, biochemical and physiological processes right from germination to maturity (Sangoi *et al.,* 2008; Khan *et al.,* 2013). Omission of P (application NK fertilizer regime) nutrient was also observed to cause reduction in maize performance in this study. This could have been due to the impaired root development and energy production under inadequate P supply (Fageria *et al*., 2008). Similarly, omission of K (application of NP fertilizer regime) nutrient negatively affected maize growth and yield. This could have been due to impaired movement of water, nutrients and carbohydrates and reduced enzyme activation and other functions under deficient K supply from the soil (Uchida, 2000; McCauley *et al.,* 2009). Combined application of a broad range of nutrients resulted in high crop yield performance compared to a narrow range of nutrients. This finding is supported by those of Dai *et al*. (2013) who reported high yields of maize and wheat under NPK application compared to PK, NK, NP and control treatments. This could have been due to the synergy that ensured availability of all crucial nutrients for maize growth. The synergy further helped in ameliorating the effects of other missing nutrients or that were under low supply. When comparing yield responses, application of N produced the highest yield followed by P and lowest yield was obtained by combined application of Zn, B, Mg, Ca and S nutrients; however, the effects of individual secondary and micro nutrients used in this study could not be separated because of combined application method used. Similar trend in maize response to N, P and K applications has been reported in western Kenya (Shepherd *et al.,* 1997; Hartemink *et al.,* 2000). Highest agronomic efficiency recorded as a result of application of P nutrient compared to other nutrients in this study is in agreement with findings by Ademba *et al*. (2015), Opala *et al*. (2015) and Opala (2017) in Western Kenya. From economic standpoint, it was observed that when one combined more nutrients for maize production, the total production costs and revenues increased with the highest values observed due to the application of NPK and NPK+ZnBMgCaS regimes. Narrow nutrient ranges recorded low benefit to cost ratios compared to their wider nutrient range counterparts. The NPK fertilizer regime recorded the highest benefit to cost ratio value due to relatively low production cost and high yields that translated to higher revenues upon the sale of the produce compared to NPK+ZnBMgCaS regime. Despite recording high grain yields, the additional costs incurred as a result of applying secondary macronutrients and micronutrients under NPK+ZnBMgCaS regime were too high to be offset by the additional revenues realized. Hence, its low benefit to cost ratio compared to NPK treatment.

Conclusion

From this study, application of a wide range of nutrients could be required for increased maize production compared to the narrower nutrient range combinations. Economic analysis showed that maize production was more profitable with application of only the three primary macronutrients (under NPK fertilizer regime).

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