Available online at www.worldscientificnews.com

World Scientific News

An International Scientific Journal

WSN 129 (2019) 96-106 EISSN 2392-2192

Growth and Yield Response of Maize (*Zea mays* L.) to a Wide Range of Nutrients on Ferralsols of Western Kenya

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ABSTRACT

Declining soil fertility is one of the main causes of low yields of maize. Farmers apply low rates of unbalanced nutrients leading to further nutrient mining. A randomized complete block nutrient omission trial with six replications was therefore set to determine maize response to the application of a wide range of nutrients from inorganic fertilizers on Ferralsols. The treatments were NK, NP, PK, NPK, and NPK + CaMgZnBS. The results showed that application of PK fertilizer resulted in low crop growth rate (CGR), and relative growth rate (RGR), and 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, Urea application recorded the highest yield (1800 kg/ha) followed by Triple Superphosphate (1300 kg/ha) then Muriate of potash (1100 kg/ha) and least by a combined application of secondary nutrients and micronutrients (ZnBMgCaS = 400 kg/ha). Highest agronomic efficiency of 32.5 kg grain /kg P applied was recorded due to P followed by K (27.5 kg grain /kg K) and least by N (15 kg grain /kg N). Based on the combined effect, application of N-P-K based fertilizers could give better yields. Use of micronutrients should be assessed further for conclusive recommendations.

***Keywords*:** Agronomic efficiency, fertilizer application, crop growth rates, maize, micronutrients yield response, nitrogen response, potassium response, phosphorus response, relative growth rate, Maize, *Zea mays*

(Received 29 April 2019; Accepted 16 May 2019; Date of Publication 17 May 2019)

1. INTRODUCTION

Maize (*Zea mays* L.) is a staple food for over 90% of Kenyans with an average consumption per capita of 103 kg/year [1]. The crop is also a key source of income, animal feed and raw material in the oil production [2, 3]. Despite its importance, maize yields are still low at 1.66 t/ha compared to the potential yield range of 6 – 10 t/ha in Western Kenya [4, 5]. Such low yields are partly due to high soil infertility caused by soil nutrient depletion and increased soil acidity [6, 23]. According to Mwangi, Mugendi, and O'Neill [7], small-scale farmers have poor nutrient management strategies as they do not apply adequate fertilizers to replenish the lost nutrients. If not well managed, such low fertilizer rates cannot adequately supply nutrients required for improved maize yields considering the high leaching, soil erosion, nutrient adsorption, and volatilization processes. The growing need for macronutrients is evident as they dictate large yield gap. For example, Kihara and Njoroge [8] reported that the inability of farmers to supply N and P nutrients could result in, respectively, 43 and 50% of yield reduction in western Kenya. Further, less research has been done on the effects of secondary nutrients (Ca, Ma and S) and micronutrients (B and Zn) on maize production in Ferralsols soil type. This is despite their reported significant contribution to growth and yield of maize [9, 10, 11, 12]. Therefore, this trial was carried out to determine the maize response to the application of a wide range of nutrients from inorganic fertilizers on ferralsols in Western Kenya.

2. MATERIALS AND METHODS

2. 1. Site description

The trial was set up at Alupe region in Busia County; located on 34º 07' 28.6" E and 00º 30' 10.1" N with an annual rainfall range of 1100 to 1450 mm and daily mean temperatures of 24 ºC. 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 predominant soil type in the region is of ferralsols with high leaching of nutrients and soil acidity [13]. The area has a bi-modal rainfall pattern, long and short rains season.

2. 2. 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 combinations 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 the rates of 120, 40, 40, 10, 10, 5 and 26.3 kg/ha using urea, triple superphosphate (TSP), muriate of potash (MOP), calcium sulphate, magnesium sulphate, zinc sulphate and borax nutrient, respectively. The trial was set during 2013/2014 short-rains season. Nitrogen was applied in three equal splits (at planting, V_{4}, and V_{10} stages) while the rest of the nutrients were applied at planting [36-40].

2. 3. Data collection

Biomass assessment was done at 30, 60, 90 and 120 (harvest stage) days after emergence (DAE). Dry weights were computed from biomass oven dried at 65 ºC to a constant weight. These weights were then expressed in tons per hectare.

Crop growth rate (CGR) was measured at 30 days interval and computed as described by [14] using the formula: CGR ($gm^{-2}day^{-1}$) = (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 a plant area.

Relative growth rate (RGR) was computed from the dry biomass collected at defined 30 days interval using the formula: RGR ($g\ kg^{-1}\ DM\ d^{-1}$) = (1/W)* (W2-W1)/ (T2-T1).

Grain yield was computed from a 15 m^2 harvest plot after adjusting for grain moisture to 13 ºC. 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).

2. 5. 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 $p \leq 0.05$ [15].

3. RESULTS AND DISCUSSION

Fertilizer application significantly influenced Crop growth rate (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 [Figure 1]. Across fertilizer regimes, maize CGRs were observed to increase and peaked at 60 to 90 DAE then declined towards 90 to 120 DAE. The decline in growth rate with plant age was probably due to the cessation of vegetative growth. A similar trend has been observed by Tajul et al [17].

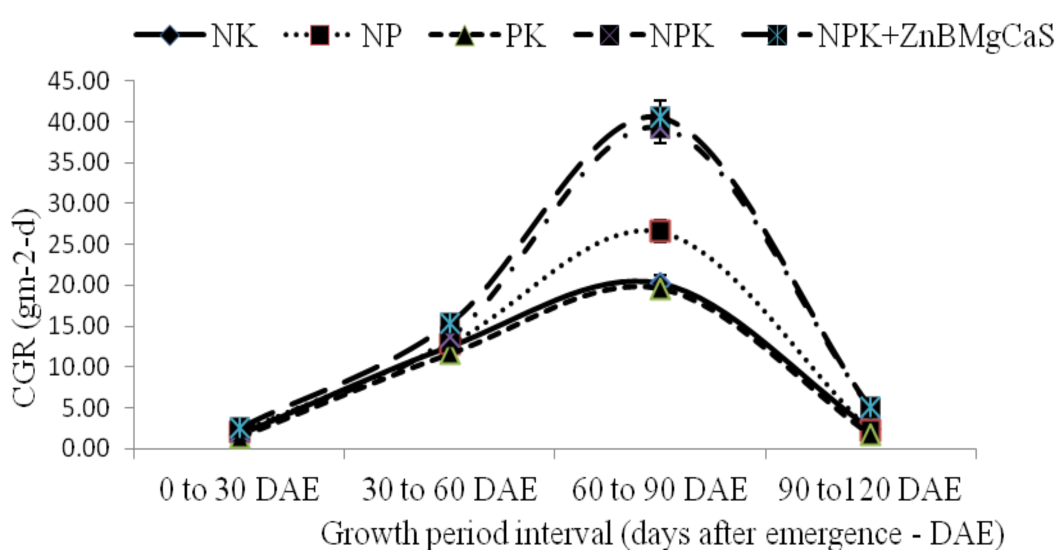

Figure 1. Maize growth rates as affected by various fertilizer regimes at different growth period intervals during the 2014 long-rains growing season at Alupe.

Significantly lower and higher maize relative growth rate (RGR) values were recorded under the application of PK and NPK + CaMgZnBS fertilizer treatments, respectively, than under other treatments at all growth period intervals [Figure 2]. The highest RGR values were recorded at 0 to 30 DAE followed by a decline across the intervals and reached the lowest values at 90 to 120 DAE. This trend is similar to those observed by Tajul et al. when investigating the effect of plant density and nitrogen level on maize [16].

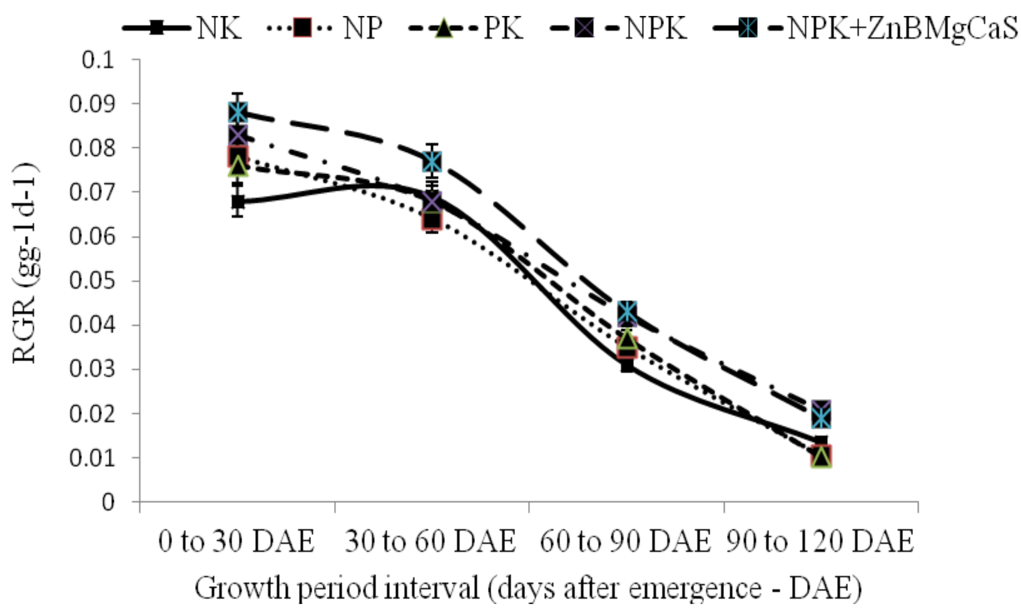

Figure 2. Maize relative growth rates as affected by various fertilizer combinations at different growth period intervals during the 2014 long-rains growing season at Alupe.

Biomass production was significantly influenced ($p < 0.001$) by fertilizer regime application. NPK + CaMgZnBS and NPK treatments recorded similar effects [Figure 3]. These two treatments generally had higher biomass than the other treatments. There were no differences among all fertilizer regimes at 30 DAE and between PK and NK and between NPK and NP fertilizer regimes at 120 DAE [Figure 3]. The lowest biomass values were recorded at 30 DAE which increased and peaked at 90 DAE before decreasing towards 120 DAE.

Grain production and yield response were significantly influenced ($p < 0.01$) by the fertilizer application (Figure 4). The PK fertilizer regime treatment recorded lower yield (2.3 t/ha) than all other treatments [Figure 4]. The NPK + CaMgZnBS treatment out-yielded NPK, NP, NK and PK treatments by 700, 1500, 1700 and 2200 kg/ha, respectively. The difference between NK and NP treatments was non-significant. All the treatments performed better than what farmers are currently getting in the region. And the yield range recorded here is similar to those reported by Tittonell et al. [17].

However, the yields attained were lower than the potential yields (of between 6 and 10 t/ha) of maize reported for the region [18, 19]. This could be due to generally low rainfall received (with very low periods of rainfall occurring during critical growth stages) and high soil acidity (pH = 4.75) reported during this trial.

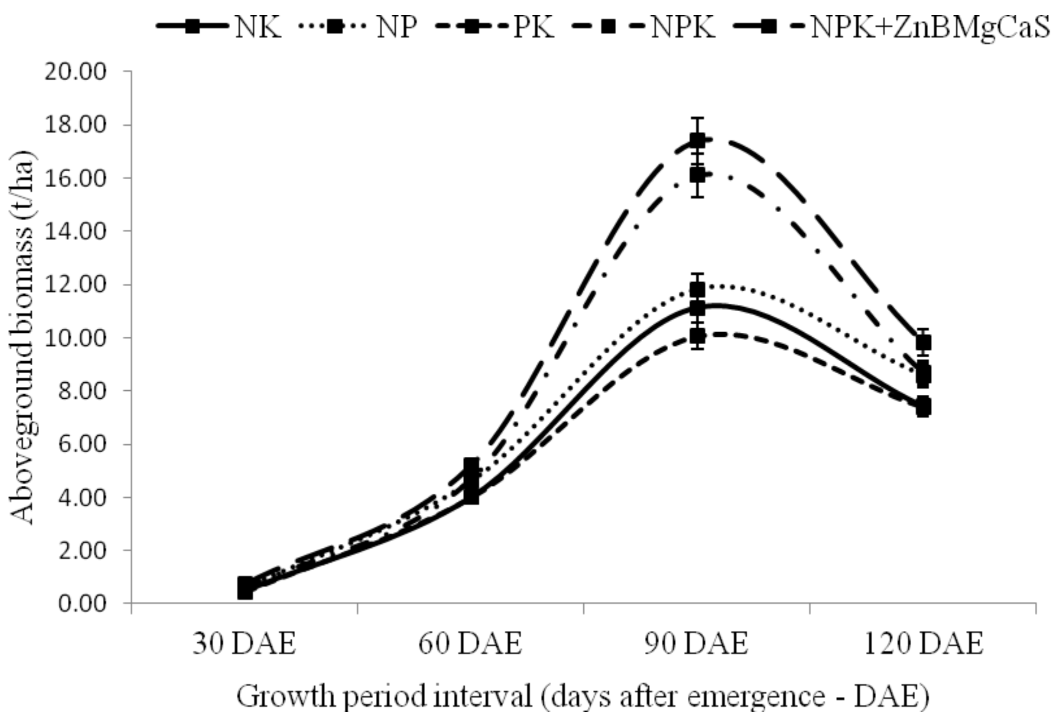

Figure 3. Mean maize biomass production as affected by various fertilizer regimes at different growth period during the 2014 long-rains growing season at Alupe.

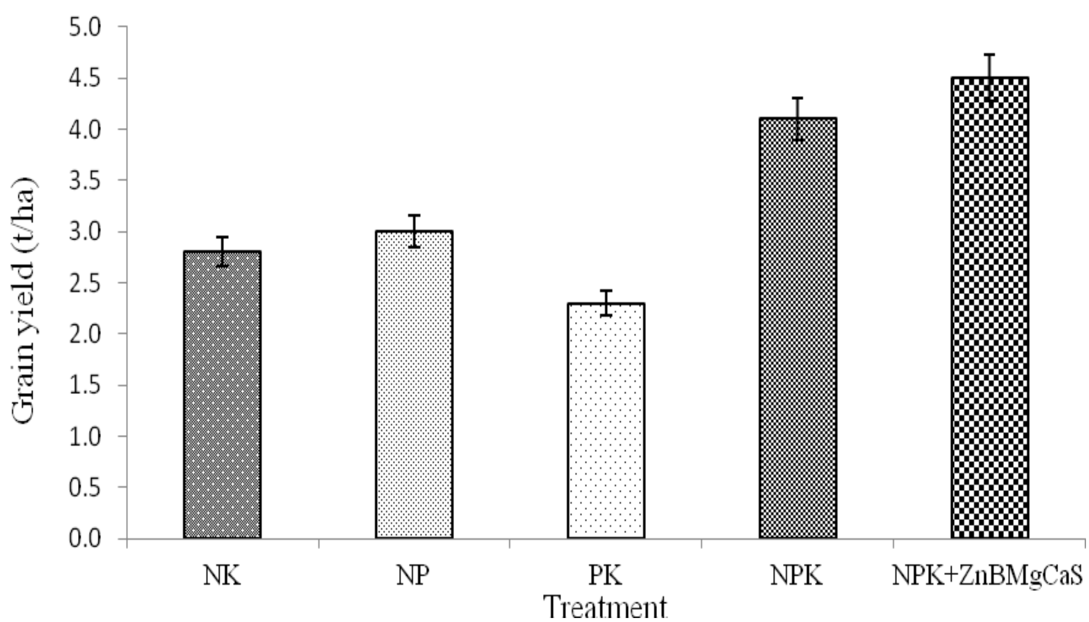

Figure 4. Maize grain yields as affected by various fertilizer regimes during the 2014 long-rains growing season at Alupe.

Other researchers have confirmed this and reported high soil acidity (due to high Al and Fe) to be one of the major constraints to crop production in Western Kenya [20, 21, 22]. Such low soil pH, normally below 5.5, has been found to cause nutrient fixation [23]. Hence, may have reduced the availability of some of the applied nutrients for maize use under this experiment.

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. [24] 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 the 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. 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 and micronutrients (ZnBMgCaS = 400 kg/ha) [Figure 5].

The effects of individual secondary nutrients and micronutrients used in this study could not be separated because of the combined application method used. A similar trend in maize response to N, P and K applications has been reported in western Kenya [25, 26]. The low response due to secondary and micronutrient application reported in this study is in agreement with the recent study by Wortmann and Sones [27] under 'Optimizing Fertilizer Use within the Context of Integrated Soil Fertility Management in Kenya' project. Highest agronomic efficiency recorded as a result of the application of P nutrient compared to other nutrients in this study is in agreement with findings by Ademba et al. and Opala, Kisinyo. and Nyambati in Western Kenya [28, 29].

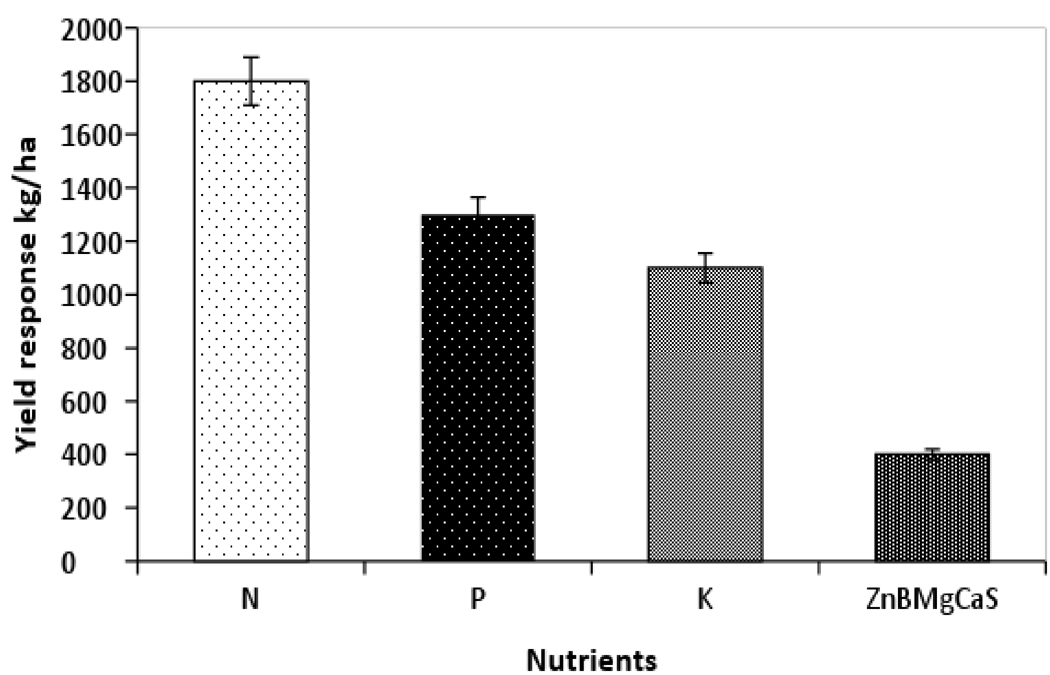

Figure 5. Maize yield responses to the application of N, P, K, and CaMgZnBS nutrients during the 2014 long-rains growing season at Alupe. The secondary macro and trace nutrients were applied together.

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 6). This was observed to increase through 60 DAE and reached a peak at 90 DAE before decreasing towards 120 DAE. At all growth periods, the application of P nutrient recorded highest agronomic efficiencies followed by the application of N nutrient and then K nutrient [Figure 6]. 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). This reported agronomic P efficiency is similar to those reported by Ademba et al. (29-32 kg grain/ kg P) in Western Kenya [28]

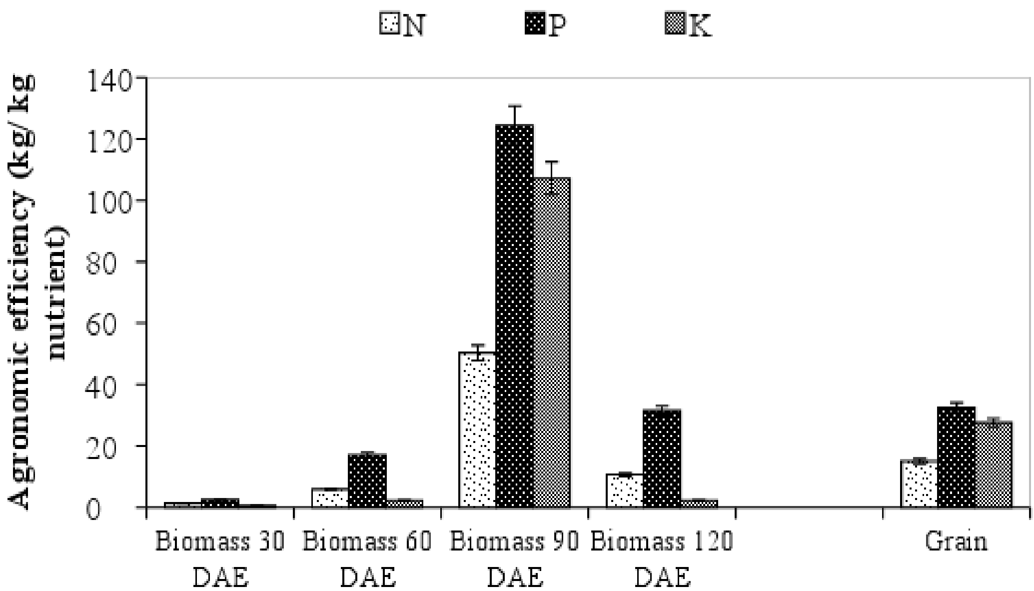

Figure 6. Agronomic efficiencies of N, P and K nutrients on biomass and grain yield production during the 2014 long-rains season at Alupe. Biomass production was considered at 30, 60, 90 and 120 days after emergence (DAE).

The omission of N (PK fertilizer regime) resulted in lower 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 [30, 31, 32].

The omission of P (application NK fertilizer regime) nutrient was also observed to cause a reduction in maize performance in this study. This could have been due to the impaired root development and energy production under inadequate P supply [33, 34].

Similarly, omission of K (application of NP fertilizer regime) nutrient negatively affected maize growth and yield. This could have been due to the impaired movement of water, nutrients and carbohydrates and reduced enzyme activation and other functions under deficient K supply from the soil [35].

4. CONCLUSIONS

From this study, application of a wide range of nutrients could be required for increased maize production compared to the narrower nutrient range combinations. Individually, N is the most limiting nutrient due to its high yield response compared to others in the omission trial. The combined application of secondary and trace nutrients (ZnBMgCaS) recorded the least response which could be due to an adequate supply of such nutrients from the soil reserve. However, the trial did not allow for the identification of individual contributions made by secondary and trace nutrients- maybe one or two played significant roles and worth supplying for maize production. Hence need to be investigated further for a better recommendation. The agronomic efficiency of P was the highest while that of N was lowest when considering the three primary macronutrients.

Acknowledgments

The authors appreciate the financial support offered by International Plant Nutrition Institute (IPNI) and International Maize and Wheat Improvement Center (CIMMYT) and the technical and professional guidance offered by College of Agriculture and Veterinary Sciences, University of Nairobi.

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