Interactive effects of Secondary Macronutrients and Micronutrients on the grain yield, nutrient uptake and use efficiencies of maize in the Guinea Savannas of Nigeria

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Abstract

To close the nutrient-related yield gaps in maize, balanced nutrition using primary and secondary macronutrients as well as micronutrients is recommended. Multi-nutrient diagnostic field trials were conducted in Guinea Savanna of Nigeria to assess the interactive effects of macronutrients and micronutrients on maize grain yields, nutrient uptake as well as N, P and K use efficiencies. The treatments consisted of a control (zero fertilizer applied), an NPK treatment and 10 other treatments in which macronutrient (Mg, S) and/or micronutrients (B, and Zn) were added to the NPK. The experiment was laid out in Randomized Complete Block Design with 3 replications. Data collected were subjected to mixed model with nutrient management strategy as fixed effects while replication nested in location and interaction between location and nutrient management strategy as random effects. The results revealed significant effects ($P<0.05$) of nutrient management strategy on maize yield, nutrient uptake and nutrient use efficiencies of N, P and K. The study revealed that yield advantage over the recommended NPK fertilizer as a result of application macronutrients and micronutrients were highest with Mg in Lere (2.4t ha^{-1}), S + B + Zn in Faskari (2.8t ha^{-1}), S + B in Doguwa (1.5t ha^{-1}) and S + Zn in Toro (2.4t ha^{-1}). Addition of Mg, S and B significantly increases macronutrient uptakes over the recommended NPK only. Agronomic use efficiency, internal utilization efficiency, apparent recovery efficiency and partial factor productivity were significantly increased with the addition of S, Mg, and B but were not improved with Zn application. It was concluded that nutrient limitations to maize in the Guinea Savanna go beyond N, P and K. This study recommends that S, Mg, and B are needed to improve maize productivity and engender improve the use efficiency of NPK fertilizers.

Keywords: Secondary macronutrients, micronutrients, maize, use efficiency, nutrient uptake

1.0 Introduction

Maize (*Zea mays* L.) is the most widely distributed cereal globally; ranking only second to rice among cereals in term of its production [1]. It is one of the grain cereals whose food value and the wide variety of usage makes it one of the world's most important crop in addressing food insecurity, poverty, and malnutrition [2]. It is grown in diverse agro-ecological zones and farming systems of sub-Saharan Africa (SSA) and it accounts for one-fifth of the total calories and protein consumed in West Africa [3]. About 208 million people in SSA depend on maize as a source of food security and economic well-being. It is increasingly becoming a key crop replacing traditional cereals like sorghum and millet [4].

In Nigeria, maize is a strategic staple crop on which many households depend for domestic consumption. Additionally, it provides many industrial uses in flour mills, breweries, confectioneries, and animal feed mills. The bulk of maize production is in the Guinea Savanna of Nigeria where favourable climatic conditions suitable for its production are present. These include the high amount and fair distribution of rainfall, high solar radiation, low night temperature and relatively low disease pressure [5]. Despite the favourable growing conditions, yields obtained by smallholder farmers are far below the attainable yields for most improved varieties and a high yield gap exists between farms. Average farmer yields stood at 2.0 t/ha although actual yields obtained in farmers' fields, could range between 0.5 to 4.0tha^{-1}, depending on how much fertilizer is used [6].

The major reason for this low yields have been attributed to several constraints; such as poor soil fertility and low nutrient availability [7-8]**,** little or no use of improved seeds, herbicides and fertilizer, lack of proper adherence to improved agronomic practices [4]**,** and increased level of abiotic and biotic constraints such as the recent outbreak of fall armyworms [9]. Poor soil fertility and low nutrient availability have been singled out as the most serious biophysical constraints that result in poor yields in SSA countries including [10-12].

In Nigeria, regional blanket fertilizer recommendations have been used as one of the intervention strategies for tackling poor soil fertility and improving crop yields and nutrient use efficiencies. This recommendation focused on three primary nutrients (N, P, and K) as the most limiting in crop production [13]. Although the use of the current fertilizer recommendation has increased crop yields, it has been established that it may have also accelerated the depletion of other nutrients not supplied leading to nutrient deficiencies and imbalances. Indiscriminate use of these unbalanced NPK aggravates micronutrients disorders which act additively along with biotic and abiotic stresses to limit crop productivity [14]. Indeed, part of the reasons why attainable yields are rarely attained despite NPK applications may be due limitations of other nutrients [15]. Similarly, strong indications that other nutrients (in addition to N, P and K) constrain maize production in SSA countries have been reported [16-18]. Such nutrients include secondary macronutrient such as sulphur [17, 19] some micronutrients such as Zinc, Boron, Copper, Iron, and Molybdenum [20-24].

Recently, several studies have shown the need to revisit the current understanding of crop nutrients need and fertilizer recommendation programs under the current crop intensification systems. For example, Shehu et al. [18] using diagnostic nutrient omission trials in the Northern Guinea and Sudan Savannas of Nigeria highlighted the need for more diagnostic trials involving the omission of secondary macronutrients and micronutrients to understand their distinctive role in limiting maize yield and the link with underlying soil characteristics. Recently reported by Kihara *et al.* [17] in a meta-analysis reported that secondary nutrients such as S and micronutrients like Zn and B are holding back crop productivity especially in soils with low response to macronutrients and that more research is needed to unravel the conditions under which application of secondary macro and micronutrients could improve crop yields. This study was set up with the following objectives; (1) Analyze the interactive effect of secondary macro and micronutrients on grain yield and nutrient uptake of maize in the Guinea Savanna and (2) Quantify maize response to nutrients and nutrient use efficiency in the Guinea Savanna of Nigeria.

2.0 Materials and Methods

2.1 Site Selection and description

Multi-nutrient omission trials (MNOT) were conducted across 12 sites in the Guinea Savanna of Nigeria (GS). The sites cut across 4 states (Katsina, Kano, Kaduna, and Bauchi). In each state, a representative farming domain was selected based on the intensity of maize production, the similarity in soil base and farmer resource endowment. Three sites were randomly selected and on-farm researcher-managed trials were established during the 2017 rainy season. The GS is considered the maize belt of Nigeria as it produces more than one-third of the cereals in Nigeria (IITA, 2014). The agroecology covers about 27.84 Million hectares of land in Nigeria. Annual rainfall in this zone ranges between 850-1500mm and the length of the growing season is between 120 to 200 days. Soils in this area are mainly luvisols, acrisols, ferralsols and lithosols and are dominated by low activity clays (LAC). Figure 1 is the map showing the sites where the trials were conducted.

2.2 Experimental treatments and field procedures

The trials consisted of twelve treatments which were arranged in a Randomized Complete Block Design with three replicates, on plot sizes of 6m x 5m. The description of each treatment is shown in Table 1. The maize was planted at 0.75 m inter-row spacing and 0.25 m intra-row spacing, using two seeds per planting hole. At two weeks after emergence, the plants were thinned to one plant per stand, resulting in a uniform plant density of 53,333 plants ha^{-1}. The variety used was IWD-C2-SYN (SAMMAZ 15) which is recommended for this agroecology. IWD-C2-SYN is an intermediate maturing, white dent open-pollinated variety with yield potential of 10t/ha. The nutrients were applied as follows; primary macronutrients were applied at 140 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}, secondary macronutrients and micronutrients in all the sites were applied at 20 kg S ha^{-1}, 10 kg Mg ha^{-1}, 5 kg Zn ha^{-1} and 5 kg B ha^{-1}. Nitrogen (N) was applied in 3 splits; a quarter at planting together will all other nutrients, and the other two equal quarters at 21 and 42 days after sowing (DAS). N, P, and K were applied in form of urea (46%N), triple superphosphate (20%P_2O_5) and muriate of potash

(60% K_2O), respectively. Sulphate of magnesium and zinc were used as the sources of Mg and Zn and Sulphur. Elemental Sulphur was also used to augment the balance of Sulphur in magnesium and zinc sulphate. Borax was used as the source of Boron. The experimental fields were kept weed-free using the integrated approach of pre-emergence herbicides and manual hoe weeding.

2.3 Soil characterization and laboratory analyses

Before the trial establishment, soil samples were taken from each experimental site and analyzed for initial nutrient status. The soil samples were collected using auger from at least five points in a W-shape to have a representative sampling. The samples were taken from 0-20cm from each plot and then bulked together and passed through 2 mm sieve to form a composite sample. The composite samples were prepared using standard procedures and analyzed for physical and chemical properties using wet chemistry. Total organic carbon was measured using modified Walkley-Black chromic wet chemical oxidation and spectrophotometric method [26]. Total nitrogen (total N) was determined using the micro-Kjeldahl digestion method [27]. Soil pH in water was measured using the glass electrode pH meter and particle size distribution using the hydrometer method [28]. Available Phosphorus, available Sulphur, exchangeable cations (K, Ca, Mg and Na) and micronutrients (Cu, Mn, Fe and Zn) were analyzed based on Mehlich 3 extraction procedure [29] and reading with inductively coupled plasma optical emission spectroscopy (ICP-OECS). Exchangeable acidity ($H^+ + Al^{3+}$) was determined by shaking soil with 1N KCl and titration with 0.5N NaOH [30]. Effective cation exchange capacity (ECEC) was calculated as the summation of exchangeable cations (K, Ca, Mg and Na) and exchangeable acidity ($H^+ + Al^{3+}$). All the laboratory analyses were carried out at Analytical Services Laboratory of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

2.4 Maize Yields and Nutrient Uptake

At physiological maturity, plants were harvested from a net plot of 9 m^2 from the four central rows. All the plants in the net plot were harvested and the total fresh weights of cobs and stover were taken in the field using a sensitive digital scale. Ten cobs were randomly selected as subsamples and they were dried over 8 days and then shelled. Thereafter, yield was determined as a function of grain weight, shelling percentage, and measured grain moisture. Grain yield was finally expressed on a dry weight basis at 15.0% moisture content. Five stover sub-sample also were taken from thoroughly mixed plants from the net plot, and then dried in a large forced air oven at 60°C for 48 hours, after which stover dry weights were determined. Subsamples of grain and stover were ground to 2 mm and digested using a nitric acid and 50% hydrogen peroxide mixture to determine N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn. These ground and digested samples were analyzed in the laboratory using standard methods [30].

2.5 Statistical Analyses

Soil physical and chemical properties were subjected to descriptive statistics to provide the estimate of the mean, standard error and coefficient of variation (CV) values at location level using JMP® Pro Version 14.0 (SAS Institute Inc., 2018). Variation in soil properties was assessed using the CV values and rated as low (<20%), moderate (20-50%) and high (>50%) according to [31].

Nutrient management strategy effects on maize grain yields and nutrient uptake were examined using a mixed model with nutrient management strategy as fixed effects while replication nested in location and interaction between location and nutrient management strategy as random effects. In addition, the yield difference of each of the nutrient management strategy relative to the check treatment (NPK) was explored to assess yield gain/loss when a nutrient was omitted or applied across the four locations.

To calculate the nutrient use efficiencies of maize, the following parameters were estimated using the following equations as described by [32];

Agronomic use efficiency (AE) of applied nutrient (kg yield increase per kg of nutrient applied

$$AE(kg/kg) = \frac{Y-Y_O}{F} \qquad [1]$$

Apparent crop recovery efficiency (RE) of applied nutrient (kg increase in N uptake per kg N applied) as

$$RE(kg/kg) = \frac{U-U_O}{F} \qquad [2]$$

Internal utilization efficiency (IE) of a nutrient (kg yield per kg nutrient uptake)

$$IE\ (kg/kg) = \frac{Y}{U} \qquad [3]$$

Partial factor productivity (PFP) of applied nutrient (kg harvested product per kg nutrient applied)

$$PFP = \frac{Y}{F} = \frac{Y_O}{F} + \text{AE} \qquad [4]$$

Where,
U = Total plant nutrient uptake in aboveground biomass at maturity (kg/ha) in a plot that received fertilizer
U_O = total nutrient uptake in aboveground biomass at maturity (kg/ha) in the control plot
Y = maize yield with applied nutrients (kg/ha)
Y_O = maize yield (kg/ha) in a control treatment
F = amount of nutrient applied (kg/ha)

3.0 Results

3.1 Soil Physical and Chemical Properties of the Study Area

Wide to moderate variability in soil physical and chemical properties were observed across the study areas. Soil particle distribution showed wide variability with the sand having the highest fraction in all the study locations (Table 2). Soil pH had low variability (CV<10%) with mean values ranging from 5.4-6.1. Mean total N ranges from 0.36 to 0.42 g kg^{-1} with the highest in Toro and lowest in Doguwa. Available S varied moderately across sites with mean values ranging from 3.67-5.86 mg kg^{-1} and the highest value in Faskari and the lowest in Doguwa. The mean available P ranged between 5.84 and 18.12 mg kg^{-1} with the highest values in Toro and the lowest in Lere. The total organic carbon content varied widely across the study sites (CV>30%) and was highest in Doguwa (3.60 g kg^{-1}) and lowest in Faskari (1.30g kg^{-1}). The mean soil Mg was generally high in all the four locations. Mean values for exchangeable Na and K showed moderate variability with mean values ranging from 0.27-0.37 cmol^{+}kg^{-1} and 0.32-0.49 cmol^{+}kg^{-1} for Na and K, respectively. Sites in Toro had the highest Mg and exchangeable acidity (1.74 and 0.01 cmol^{+}kg^{-1}, respectively). The concentration of Ca and ECEC were highest in Doguwa with mean values ranging from 1.07-2.95 and 2.35-5.09 cmol^{+} kg^{-1} for ECEC; while for exchangeable acidity (EA), it was from 0.00 to 0.001 cmol^{+}kg^{-1}. Mean Cu concentration was highest in Faskari (2.55 mg kg^{-1}) and lowest in Lere (1.07 mg kg^{-1}). Among the locations, mean available Mn and Fe were highest in Lere (57.31 and 125.28 mg kg^{-1}, respectively) while For Zn, the concentration was highest in Doguwa (16.01 mg kg^{-1}).

3.2 Effects of Nutrient Management Strategy on Maize Grain Yield

The variance components and percent contributions of the random terms specify in the model are presented in Table 3. The lowest percent contribution on maize yield and N uptake was from replication nested within location (4.3% and 2.6%, respectively). The unexplained variability in macronutrients and micronutrients was due to noise (residual) with percent contribution for all the variables >50%. Highest variance and percent contribution on maize yield was from the interaction between location and treatment effects (46%). The location effects on all the nutrient uptakes were generally 5% which indicates that any difference or variability observed with nutrient uptake was not majorly due to location effects but possibly due to treatment effects. Overall, the noise variance components were high for all the variables.

Table 4 shows the effects of nutrient management strategies on maize grain yield and nutrient uptakes in the Guinea Savanna of Nigeria. Maize grain yield was significantly ($P<0.001$) influenced by nutrient management strategy. In all cases, the addition of macronutrients and/or micronutrients led to about 4-fold increase in grain and stover yield relative to the control. The treatment NPK + Mg produced the highest grain yield (5.72t ha^{-1}) followed by NPK + S + B + Zn (5.65t ha^{-1}). Lowest grain yield was produced by the control treatment (0.42t ha^{-1}) followed by the NPK + Zn (3.88t ha^{-1}). Other treatments did not differ significantly from each other. Generally, treatments that contained NPK + S consistently had yields that ranked in the highest yielding group. Addition of Zn to NPK did not appreciably influence maize grain yields over the check treatment (NPK).

3.3 Relative Maize Grain Yield Response to Nutrient Management Strategies

Figures 2 show the interactive effect of the addition of nutrients on maize grain yield across four locations in the Guinea Savanna of Nigeria. There was a wide variation among the locations in terms of loss or gain in grain yield resulting from the addition of single macro and micronutrients or a combination of both nutrients. Addition of secondary macronutrients generally led to a positive yield advantage over recommended NPK. Yield gains due to sulphur application relative to the recommended NPK was highest in Lere (1.8t ha^{-1}) and lowest in Toro (0.1t ha^{-1}). In the case of Mg, highest yield increment over recommended NPK alone was observed in Faskari (2.5t ha^{-1}). Generally, treatments that contained +Mg had consistently higher yields than other treatments.

Addition of B showed a variable response across locations, in Toro and Lere, yield gains of 0.4 and 1.4t ha^{-1} were observed. In Doguwa and Faskari however, a reduction in yield was observed with the addition of B (0.1t ha^{-1}). A similar response was observed with the addition of Zn where a negative yield response (yield reduction of 0.6 and 0.8t ha^{-1}) was recorded in Doguwa and Lere respectively. When either secondary macro or micronutrients are used in combination, a general yield gain was recorded in all locations except in Doguwa where an addition of S+ B + Zn + Mg resulted in a yield reduction of 0.5t ha^{-1}. Highest yield gains were observed with the addition of S+B in Doguwa (1.58t ha^{-1}), S + B + Zn in Faskari (2.8t ha^{-1}), Mg in Lere (2.48t ha^{-1}) and S + Zn in Toro (2.08t ha^{-1}).

3.4 Nutrients Uptake and Use Efficiencies

Nutrient management strategies had a positive significant effect on total N, P, K, Ca, Mg, Cu, Fe, and Mn uptakes but did not significantly influence Zn uptake ($P>0.05$) as presented in Table 4. The control treatment had the lowest total uptakes of all the nutrients. Highest N, P, K, Ca and Mg uptakes were recorded for NPK+Mg treatment (128 kg ha^{-1}, 17 kg ha^{-1}, 34 kg ha^{-1}, and 24kg ha^{-1}, respectively). The total Cu uptake was highest for NPK + S + B (1.57kg ha^{-1}) while total Fe uptake was highest for NPK + S + B+ Zn (0.34 kg ha^{-1}).

Addition of secondary macro and/or micronutrients generally increases N, P and K use efficiencies (Figure 3). Mean agronomic N use efficiency (AEN) ranges from 21.4 to 34.6 kg grain per kg N applied with the highest value observed in NPK + S + B + Mg plots and the least for NPK + Zn plots. Application of Zn alone to NPK did not increase AEN beyond that observed in NPK only plots as mean AEN of NPK + Zn was less than that of NPK only. A similar trend was observed with P and K agronomic use efficiencies (AEP and AEK). The internal N utilization efficiency (IEN) was highest for NPK and lowest for NPK +Zn. An opposite trend was observed in the case of IEP were highest values were recorded for NPK + Zn and lowest for NPK. IEK was highest for NPK + S +Zn and lowest for NPK + S + B + Zn + Mg. The IEP were mostly lower than IEN and IEK. The results further revealed that highest mean N apparent recovery efficiency (REN) was highest for NPK + Mg and lowest for NPK +

Zn whereas REP was highest for NPK + S and lowest for NPK + Zn. REN was consistently higher than REP and REK. Mean PFP was consistently higher for P than N and K. PFP-N was highest for NPK + S + B + Zn and lowest for NPK + Zn. Similar trends were observed with P and K. Application of secondary macronutrients and/or micronutrients increase N, P and K use efficiencies beyond those observed with recommended NPK with the exception of NPK + Zn. All treatments with +Zn have consistently lower nutrient use efficiencies compare to other treatment combinations.

4.0 Discussion

4.1 Variation in Soil Physical and Chemical Properties

Most soil physical and chemical properties showed moderate to wide spatial variability across the study sites. Soil pH shows moderate variability with slightly acidic pH in Faskari, moderately acidic in Toro and Doguwa and strongly acidic reaction in Lere using the ratings of Black [33]. The strongly acidic pH in Lere implies low P availability. All the sites have pH and exchangeable acidity within the range considered optimum for most crop growth and development. Mean values of total N and organic carbon in the soils fell within low fertility status as suggested by [34]. The low total N, ECEC, and total C in all the sites could be due to the fact that Savannahs are known to be inherently low in fertility partly because they have low nutrient reserves and as a result of the removal of crop residues at harvest without returning them [35]. Several studies have reported similar findings [36-38]. The soils in Doguwa and Faskari had low available P while those in Lere and Toro have medium available P using classification of [34]. Mean available S fell within low fertility class in Toro and Doguwa while in Lere and Faskari, they were within the medium class as suggested by the classification of [38]. In Lere and Faskari where mean available S was medium may be due to historic residual S applied through S-containing fertilizers such as SSP for other crops in the fields. High exchangeable K content was observed in all the four locations while for exchangeable Na, the mean soil content was medium in all the study sites according to the classification suggested by [34]. The moderate to high K content in all the sites could be due to residual effects of historic K application through NPK fertilizers. Exchangeable Ca fell within medium fertility class in Doguwa and Faskari and low fertility class in Toro and Lere while exchangeable Mg was medium across all the sites. Available Fe and Zn were within high fertility class in all the sites except for Zn in Faskari which fell within the low fertility category using classification of [34]. The concentration of Cu varied widely and was low in Toro and Lere and medium in Doguwa and Toro. Very high Mn concentration was observed in all the sites. The low Cu concentration in Lere and Toro, and low Zn in Faskari indicates the potential development of their deficiencies in those areas and this could partly be attributed to their strong sorption capacity and due to nutrient mining through a historic application of NPK only [21]. In addition, the soils in those sites have a high sand fraction and are generally sandy in texture, sandy soils are known to be highly prone to nutrient leaching due to low water and nutrient holding capacity. Sandy soils and highly leached soils generally have low available Zn and organic carbon [39]. Camberato and Maloney [40] also reported that soils that exhibit low OC and high P levels tend to be deficient in Zn.

4.2 Nutrient Uptake and Use Efficiencies

Across all nutrient management strategies, there were differences in the total uptake of both macronutrients and micronutrients. Previous studies reported significant effects of mineral fertilizers on nutrients uptake and accumulation and consequently crop yields [41]. N and P uptakes tended to be highest. Iron uptake and its availability to plants depend on several soil properties such as pH. In Doguwa and Toro where pH is moderately acidic, they tend to have low Fe uptake. Djalovic *et al* [42] also suggested that organic matter content in the soil mediate Cu uptake in crops and the low total organic carbon in the study areas could be the reason for low uptake of the micronutrients.

Addition of secondary macronutrients and/or micronutrients enhances agronomic use efficiency of N, P and K. Agronomic use efficiency reflect the overall efficiency with an applied nutrient and is used as an indicator of the plant's ability to increase grain yield in response to an applied nutrient. N, P and K use efficiencies were highest with NPK + Mg treatment. These findings are in conformity with the results of previous studies who reported that adequate soil Mg exhibit favourable effects on N use efficiency [43-44]. Dalovic *et al* [42] further explained that Mg assists the crop to access and utilize N and called the phenomenon Mg-induced N uptake. Magnesium is mainly transported in the plant by mass flow, any abiotic stress such as moisture stress could inhibit its uptake. The low N use efficiency observed with other treatments could be due to imbalanced NPK fertilizer practices which could lead to low N agronomic use efficiency and apparent recovery efficiency. The agronomic use efficiency, internal utilization efficiency, and apparent recovery efficiency have frequently been used to characterize the nutrient effects [45-47, 32]. Other studies have acknowledged that the application of micronutrients is known to also increase the use efficiency of macronutrients [16] and also enhances higher macronutrients apparent recoveries [48].

The observed enhanced use efficiencies of N, P and K due to the addition of secondary macronutrients and/or micronutrients is in conformity with the observation of [49] who suggested that for better crop yields, a wider range of nutrients other than NPK may be necessary to provide better-balanced nutrient supply through improved agronomic efficiency of the NPK and engender nutrient use efficiencies in some soils.

4.3 Maize Response to Secondary Macronutrients and Micronutrients Application

There was a wide variation in the response of maize grain yield to the addition of a single macronutrient or micronutrient or when either is used in combination as indicated by gain or loss in grain yield. This indicates the wide diversity and heterogeneity in soil and maize growing conditions in the study areas. Other studies have also reported a high degree of variability in crop response to nutrients that are associated with variability in soil characteristics within and across sites in sub-Saharan Africa [18,17,50,51]. Kihara *et al.* [50] have indicated that crop production constraints vary considerably even within sites and that addressing limitations in secondary and micronutrients and increasing soil carbon can improve crop responses to fertilizers.

The addition of secondary macronutrient (S and/or Mg) to NPK led to over 1t ha^{-1} increase in grain yield compared to NPK only. This finding is in conformity with the result from a meta-analysis by [17] who reported that application of S or micronutrients resulted in a 0.84t ha^{-1} increase in grain yield compared to NPK only in several SSA countries including Nigeria. This represents 25% yield increment over the values obtained using recommended NPK fertilizers. In case of Mg, higher gains in grain yield more than that with S were obtained in all the four locations with the highest gain of about 2t ha^{-1} observed in Faskari. In an experiment in southwestern Nigeria, [20] reported that application of 12.5kg ha^{-1} of Mg increases grain yield of QPM by 18.8% than NPK only for a single cropping season but had no significant effect when averaged for three seasons. In a 3 years maize field trial by [52], it was reported that magnesium applied as magnesium sulphate led to grain yield gain of 16.5% relative to NPK only. Jones and Huber [53] reported that when Mg was applied in addition to NPK, it enhances yield only condition of lower N rate. This phenomenon can be related to the physiological function of Mg^{2+}, which is responsible for nitrate anions uptake by plant roots from the soil solution.

Like with secondary macronutrients, variable response to micronutrients was observed in all the four locations. Where the responses to micronutrients are positive, it indicates that these nutrients are limiting crop productivity, and such may be more profound in areas with low response to macronutrient [17]. Micronutrients are could also limit maize growth and especially in soils that are continuously cropped without returning these nutrients [16]. Zinc has been recognized as the most critical micronutrient limiting crop productivity worldwide because of its role in protein synthesis, and its catalytic action in the metabolism of protein, structure, and function of membranes, expression of genes and oxidative stress tolerance [54]. Several researches have shown yield advantage with Zn application, for example; Ehsanullah (2015) in an experiment conducted in Pakistan reported that Zn application significantly increases maize grain yield and other traits such as plant height and seed weight. Kihara *et al.* (2017) also reported yield increment of 15% due to Zn application over NPK in several countries of SSA.

In Doguwa and Lere locations, there was a yield loss with Zn application and this could be because, in these locations, the soils have a substantial amount of Zn above the critical level such that additional application of Zn would have decimated the grain yield. Previous studies in the sites in the Guinea Savannah have reported the sufficiency of Zn in some of the soils. [56], reported that Zn and B are already in sufficient quantity in the Gongola Basin of the Guinea Savannah of Nigeria.

Previous studies have also hinted at the need to include micronutrients and secondary macronutrients in maize fertilization programme for achieving attainable yields through balanced crop nutrition [49, 57]. Chianu *et al.* [49] also showed that part of the reasons why yield potential for improved varieties are rarely achieved despite NPK application could be due to other nutrients limitations because of accelerated nutrient depletions not supplied through NPK fertilizers [15]. Similarly, many soils become deficient in secondary macronutrients and micronutrients when NPK status is restored [58-60]. These together with other reasons such as management, amount and distribution of rainfall during the experimental period could have been the reasons why the application of secondary macronutrients and micronutrients performed better relative to NPK in terms of yield in all the locations except for the combined application of S, Mg, Zn and B in Doguwa.

According to [17], the response of crops to nutrients including micronutrients depends on among other factors (e.g. soil acidity, and nutrient interactions), the level of crop available nutrients in the soil. For example, the response of maize to Zn is low under high P levels as there is an antagonistic interaction between high P levels and Zn. Soils in Doguwa and Lere have high sand content and generally have sandy to sandy loam texture. This type of soil just like highly leached acid soils generally have low crop available Zn [60]. Similarly, such type of soils is prone to nutrient leaching due to poor water and nutrient holding capacity. These features could be part of the reasons why there was a negative response to Zn in those locations.

Most researches in SSA investigated SMNs singly but results from this study suggest that multiple effects are also common. Vanlauwe *et al*. [16] also hinted that multiple rather than individual deficiency are the norms in most part of SSA. Similarly, nutrient interaction influences crop yield as many secondary macronutrients and micronutrients are interrelated in their metabolic functions and uses similar rhizosphere transporters and could, therefore, have an antagonistic or additive relationship [60]. Application of S, Mg, Zn, and B together with NPK, led to a yield gain of more than 1t ha^{-1} in all the locations except in Doguwa. This is similar to the finding of [16] who reported that supplementation by S, Zn and B increases maize yield by 40% over standard NPK recommendation in certain SSA countries. In a nutrient omission trial in Mozambique, application of Mg, S, Zn, and B lead to 1.3t ha^{-1} more yield than NPK only. Similarly, In Ethiopia, with balanced NPK across 9 sites, yields were 3t ha^{-1} but with S, Mg, Zn, and B supplementation, the yield of 4.2t ha^{-1} was observed [16].

5.0 Conclusion

Maize productivity can be increased in the guinea Savanna of Nigeria when nutrient limitations and imbalances are appropriately addressed through revising the current fertilizer recommendation programmes to include other nutrients that are critical to improve crop yields and use efficiencies of NPK fertilizers. There was a high variability in maize response to secondary macronutrients and micronutrients in the guinea Savanna of Nigeria. Application of Mg in Lere resulted in about 2.5t ha^{-1} more grain yield compared to the recommended NPK fertilizer, indicating a 36% yield increment. This study further revealed that in Faskari, the addition of S+B led to yield advantage of 25% over recommended NPK while in Doguwa, about 40% yield gain was achieved with the application of S + B + Zn. When S + Zn was applied to the NPK in Toro, yield increment of 34% over NPK only was realized. These varied responses indicate that attention should also be giving to these nutrients (Mg, S, S + Zn and S + B + Zn) that produced higher grain yield relative to the check (NPK). Similarly, more researches in to understanding the interactive effective of secondary macronutrients and micronutrients on different maize genotypes, other high value crops, agro-ecologies and other conditions are needed to provide a more in-depth basis for evaluating the agronomic and economic efficiency of revising current soil fertility management options, based on which recommendations for improved soil management could be rooted.

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7.0 Reference

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Table 1: Description of the Treatments for the Study

Code	Treatment	Description
T1	Control	No fertilizer application. Used to measure grain yield as an indicator of the effective indigenous N, P, K, S, Zn, Mg and B supply from soil, rainwater, crop residue and or atmosphere.
T2	NPK	N, P, and K applied at the recommended rate (FFD, 2012). Used to estimate the nutrient-limited yield gap and evaluate agronomic use efficiencies of N, P, and K. This treatment served as a check.
T3	NPK + S	This treatment provides the estimate of the effect of sulphur as a secondary macronutrient on maize productivity in addition to NPK to allow for evaluating the contribution of S to nutrient-limited yield gap
T4	NPK + B	This treatment provides the estimate of the effect of Boron as a micronutrient on maize yield in addition to NPK to allow for evaluating the contribution of B to nutrient-limited yield gap
T5	NPK + Zn	This treatment provides the estimate of the effect of Zinc as a micronutrient on maize yield in addition to NPK to allow for evaluating the contribution of Zn to nutrient-limited yield gap
T6	NPK + Mg	This treatment provides an estimate of the effect of Magnesium as a secondary macronutrient in addition to NPK to allow for evaluating the contribution of Mg to nutrient-limited yield gap
T7	NPK + B + Mg	This treatment provides the estimate of the interactive effect of Boron and Magnesium on maize yield in addition to NPK
T8	NPK + S + B	Used to measure grain yield to measure the combined effect of macro and micronutrients on maize productivity.
T9	NPK + S + Mg	This treatment has recommended N, P, K, S, and Mg rates applied. Used to measure grain yield to estimate the combined effect of primary (NPK) and secondary (S and Mg) macronutrients on maize productivity.
T10	NPK + S + B + Zn	This treatment was used to assess the interactive effects of N, P, K, S, B and Zn and their contribution to maize productivity
T11	NPK + S + B+ Mg	Recommended rates of these nutrients will be applied. The treatment provides an estimate of the interactive effects of S, B, and Mg in addition to NPK on maize.
T12	NPK + S + B+ Mg + Zn	S, B, Zn, and Mg will be applied at recommended rates in addition to NPK to provide an estimate of their effect on maize productivity.

Table 2: Soil physical and chemical properties of the experimental sites.

Variable	Location				CV (%) [#]	[†]SE ±
	Toro	Lere	Doguwa	Faskari		
Particle size (%)						
Clay	8.6	10.6	23.9	17.3	55.95	2.439
Silt	11.9	19.9	29.3	31.2	43.86	2.925
Sand	79.5	69.5	46.8	51.5	27.72	4.945
Soil reaction						
pH	5.9	5.4	6.1	5.8	5.95	0.099
Macronutrients and organic carbon						
Total nitrogen (gkg^{-1})	0.42	0.41	0.36	0.4	26.34	0.03
Available P (mgkg^{-1})	18.12	5.84	8.45	15.14	47.11	1.62
Available S (mgkg^{-1})	3.88	5.5	3.67	5.86	43.78	0.029
Organic carbon (gkg^{-1})	2.43	2.65	3.6	1.3	39.87	0.29
Micronutrients (mg kg^{-1})						
Zn	9.61	6.64	16.01	1.32	99.78	2.42
Cu	1.66	1.07	1.17	2.55	55.78	0.26
Mn	39.7	57.31	47.31	30.64	38.65	4.88
Fe	114.44	125.28	111.43	104.2	22.91	7.53
Exchangeable cations (cmol^{+} kg^{-1})						
Na	0.27	0.33	0.32	0.37	25.39	0.024
K	0.35	0.49	0.46	0.32	26.59	0.03
Mg	1.74	1.14	1.31	0.68	60.91	0.21
Ca	1.55	2.86	2.95	1.07	60.93	0.37
Effective CEC	3.37	3.38	5.09	2.35	43.59	0.45
Exchangeable acidity	0.01	0	0	0.001	39.2	0.001

[#] CV= Coefficient of variation

[†] SE=Standard error

Table 3: Variance Components and Percent Contribution of Random Factors to Grain Yield, Total Macronutrients and Micronutrients Nutrient Uptake of Maize in the Guinea Savanna of Nigeria

Random effects	Grain yield	Total N uptake	Total P uptake	Total K uptake	Total Ca uptake	Total Mg uptake	Total Cu uptake	Total Fe uptake	Total Mn uptake	Total Zn uptake
Location (L)	135629	19.9	0.5	-34	4.8	-0.00001	-0.69	-0.024	0.0008	-0.00035
	(15.5)	*(2.3)	(2.4)	(-4.1)	(4.2)	(-0.06)	(1.4)	(-4.8)	(3.4)	(-0.7)
Rep[Location]	37668	-22.6	0.1	30	3.4	-0.008	1.163	0.039	-0.0004	-0.00205
	(4.3)	(-2.6)	(0.6)	(3.7)	(2.9)	(-6.3)	(2.4)	(8)	(-1.6)	(-4.2)
Location*Treatment	403852	121.9	-0.2	227	0.8	-0.011	-5.212	-0.011	0.0005	0.001054
	(46.1)	(14.1)	(-.0.8)	(27.9)	(0.7)	(-8.01)	(10.6)	(-2.1)	(2)	(2.2)
Residual	298164	746.3	19.2	591	105.4	0.132	54.074	0.487	0.022	0.049864
	(34.1)	(86.2)	(97.8)	(72.6)	(92.1)	(100)	(85.6)	(99)	(96.2)	(92.9)
Total	875312	865.5	19.6	814.4	114.5	0.132	49.3	0.5	0.0232	0.050919

Values in parenthesis ( ) are percent contribution

Table 4: Maize Grain Yield and Uptake of macronutrients and micronutrients as influenced by nutrient management strategies

Treatment	Grain yield (t ha^{-1})	Total N uptake	Total P uptake	Total K uptake	Total Ca uptake	Total Mg uptake	Total Cu uptake	Total Fe uptake	Total Mn uptake	Total Zn uptake
		kg ha^{-1}								
control	0.42±0.309^{e}	25±11.5^{c}	8±1.6^{bcd}	54±11.5^{ab}	11±3.8^{de}	5.3±2.33^{c}	0.32±0.24^{b}	0.03±0.056^{cd}	0.27±0.11^{b}	0.14±0.08
NPK	3.79±0.309^{d}	76±11.9^{abc}	12±1.7^{abc}	72±11.9^{ab}	13±4^{cde}	12.2±2.55^{abc}	0.54±0.26^{ab}	0.19±0.059^{a-d}	0.48±0.12^{ab}	0.22±0.085
NPK+B	4.20±0.309^{cd}	99±9.8^{ab}	12±1.3^{abc}	94±10.0^{a}	31±3.1^{ab}	20.7±1.77^{a}	1.15±0.19^{ab}	0.04±0.046^{d}	0.85±0.09^{a}	0.3±0.064
NPK+Mg	5.72±0.309^{a}	128±10.1^{a}	14±1.4^{ab}	101±10.3^{a}	34±3.2^{a}	23±1.88^{a}	1.18±0.19^{ab}	0.15±0.048^{a-d}	0.77±0.09^{ab}	0.35±0.068
NPK+S	4.73±0.309^{a-d}	111±9.8^{ab}	17±1.3^{a}	80±10.0^{ab}	26±3.1^{a-d}	16.3±1.77^{ab}	1.09±0.19^{ab}	0.31±0.046^{ab}	0.77±0.08^{ab}	0.28±0.064
NPK+S+B	5.17±0.317^{abc}	110±9.8^{ab}	13±1.3^{abc}	100±10^{a}	29±3.1^{abc}	18.2±1.77^{ab}	1.57±0.18^{a}	0.1±0.046^{bcd}	0.81±0.08^{a}	0.37±0.064
NPK+S+B+Mg	4.97±0.309^{abc}	97±10.1^{ab}	15±1.4^{ab}	75±10.3^{ab}	24±3.2^{a-e}	17.5±1.88^{ab}	1.06±0.19^{ab}	0.27±0.048^{abc}	0.64±0.09^{ab}	0.27±0.068
NPK+S+B+Zn	5.65±0.309^{ab}	103±9.8^{ab}	16±1.3^{a}	82±10.1^{ab}	23±3.1^{a-e}	14.8±1.77^{abc}	1.18±0.18^{ab}	0.34±0.046^{a}	0.63±0.08^{ab}	0.22±0.064
NPK+S+B+Zn+Mg	4.59±0.309^{bcd}	118±10.5^{ab}	7±1.4^{cd}	85±10.6^{ab}	22±3.4^{a-e}	14.7±2.02^{abc}	1.47±0.21^{ab}	0.05±0.05^{cd}	0.82±0.10^{ab}	0.41±0.072
NPK+S+Mg	4.72±0.309^{a-d}	110±10.11^{ab}	9±1.4^{bcd}	63±10.3^{ab}	21±3.2^{a-e}	13.5±1.88^{abc}	1.13±0.19^{ab}	0.13±0.048^{a-d}	0.57±0.09^{ab}	0.2±0.068
NPK+S+Zn	4.75±0.317^{a-d}	97±9.8^{ab}	10±1.3^{bcd}	63±10.0^{ab}	17±3.1^{b-e}	11.2±1.77^{bc}	0.7±0.18^{ab}	0.24±0.046^{a-d}	0.46±0.08^{ab}	0.09±0.064
NPK+Zn	3.88±0.309^{d}	68±11.0^{bc}	4±1.5^{d}	37±11.1^{b}	9±3.6^{e}	6.2±2.14^{c}	0.51±0.22^{b}	0.06±0.053^{cd}	0.59±0.11^{ab}	0.1±0.076
Prob > F	<0.0001	<0.0001	<0.0001	0.0061	<0.0001	<0.0001	0.0064	<0.0001	0.0081	0.0521

Levels not connected by same letter(s) are significantly different.

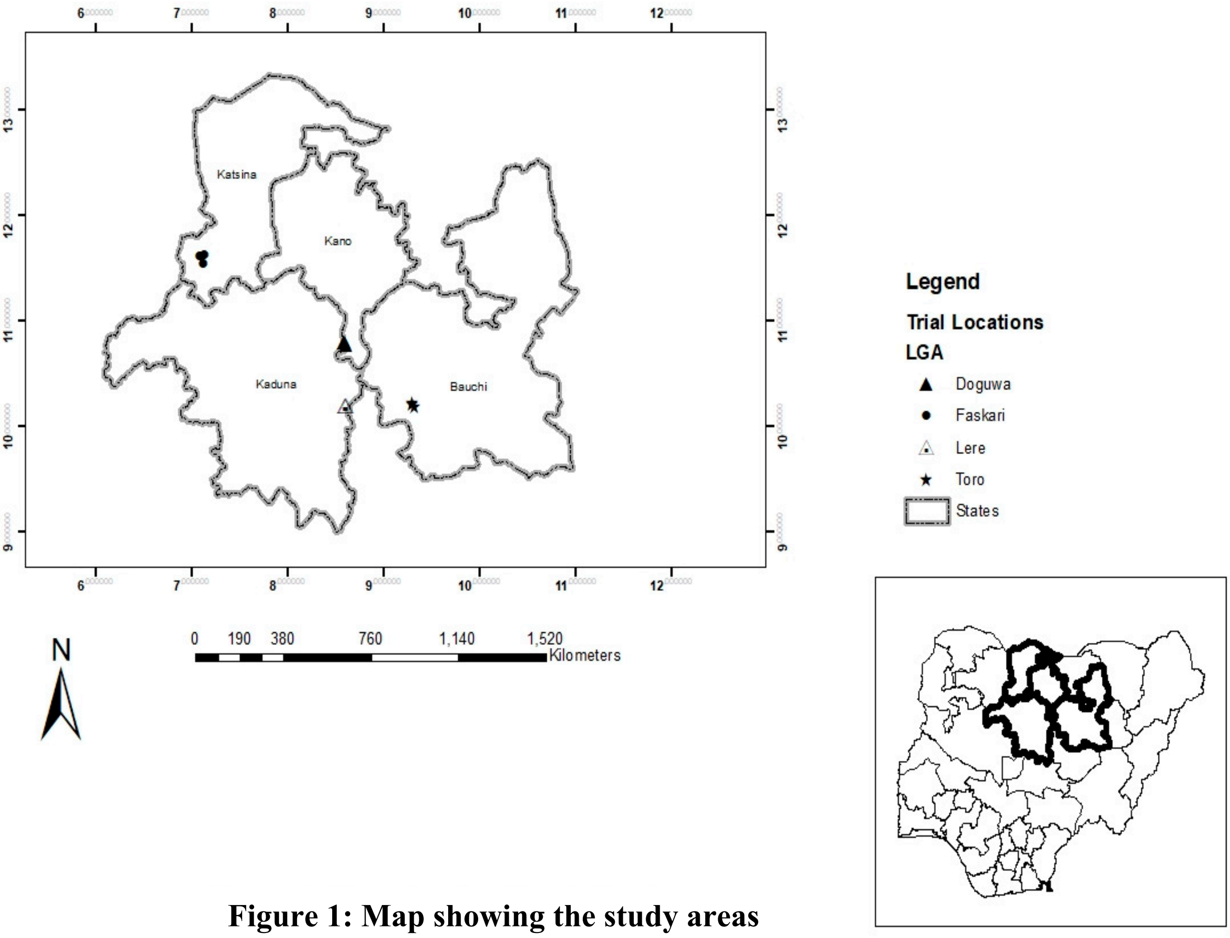

Figure 1: Map showing the study areas

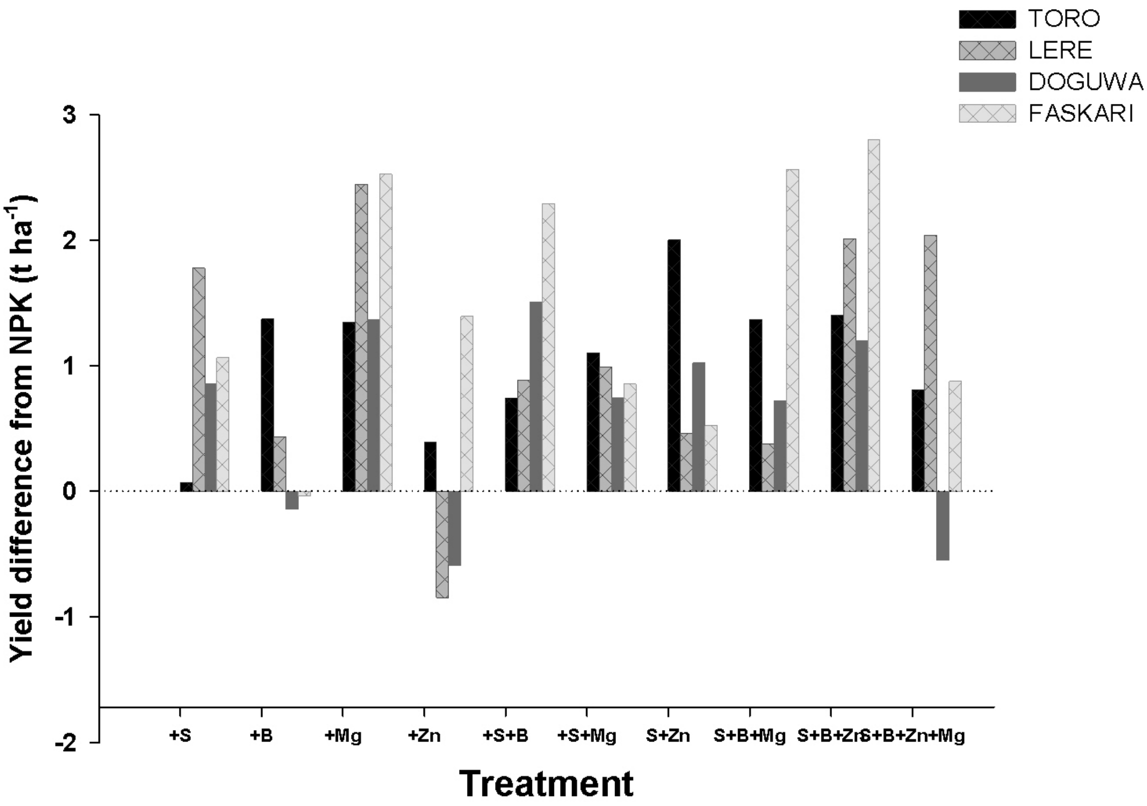

Figure 2: Maize yield response to the application of secondary macro and micronutrients at Doguwa, Faskari, Lere, and Toro as a yield difference relative to NPK.

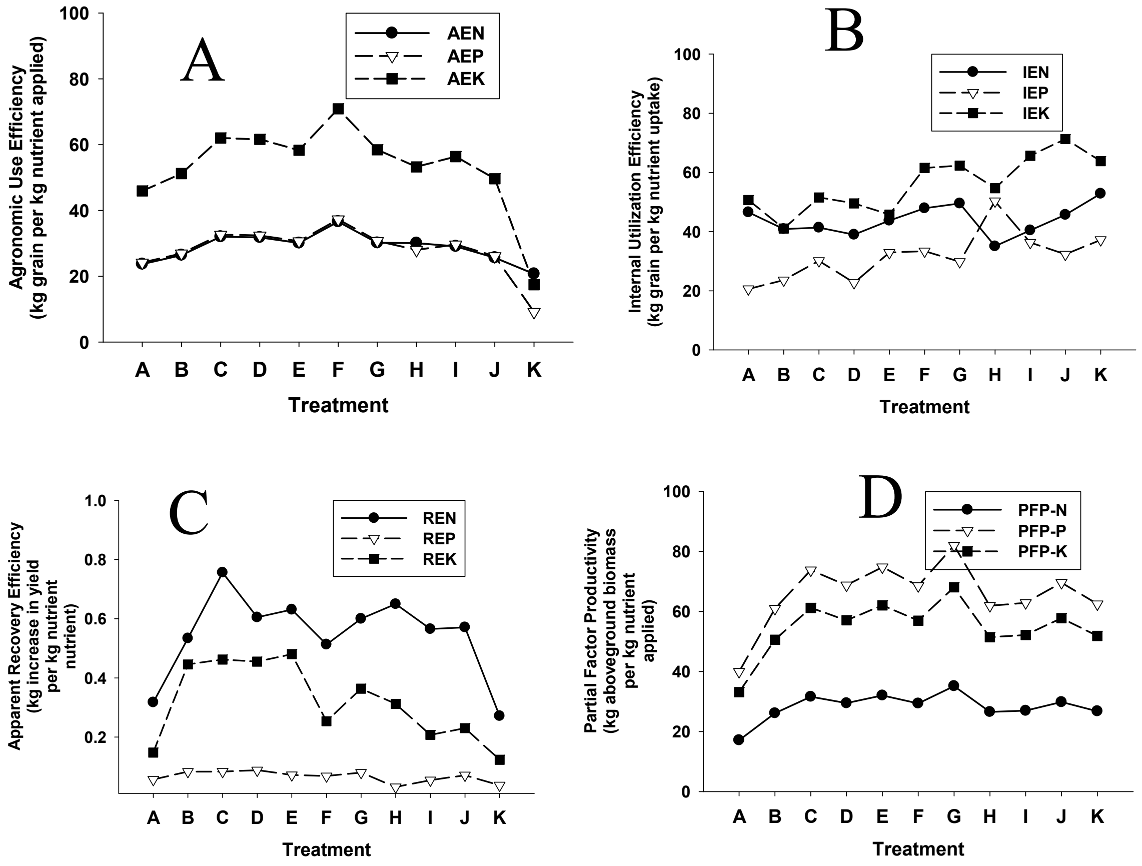

Figure 3: Effects of nutrient management strategy on agronomic use efficiency (A), internal utilization efficiency (B), apparent recovery efficiency (C) and partial productivity (D) of N, P and K.

A = NPK, B = NPK+B, C = NPK+Mg, D = NPK+S, E = NPK+S+B, F = NPK + S + B + Mg, G = NPK + S + B + Zn, H = NPK + S + B + Zn + Mg, I = NPK + S + Mg, J = NPK + S + Zn, K = NPK +Zn