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EFFECTS OF INORGANIC FERTILIZER APPLICATION ON GRAIN YIELD, NUTRIENT USE EFFICIENCY AND ECONOMIC RETURNS OF MAIZE IN WESTERN KENYA

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ABSTRACT

Declining soil fertility levels due to application of low rates and unbalanced nutrientsis one of the main causes of low yields in western Kenya. We therefore designed a randomized complete block nutrient omission trialwith six replications to determine the effects of inorganic fertilizers on grain yield, nutrient use efficiency and economic returns 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 short plants, slow crop growth rate (CGR), and relative growth rate (RGR), small leaf area 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 macro and micronutrients (ZnBMgCaS = 400 kg/ha). Highest agronomic efficiency of 32.5 kg grain /kg nutrient applied was recorded due to Pfollowed 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 fertilizerthan 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 yields but was not economical. Therefore, farmers could be encouraged to apply a combination of N, P and K fertilizers only for better return on investment.

Key words: Agronomic efficiency, economic analysis, fertilizer application, growth rates,maize, micronutrients yield response, nitrogen response, potassium response, phosphorus response.

1. Introduction

Maize is a staple food for over 90% of Kenyans with an average consumption per capita of 103 kg/year [1, 2]. Other than being an important source of food, the crop is a key source of income to the smallholder farmers, a source of animal feed and raw material in the oil production [3]. It is estimated that smallholder farmers account for about 80% of the total maize produced in Kenya[4]. Despite the importance of maize, smallholder farmers still record low yields (average of 1.66 t/ha) compared to the potential yield range of 6 – 10 t/ha in Western Kenya [5,6]. Such low yield in the region is partly due to high incidences of pest attack and soil infertility caused by soil nutrient depletion as reported by [7, 8, 9, 10]. According to [11], 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 and unbalanced extension officer to farmers ratio currently at 1: 1000 compared to the recommended ratio of 1: 400 by FAO and World Bank- and dissemination of blanket and obsolete fertilizer recommendations have significantly contributed to the current low fertilizer use and the subsequent low maize yields. 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 fertilizer rates being promoted cannot adequately supply nutrients for improvedmaizeproductivity while at the same time adjusting for inefficienciescaused byleaching, erosion, adsorption andvolatilizationprocesses. The growing need forprimary macronutrients is evident. For example, [12] 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 [13,14, 15,16]. Therefore, astudy was carried out to determine the effects of inorganic fertilizers on grain yield, nutrient use efficiency and economic return of maizein Western Kenya.

2. Materials and Methods

2.1. Site description

The trial was set up atAluperegion in Busia County;located on 34^{0} 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 ^{0}C. 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 [17]. The area has a bi-modal rainfall pattern, wet seasons from March to May (long rains season) and October to December (short rains season).

2.2. Experimental design and treatments

The experiment was arranged in a randomized complete block design withsix replicateseach measuring 8m by 10m. 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 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. Maize variety DK 8031 was used for the trials.

2.3. Agronomic practices

During 2013/2014 short rains season, DK 8031 maize variety was planted to deplete nutrients from the fields. During 2014 long rains season, tilling of land was done a week before the onset of the rains using conventional hand 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, V_4 and V_{10} stages) while the rest of the nutrients were applied at planting. The V_4 and V_{10} are vegetative (V) growth phases of maize when the crop has 4 and 10 visible leaf collars, respectively[18]. The 1st and 2nd weed control activity was done at V_4 and V_{10}, respectively, of maize growth stages using hand hoes. All the plots were harvested at the fourth month after emergence - the maturity stage.

2.4. Data collection

Plant height: Plant heights were recorded at physiological maturity. Ten plants were randomly picked within the plot and their heights measured from the base to the tip of the plant. The average plant heights were recorded in centimetres.

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Plant leaf area index: Maize leaf area indices (LAI) were determined at soft dough stage by taking leaf length and width and computed using the formula: LAI = total plant leaf area (cm^2)/ ground area covered by a plant (cm2) [19].

Biomass assessment: Aboveground 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 ^{0}C to a constant weight. These weights were then expressed in tons per hectare.

Crop growth rate (CGR): The CGR was measured at 30 days interval and computed as described by[20] 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 plant area.

Relative growth rate (RGR): This was computed from the dry biomass collected at defined 30 days interval using [17] 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 13^{0}C.

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 (seeds, fertilizers and pesticide)[21][**Table 1**]. 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 yield. 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 TVC.

Table 1: Summary of economic data collected during maize production as expressed as unit price

Item	Measurement unit	Unit cost ($)
Output		
Maize grain yield	kg	0.45
Maize stover yield	ton	22.47
Inputs		
Labour	Man-day	3.93
Maize DK 8031 seeds	Kg	2.25
Urea	Kg	0.56
Triple super phosphate	Kg	0.9
Muriate of potash	Kg	0.79
Calcium sulphate	Kg	3.37
Magnesium sulphate	Kg	6.74
Zinc sulphate	Kg	0.79
Borax	Kg	5.62

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 $p \leq 0.05$ [22]. Net benefits and benefits to cost ratio were computed to determine the profitability of various fertilizer combinations.

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3. Results

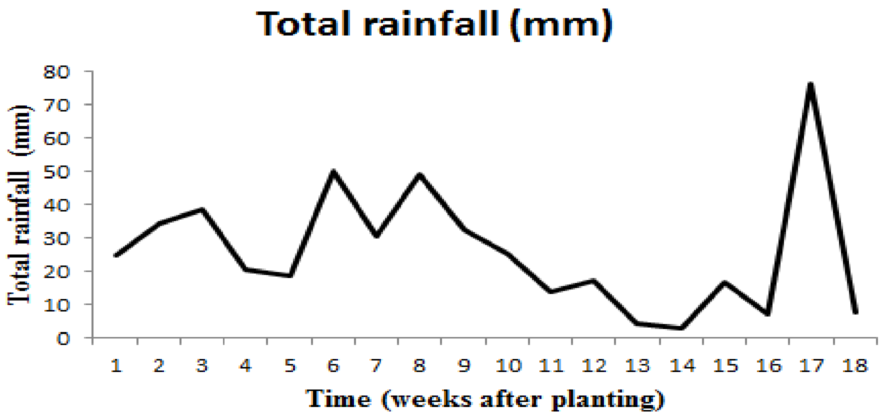

Figure 1: Total rainfall received during the 2014 long rains seasonas recorded at Kenya Agricultural and Livestock Research Organization (KALRO) - Alupe research station in Busia County.The growing periods are expressed in terms of weeksfrom the time of planting to harvesting.

Leaf area index: Fertilizer application significantly influenced ($p < 0.05$) maize leaf area indices[**Figure** 2]. Lower (2.6) and higher (3.8) leaf area indices were recorded under PK and NPK+CaMgZnBS treatments, respectively, than in other treatments[**Figure** 2]. There were no significant differences recorded between NK and NP and between NPK and NPK+CaMgZnBS treatments. Generally, maize LAI responded in the order of NPK+CaMgZnBS>NPK>NP>NK>PK.

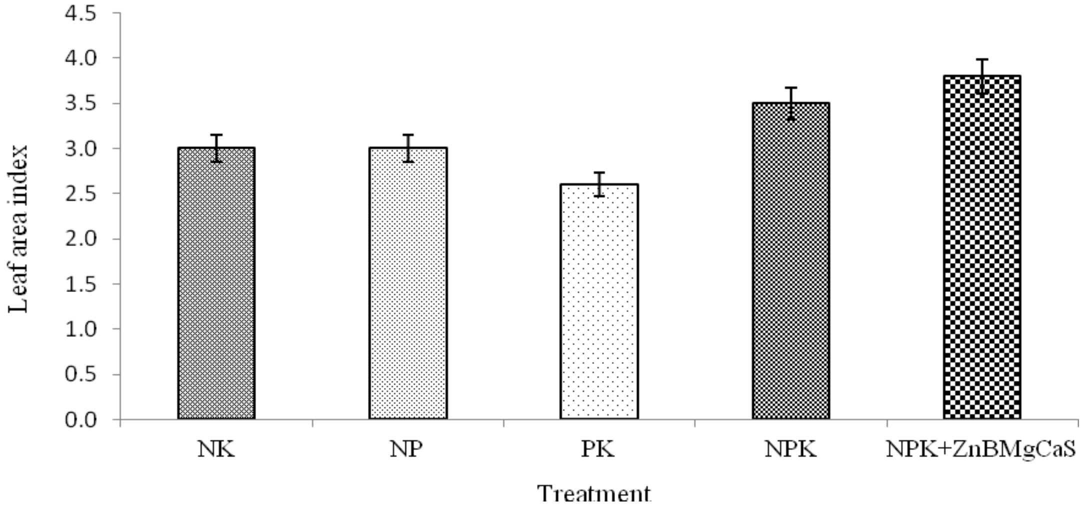

Figure 2: Maizeleaf area indicesas affected by the application of various fertilizer regimes during the 2014 long rains growing season Alupe in Busia County.

Plant height: Fertilizer application significantly influenced ($p < 0.05$) maize plant heights [**Figure** 3]. Maize plants treated with NPK+CaMgZnBS were 13, 35, 42 and 48 cm taller than those treated with NPK, NP, NK and PK fertilizer regimes, respectively. The PK treatment recorded the shortest plants. There were no significant differences between PK and NK and between NK and NP treatments.

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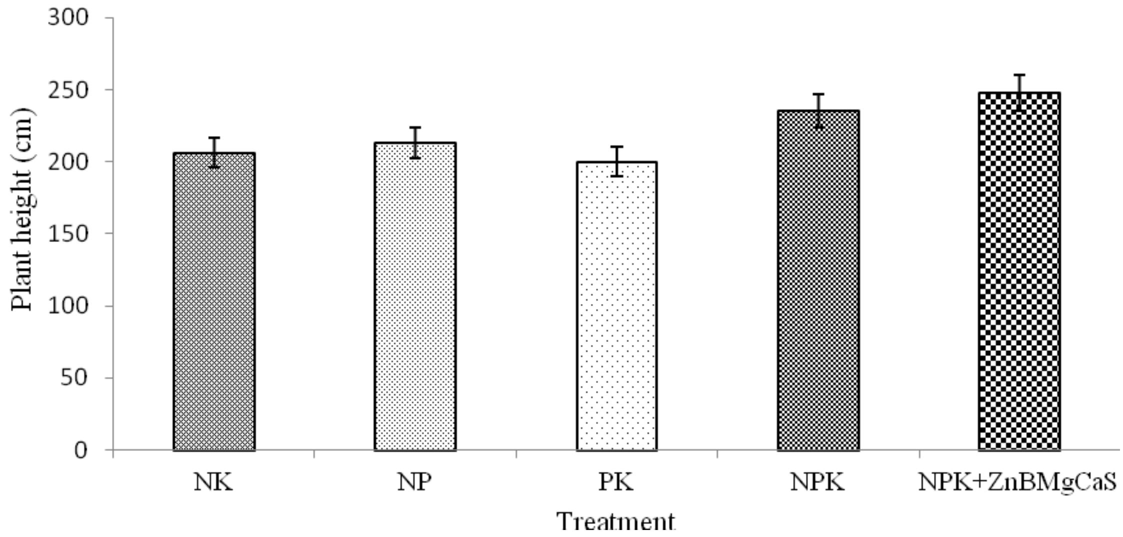

Figure 3: Mean maize plant heightas affected by the application of various fertilizer regimes during the 2014 long rains growing season at Alupe in Busia County.

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[**Figure** 4]. Across fertilizer regimes, maize CGRs were observed to increase and peaked at 60 to 90 DAE then declined towards 90 to 120 DAE.

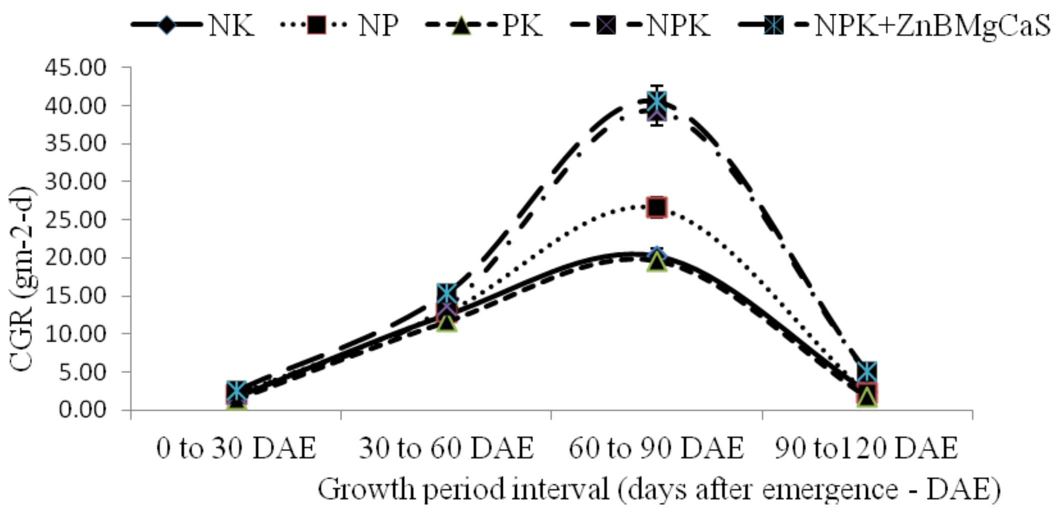

Figure 4: Maize growth ratesas affected by various fertilizer regimes at different growth period intervalsduring the 2014 long rains growing season at Alupe in Busia County.

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[**Figure** 5]. There were no significant differences between NK and NP across all the growth intervals and between NPK+CaMgZnBS and NPK at 60 to 90 DAE and 90 to 120 DAE intervals (**Figure** 5). 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.

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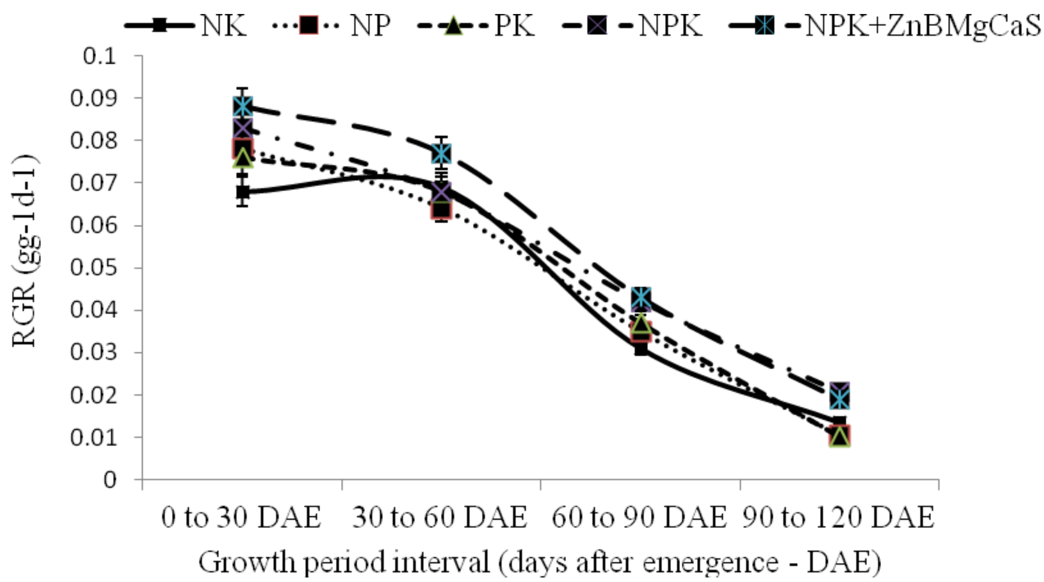

Figure 5: Maize relative growth ratesas affected by various fertilizer regimes at different growth period intervalsduring the 2014 long rains growing season at Alupe in Busia County.

Aboveground biomass: Biomass production was significantly influenced (p< 0.001) by fertilizer regime application. Similar effects were recorded between NPK+CaMgZnBS and NPK treatments[**Figure6**]. These two treatments generally had higher biomassthan 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[**Figure6**]. The lowest biomass values were recorded at 30 DAE which increased and peaked at 90 DAE before decreasing towards 120 DAE.

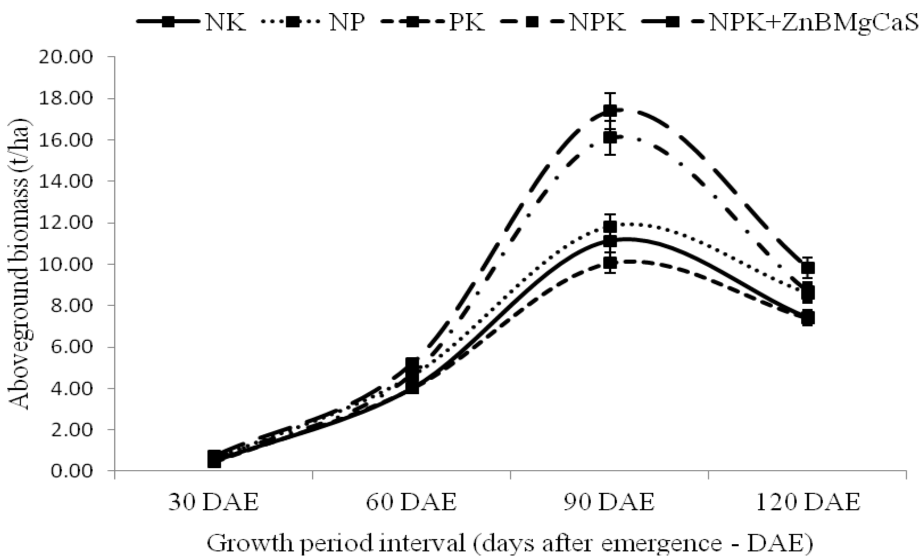

Figure6**:** Mean maize biomass production as affected by various fertilizer regimes at different growth period during the 2014 long rains growing season at Alupe in Busia County.

Grain production and yield response: Grains were significantly influenced (p< 0.01) by the fertilizer regimes (**Figure** 7). The PK fertilizer regime treatment recorded lower yield (2.3 t/ha) than all other

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treatments[**Figure** 7]. 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.

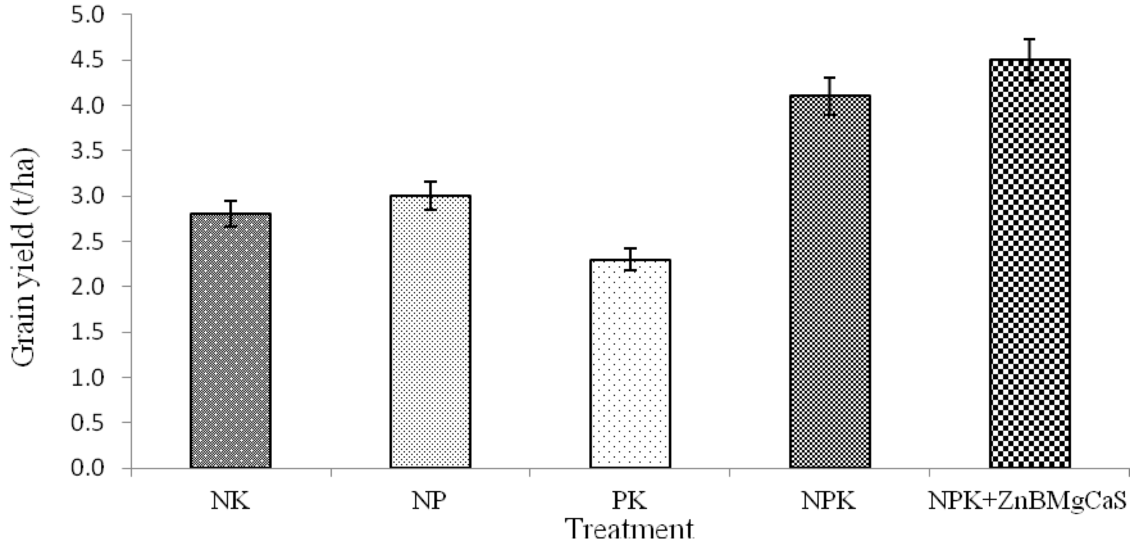

Figure 7: Maize grain yieldsas affected by various fertilizer regimes during the 2014 long rains growing season at Alupe in Busia County.

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 and micronutrients (ZnBMgCaS = 400 kg/ha)[**Figure** 8].

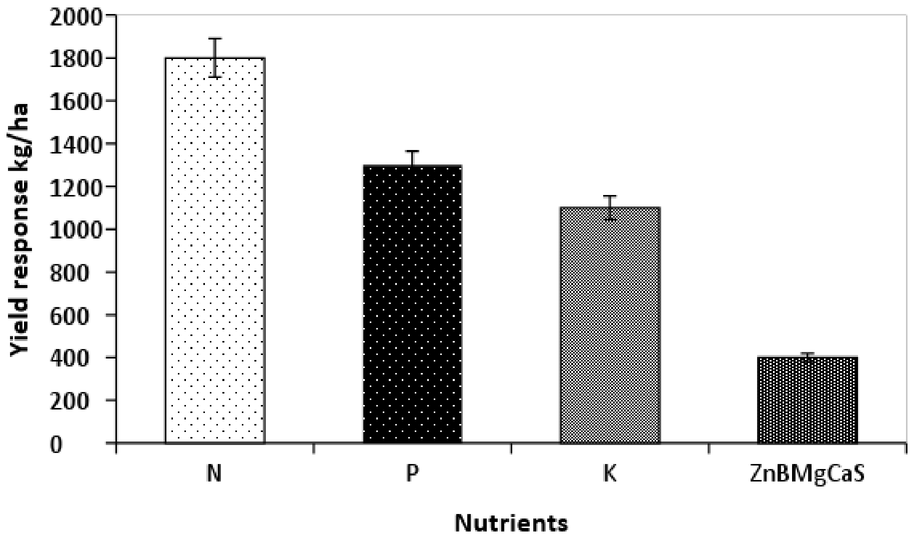

Figure 8: Maize yield responses due to application of N, P, K and CaMgZnBS nutrients during the 2014 long rains growing season at Alupe in Busia County. The secondary macro and trace nutrients were applied together

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** 9). 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. At all growth periods, application of P nutrient recorded highest agronomic

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efficiencies followed by the application of N nutrient and then Knutrient[**Figure** 9]. 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).

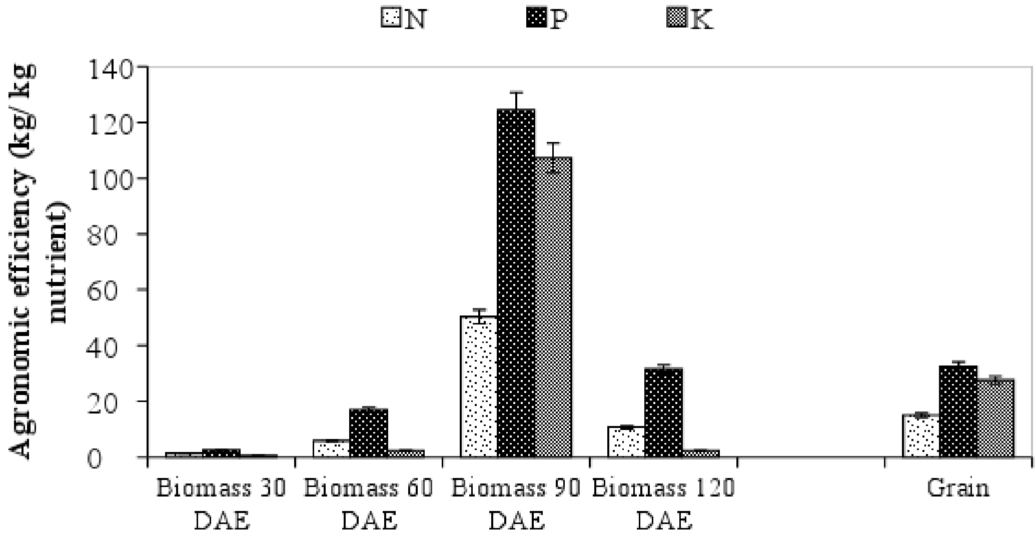

Figure 9: Agronomic efficiencies of N, P and K nutrients on biomass and grain yield production during the 2014 long rains growing season at Alupe in Busia County. Biomass production was considered at 30, 60, 90 and 120 days after emergence (DAE).

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** 2]. 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. 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 benefit to cost ratio was affected by fertilizer regimes - 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** 2]. The NK and NP regimes recorded similar benefit to cost ratio values.

Table 2: 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

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4. Discussion

Application of a wide range of 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 [23, 24]in Western region. This could be due to generally low rainfallreceived (with very low periods of rainfalloccurring during critical growth stages) and high soil acidity (pH = 4.75) reported during this trial. 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 [25,26,27]. Such low soil pH, normally < 5.5, has been found to cause nutrient fixation [28]. Hence, may have reduced the availability of some of the applied nutrients for maize use under this experiment.

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 [29,30,31]. 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 [32, 33]. 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 [30,34]. Combined application of a broad range of nutrientsresulted in high crop yield performance compared to a narrow range of nutrients. This finding issupported by those of [35] 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 lowestyield 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 [36, 37]. 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 [38,39] in Western Kenya.

Economic analysis showed varied effects on both variable costs and revenues due to the application of different fertilizer regimes on maize production. From this study, it was observed that when one combined more nutrients for maize production, the total production costs and revenues increasedwith the highest values observed due to the application of NPK and NPK+ZnBMgCaS regimes. The increase in production costs was due to the additional cost of individual fertilizers and labour constituting their application. 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 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.

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5. 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. 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 adequate supply of such nutrients from the soil reserve. However,the trialdid not allow for the identification of individual contributions made by secondary and trace nutrients. The agronomic efficiency of P was the highest while that of N was lowest when considering the three primary macronutrients. 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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Conflicts of Interest

The authors declare no conflict of interest.

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