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Grain Yield and Yield Components Response to Omission of Nutrients on Maize (Zea Mays L.) at Kersa District, Jimma Zone, Ethiopia

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Abstract
The nutrient supply capacity of a soil varies with soil types as well as with farmers' crop management practices. Yet fertilizer application in Ethiopia is based on regional recommendations, which do not take in to account the variability in soil types as well as farmers' crop management practices. Thus, site specific fertilizer recommendation that considers soil variability and difference in farmers' crop management practices is quite important. A field experiment was conducted with an objective to identify which of macronutrients N, P and K are limiting maize grain and yield components in the study area during 2017/18 cropping season. The experiments were laid out in a completely randomized block design with six treatments replicated across six farmers' fields in Kersa district, Jimma zone, south western Ethiopia. The trial consisted of six treatments, which include the unfertilized control, PK, NK, NP, NPK and NPK+. Maize grain yield was the highest for the NPK treatment followed by NPK+ treatment but lowest for the unfertilized control and N omitted plots. The magnitude of grain yield reduction due to nutrient omission followed the trend of N omission> P omission> K omission. In the absence of N, P, and K maize grain yields were significantly lower compared to that of NPK and NPK+ treatments. From among the different treatments, NPK gave the highest grain yield(9185 kg ha^{-1}), while the control treatment gave the lowest grain yield (1861.3 kg ha^{-1}).Grain yield levels obtained for different fertilizer treatments were ranked as NPK > NPK+>NP>PK>NK, illustrating that N deficiency was the most yield limiting nutrient followed by P and K in that order. Therefore, the use of appropriate balanced fertilizers should be used for efficient nutrient uptake which ultimately increases maize productivity.
Keywords: Maize, Nitrogen, Nutrient omission, Phosphorus, Potassium
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INTRODUCTION

Most soils cannot supply all essential plant nutrients in sufficient amounts to support good crop growth and yield and hence the application of fertilizer is one of the most effective means to increase nutrient uptake in crop plants and improve crop yields and quality (Kumar *et al*., 2012).Low soil fertility is a major factor implicated for the generally low crop yields in most agro-ecological regions of the world (Neumann *et al*., 2010). Both macro and micro-nutrients play an important role in influencing plant growth and hence yields (Haettenschweiler *et al*., 2000). Crop productivity is affected by the type as well as amount of fertilizer applied to the plants. Mineral fertilizers are the major nutrient sources to supply sufficient nutrients in soil as well as to promote better plant productivity.

Low soil fertility status of agricultural land of smallholders is mentioned as one of the main constraints of crop yields in Ethiopia. In addition to the low soil fertility status of Ethiopian soils, partly due to the removal of nutrients through harvested products and losses through erosion and leaching, phosphorus fixation and aluminum toxicity are two major constraints of most Ethiopian soils (Agegnehu *et al*., 2006). This is particularly apparent in soils with pH less than 5.5, the effect being attributed mainly to nutrient deficiency and toxicity. In such soils, phosphate is unavailable to plant roots because of fixation unless it is applied in large amounts (Marschner, 2012). Many empirical studies (Hailu, 2010; Getachew *et al*., 2012; Bogale, 2014) have documented the problem of low soil nutrient reserves and negative nutrient balances in croplands with few or no external nutrient inputs compared to the nutrient status of forest areas, grazing or well managed lands. Maize is a high nutrient-demanding crop, requiring the intensive application of inorganic or organic fertilizers to produce a high yield (Asadu and Unagwu, 2012). Fertilizers are needed to replenish the nutrients that are removed from the soil when plants are collected and to supplement the soil with more nutrients to increase production (Awotundun, 2005).

Nitrogen (N), phosphorus (P) and potassium (K) are macronutrients that play a major role in plant growth and crop yields (Marschner, 2012). In smallholder farming systems in sub-Sahara Africa (SSA), removal of N, P and K from fields through crop harvest and farms often exceeds input via applied fertilizers. Ethiopia is considered as one of the most vulnerable countries in SSA with regard to soil fertility depletion because of its mountainous topography and intensive farming systems based on small cereals. Indeed, national averages of nutrient balances were estimated at -41kg N,-6kg P and -26 kg K per hectare per year, which is among the highest nutrient depletion rates for Sub-Saharan Africa (Stoorvogel and Smaling, 1993). Yet, soil nutrient balances can differ considerably between different crops, farming systems and agro-ecological zones (Sommer *et al*., 2014). Restoring soil fertility is, therefore, a key priority of the government of Ethiopia. Such negative N, P, K balance sheets lead to a gradual and insurmountable decrease in N, P and K soil fertility status (Roy *et al*., 2003 and Smaling, 1993). Restoration of soil fertility status and the provision of crop specific N, P and K recommendations are prerequisites to increase crop yields.

Imbalanced fertilizer applications during maize cultivation deplete soil nutrients ultimately leading to production decline as well as to deterioration of soil physical and chemical properties. The major problems of maize production in southwestern Ethiopia are infertile soils with high soil acidity and low available phosphorus content. Maize grain yields are variable across farmers' fields. This is due to variability in soil conditions, management practices and crop response to nutrients. Chemical fertilizers play a significant role in yield increment however, the application of higher amount of fertilizers do not always result in increased maize yield (Amujoyegbe *et al*., 2007). Nutrient limitation in soils has led to a drastic decline in maize yields in most smallholder farms. This is caused by decline in soil fertility (Nziguheba *et al*., 2002a, b), which inevitably leads to low agricultural productivity. It is evident that agricultural output is fundamentally affected by productivity status of soil. This decline in soil fertility has decreased farmland productivity in most smallholder farming communities (Amede, 2003). The existing fertilizer recommendation is based on blanket recommendation which assumes that the need of a crop for nutrients is constant over time and large areas. Research that aims to improve soil fertility management and productivity of small-scale farmers has to reckon with soil variation by identifying the most limiting nutrient elements and come up with flexible recommendations rather than blanket recommendations (Kolawole *et al*., 2018). Moreover, the need for supplemental nutrients vary greatly among fields, seasons and years and a blanket dose of fertilizer will not fit to all fields. Therefore, the objectives of this study were to identify the most yield limiting nutrient in maize and to quantify the magnitude of yield limitation due to different nutrient omission namely: N, P, K and secondary and micronutrients in the study area.

Materials and Methods

General Description of the Study Area

The study was conducted in Kersa district, Jimma Zone, Oromia National Regional State, Southwestern Ethiopia. Kersa is one of the districts in Jimma Zone of Oromia Region. Geographically, the district is located between 7°35′–8°00′N latitudes, 36°46′–37°14′E longitude and altitude that ranges from 1740 to 2660 m.a.s.l and consists of 10percent dega, and 90 percent woinadega, agro ecologies. The main rainy season in Kersa area stretches from March to September and the area receives an average annual rainfall of 900-1300 mm. Temperatures are moderate ranking from 20-28^{O}C with variations across specific agro-ecologies. The dominant soil type in the experimental site was Nitisols. Acidity ranges from medium to strong, and pH is generally less than 6 (Feyissa &Mebrate, 1994; Schmitt, 2006).

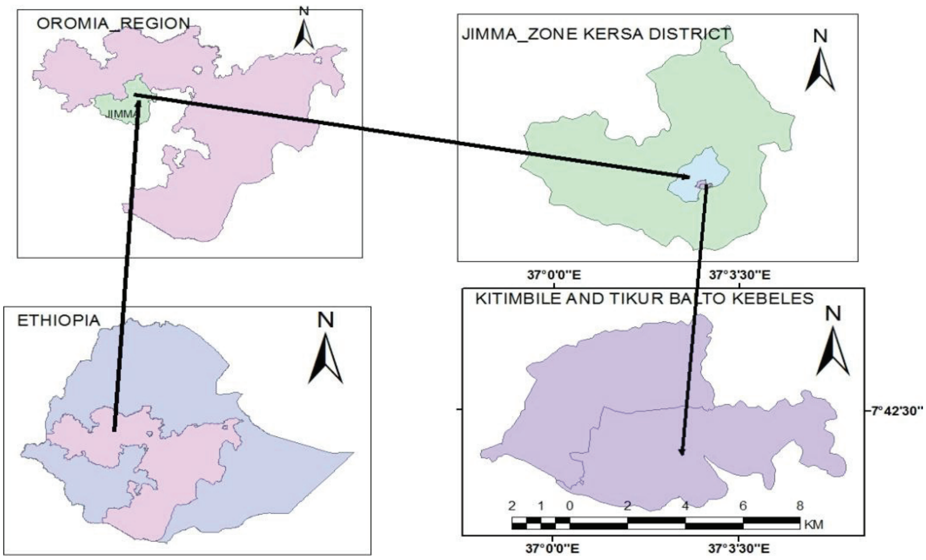

Figure 1: Map of the study area Kersa district-Jimma Zone, Oromia National Regional State.

Experimental Design and Treatments

The nutrient omission trials (NOTs) consisted of six treatments that included: the unfertilized control, PK (0-40-40), NK (120-0-40), NP (120-40-0) NPK (120-40-40) in kg ha^{-1} and NPK + secondary nutrients such as sulphur (S), calcium (Ca), magnesium (Mg) + micro-nutrients such as boron (B) and zinc (Zn), which here after is denoted as NPK+. The rate of each nutrient in the NPK+ treatment were 120-40-40-20-10-10-5-5 (kg ha^{-1}) in that order. The experiment was conducted during main rainy season in 2017/18 at Kersa district. The treatments were laid out in a Randomized Complete Block Design. The experiment was established on six selected farmers' fields as replications. Choice of the experimental fields was limited to farmer fields currently in crop production. The plot size used was 4.5 m x 4.2m (18.9m^2).

Land preparation, fertilizer application and planting

The experimental fields were prepared using a local plow (maresha) according to farmers' conventional farming practices. The fields were ploughed two times to a depth of 15-20 cm and furrows were constructed by a hand-held hoe. Hybrid maize (BH 661) which is high yielder as compared to other improved maize varieties in the study area was used as a test crop. A plant spacing of 75 cm (inter-row) and 30 cm (intra-row) was used. Two seeds of maize were planted per hill and later thinned to one seedling ten days after emergence. Other appropriate agronomic management practice was followed uniformly across treatments and farmers fields. Urea, triple super phosphate (TSP), murate of potash (MOP), hydrated forms magnesium sulphate (MgSO4), calcium sulphate (CaSO4), zinc sulphate (ZnSO4), and borax were used as fertilizer sources for N, P, K, Mg, Ca, Zn and B, respectively.

The nutrients were applied based on nutrient requirements to achieve the expected attainable yield without nutrient limitation in each field. Basal fertilizer was applied in the planting holes at sowing time. Half of urea, whole of TSP, murate of potash, calcium sulphate, magnesium sulphate, Zinc sulphate and borax were spot applied in the planting holes at planting. The applied fertilizers were covered with some soil before placing the seeds to avoid direct contact of seed with fertilizer. Fertilizers were pre-weighed, using a suitable balance, for each plot before going to the field. The remaining half (1/2) of urea was top dressed by spot-application five weeks after emergence (35DAE) for all plots receiving N. There were totally seven rows and 14 planting stations (maize) per row in the plot.

Soil Sampling and Analysis

Representative soil samples were collected from the experimental fields at the depth of 0-20 cm before planting, prepared and analyzed following standard laboratory procedures for some selected soil physico-chemical properties.

Crop management

The trials were researcher-designed and managed to ensure uniformity and optimal management. Uniformity in management was ensured and the following standard agronomic practices were followed. The plots were regularly weeded to minimize any impact of weed pressure on maize performance. Pest infestation and disease symptoms were monitored regularly and controlled appropriately.

Soil sample analysis

From the composite soil samples, parameters were analyzed for soil pH, organic carbon, total nitrogen, available phosphorus, particle size and bulk density. Selected soil physical and chemical properties were analyzed at Jimma Agricultural Research Center, Soil and Plant Analysis Laboratory. Bulk density of the soil samples was analyzed on undisturbed soil samples collected using the core sampling method (Sahlemdhin and Taye, 2000). The pH of the composite soil samples was measured potentiometric method in 1:2.5 soil water suspensions (McLean, 1982). Organic carbon content was determined by the wet oxidation method of Walkley and Black (Nelson *et al*., 1982) and total nitrogen by the semi-micro Kjeldahl method (Okalebo *et al*., 1993).Available soil P was determined according to Bray-II method as described by Bray and Kurtz, (1945). The particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986).Soils were analyzed for exchangeable acidity following extraction by 1M potassium chloride and titration of the extract against sodium hydroxide solution following the procedure described by Okalebo *et al*. (2002).

Agronomic Data Collection

Relevant plant parameters were recorded from the five central rows (12.6 m^2) out of the seven rows per plot (14.6m^2). Among the measures of plant parameters include plant height, leaf area, stand count, number of cobs per plot, weight of cobs per plot, weight of five cobs for determination of shelling percentage, weight of grain yield, and stover yield.

The height (cm) of five randomly selected plants per plot were measured from ground level to the point where the tassel started branching when 50% of the plants in the plot reached tasselling stage and the mean value was taken as plant height. Stem girth were measured at 50cm from the ground level of five randomly taken plants using caliper. Leaf area Index was determined on five randomly selected plants per plot with the method developed by McKee (1964).Harvest index was calculated as the ratio of grain yield to above ground biomass yield on dry weight basis (Donald and Hamblin, 1976).Grain and stover yields were determined by harvesting the entire net plot area of (3m x 4.2m=12.6 m^2) and converted into kilogram per hectare. The harvested grain yield was adjusted to 12.5% moisture level (Birru, 1979; Nelson *et al*., 1985). The adjusted seed yield at 12.5% moisture level per plot was converted to grain yield as kilogram per hectare; whereas stover yield was weighed after leaving it in open air for 7 days. The above ground total biomass yield was calculated as the sum of the grain and stover yields.

$$AE = \frac{Grain\ yield\ of\ fertilized\ plot - Grain\ yield\ of\ control\ plot}{Fertilizer\ applied\ kg/ha}$$

Harvesting and determination of grain and biomass yield

Harvesting was done after the crop has reached physiological maturity and the cobs have dried through monitoring the grain moisture content. First, the number of plants in the net plot were counted and recorded on the harvest form. All the plants in the net-plot were cut at the soil surface and total stover fresh weights determined in the field. The cobs were then harvested in such a way that the husk still remain on the plant. The cobs were counted and the weight of the total number of cobs was determined. Grain and stover yields were determined by harvesting the entire net plot area of 5 rows x 4.2 m (leaving out 2 rows from each end) and converted into kilogram per hectare. Grain yield was adjusted to 12.5% moisture level; whereas stover yield was weighed after leaving it in open air for 7 days. The total dry matter yield, grain yield (at 12.5% moisture content), and harvest index were calculated using the following formulae:

Representative stover was selected randomly, cut into small pieces, well mixed and a subsample was measured. The weight of this fresh sub-sample was recorded. The subsample was bagged and taken to the lab for drying. Five (5) cobs were also randomly selected and fresh weight was determined by ordering the cobs from small to large.

Statistical Data Analysis

The collected agronomic data were analyzed using statistical analysis software (SAS) 9.3 (SAS, 2012). Analysis of variance (ANOVA) was carried out to determine whether there was a significant difference among treatments. Mean separation of significant treatments was carried out using the least significant difference (LSD) test at $P \leq 0.05$ levels. Correlation analysis was done to establish the relationship between yield and yield components.

Results and Discussion

Table1: Selected physicochemical properties of soil before planting maize on farmer's field

Treatments	Farm-1	Farm-2	Farm-3	Farm-4	Farm-5	Farm-6
Sand (%)	54.00	56.00	64.00	58.00	54.00	64.00
Silt (%)	12.00	10.00	12.00	20.00	24.00	6.000
Clay (%)	34.00	34.00	24.00	22.00	22.00	30.00
Textural class	SCL	SCL	SCL	SCL	SCL	SCL
BD(g/cm^3)	1.060	1.020	1.160	1.170	1.120	1.020
pH-H_2O(1:2.5)	4.990	4.890	4.540	4.770	5.100	5.140
OC (%)	2.180	1.995	2.293	2.500	1.595	1.687
Total N (%)	0.165	0.151	0.190	0.207	0.174	0.104
Av.P (mg/kg)	0.957	0.878	2.761	3.388	3.545	7.251
CEC(cmol(+) kg^{-1}	12.44	15.92	15.98	17.10	13.60	20.16
Ex.A(meq/100g)	1.610	1.620	1.860	1.520	1.080	1.016

SCL=Sandy Clay Loam, BD: Bulk Density

Effect of fertilizer treatments on different parameters

Plant height

Plant height of maize was significantly affected ($p<0.05$) by fertilizer treatments. Significantly the tallest plant (296.5cm) was obtained with the application of NPK+ and NPK (285.5cm) treatments compared to all the other treatments, while significantly the shortest plant (228.4 cm) was recorded for the control treatment followed by N-omitted (245.5cm) and P omitted (266cm) treatments (Table 2). The extent of plant height reduction due to nutrient omission was in the order of N omission>P omission>K omission. The increment in plant height might be due to increase in cell elongation and more vegetative growth attributed to the balanced application, especially of primary nutrients N, P and K. On the other hand, the shortest plant in unfertilized plots might have been due to insufficiency of indigenous nutrients supplied by the soil to support plant growth as a result of low soil fertility status of the farms. Supporting the result of the current study, Landon, 1991 reported that plant growth and development will be significantly retarded if soil nutrients are less than their critical value for a crop or not adequately balanced with other nutrient elements. Thus, our results indicated that balanced nutrient application has considerably enhanced the maize vegetative growth such as plant height compared to unbalanced nutrients.

The increase in plant height with the application of balanced NPK fertilizer could be due to their synergistic effects and the fact that N is considered as one of the major limiting nutrients in plant growth and adequate supply of it promotes the formation of chlorophyll which in turn resulted in higher photosynthetic activity, vigorous vegetative growth and taller plants. Phosphorus is required for shoot and root development where metabolism is high and cell division is rapid while K is required for stomata regulation and hence entry of raw materials of photosynthesis and water regulation.

Our results are in line with the findings of Adekayode and Ogunkoya (2010), who also reported significant difference in maize plant height in plots treated with balanced fertilizers compared to the unfertilized plots. Kumar *et al*. (2005) also reported that plant height significantly varied with the application of different fertilizer levels.

Leaf area index

Leaf Area Index of maize was significantly affected ($P <0.05$) by fertilizer treatments (Table 2). Significantly the highest leaf area index (3.92) was obtained with the application of balanced NPK and NPK+ (3.69) both of which were at par. The lowest LAI (2.15) and (2.48) were obtained from the control and N-omitted treatments, respectively (Table 2). The LAI increased by 63.3% due to application of NPK when compared to N omitted treatment and this increase was attributed to only N effect, while LAI increased by 76% due to NPK application compared to the P omitted treatment and the increase was solely due to P effect.

The leaf area index significantly increased with the application of balanced NPK fertilizer because of vigorous growth of the crop and leaf expansion in length and width. Leaf area index has primary importance in increasing the yield of crop. The reason for an increase of leaf area index could be attributed to development of more above ground biomass with expanded leaves produced in response to nitrogen. Phosphorous also promotes rapid canopy development and contributing to root cell division. Leaf expansion was improved in plants by giving chemical fertilizers and was illustrated in terms of leaf length and width (Valero *et al*., 2005). Kumar *et al*. (2005) reported that growth of maize plants in terms of leaf area index varied significantly due to different nutrient applications. He reported the maximum leaf area index, from application of NPK as compared to the other treatments. Greater LAI in NPK treatment was attributed to production of new leaves and increase in size of the existing leaves (Bandyopadhyay *et al*., 2010).

Yield and Yield Components

Effect of nutrient omission on maize grain yield

The results of the nutrient omission trials showed that there was a significant fertilizer treatment effects on yields of maize (Table 2). The highest maize grain yield (9185 kg/ha) was recorded with the NPK treatment followed by the NPK+ treatment (8362.1 kg/ha).Our findings are in line with the results of Adediran and Banjoko (2003), who reported high yields in treatments with balanced fertilizer treatments. Treatments, NPK, NPK+ gave progressively higher yields in that order because they had adequate supply of all primary nutrients. This can be attributed to optimum utilization of solar light, higher assimilates production and its conversion to starches which resulted higher grains number (Derby *et al*., 2004). The results indicate low grain yield was achieved for the treatment to which PK was applied (i, e N omitted plot). This shows that N was the most grain yield limiting nutrient in this experiment. This agrees with the report of Sangoi *et al*. (2007), who found that lack of N before or at sowing results in highly reduced grain yield in maize. Further, studies conducted by Samira *et al*. (1998) and Torbert *et al*. (2001) found that N application increased yield and yield components of maize. Studies by Jones (2003) indicated that plants suffering from N deficiency mature earlier thus the vegetative growth stage is shortened leading to low grain yields. Further, Malhia *et al*. (2001) and Murshedul *et al*. (2006) reported that adequate supply of nitrogen leads to a significant increase in grain yield and its components.

Following the control and PK treatments, the NK treatment where P was omitted gave lower grain yields. This observation was in line with the results of Kogbe and Adediran (2003), who also found that the application of inadequate P depressed maize grain yield. Grant *et al*. (2001) reported that plants require adequate P from the very early stages of growth for optimum production and this could be the reason why yield was depressed due to P omission in the current study. Tang *et al*. (2007), Krishna (2002), and Bunemann *et al*. (2004) also reported depressed maize yields when P supply was inadequate over the entire maize growth period supporting our current observation. Enhanced early-season P nutrition in maize increased the dry matter partitioning to the grain at later development stages (Gavito and Miller, 1998) and P omission will have the counterpart effect thus depressing grain yield as observed in the current study for P omitted treatment. There exists low biomass production of maize under P deficiency in field conditions since the aboveground biomass accumulation was severely reduced (–60%) during early stages of maize growth (Plénet *et al*., 2000). Phosphorus deficiency results in plants that grow slowly with poorly developed root systems and small leaves of grayish-green color (Plénet *et al*., 2000).

Nitrogen was the most grain yield limiting nutrient in the current study. However, both P and K omissions also significantly reduced the grain yield in all the maize farms ($p < 0.05$). Nitrogen had a major effect on growth and yield of maize. P was the next most important yield-limiting nutrient after N in the current study.

Table 2: Effect of omitting different nutrients on maize plant height, Leaf area Index, grain yield, and biomass yield and harvest index

Treatments	Plant height(cm)	Leaf Area Index	Grain Yield (kg/ha)	Biomass yield (kg/ha)	Harvest Index (%)
Control	228.37d	2.15d	1861.3f	3786.6f	32.97d
PK(-N)	245.50cd	2.48d	2680.6e	5297.2e	33.56d
NK(-P)	266.00bc	2.98c	4270.4d	6465.6d	39.79c
NP(-K)	281.70ab	3.51b	7959.0c	8483.8c	44.27b
NPK	285.50ab	3.92a	9185.1a	10307.8a	47.15ab
NPK+	296.50a	3.69ab	8362.1b	9299.9b	47.36a
Mean	267.26	3.12	5719.732	7273.493	40.85
LSD(0.05)	24.85	0.32	389.69	606.45	3.02
CV (%)	7.82	8.71	5.73	7.01	6.21

Grain and biomass yield of maize was significantly affected ($P<0.05$) by the fertilizer treatments (Table 3). Grain yield of maize significantly differed for all fertilizer treatments. Significantly the highest grain yield (9185 kg ha^{-1}) was obtained with the application of NPK fertilizer compared to all the other treatments followed by the application of NPK+ (8362.1 kg ha^{-1}), while the lowest grain yield was recorded for the control treatment (1861.3 kg ha^{-1}) and N-omitted treatment (2680.6kgha^{-1}). The present result agrees with the finding of Tesfaye *et al*. (2019), who also observed the highest maize grain yield from the NPK treatments than the other treatments both in Bako Tibe and four districts of Jimma Zone. The fact that the highest maize grain yield was recorded for the NPK treated plots compared to the rests of the treatments has the implication that the current blended fertilizer should contain potassium both to enhance maize productivity as well as to safeguard further depletion of soil K. Other treatments, such as NP, NK and PK were lacking at least one major nutrient, i.e., N, P or K, and thus may induce a specific nutrient deficiency stress and retard overall growth of maize with a concomitant reduction in yield. Results showed that yield increase due to nitrogen application was 6504.5 kg ha^{-1}. Likewise, yield increase due to P application was 4914.7 kg ha^{-1}. The yield increase due to K application was only 1,226.1 kg ha^{-1}.The yield response to K fertilizer was much lower than to the crop response to N or P application, most likely due to high inherent soil K levels, which might be sufficient to satisfy the crop K demand. On the other hand, yield increase due to supplementing NPK with secondary and micronutrients was, 823 kg ha^{-1}. The result suggests that supplementing N and P fertilizers with K is more useful than supplementing with secondary and micronutrients, since there was no yield increase due to the later. There was no positive impact of secondary and micronutrient on maize grain yield in the study area. Therefore, application of fertilizer containing secondary and micronutrient is not an urgent matter at least in the current study. However, balanced application of N, P and K fertilizers is quite important since such application significantly improved recovery efficiency. The highest grain yield in NPK treated plot could be due to highest final plant height (285.5cm), leaf area index (3.92), and harvest index (47.15%), respectively, suggesting that the improvement in the yield attributes might have increased the grain yield. This could be justified by the positive linear correlation between grain yield and plant height (0.701**), and biomass yield (0.992**) (Table 3).Lemcoff and Loomis (1986) also reported that application of balanced amount of nutrient increases nutrient uptake which facilitates more photosynthetic activity and more partitioning of dry matter to the ears, consequently increase in yield components and grain yield of maize. This forms the basis for high yield under high nutrient availability.

The lowest grain yield in PK (-N) and unfertilized control treatments indicate that N application cannot be substituted and has highest contribution in maize yield. It could be due to high effect of N on chlorophyll formation, photosynthesis and assimilate production because nitrogen stress reduces crop photosynthesis by reducing leaf area development and leaf photosynthesis rate by accelerating the leaf senescence (Diallo *et al*., 1996). Moreover, under N deficiencies, a considerably large proportion of dry matter is partitioned to roots than shoots, leading to reduced shoot/root dry weight ratio (Rufty *et al*., 1988) and consequently the grain yield. Another strong reason might be due to low indigenous N supply capacity, as the soil of sloppy land is prone to soil and nutrient erosion.

Among the chemical fertilizers, nitrogen is also considered one of the most important factors affecting crop morphology, physiological traits and grain yield (Khan *et al*., 2008). The main role of N in the plant is its presence in the structure of protein, the most important building substances from which the living material or protoplasm of every cell is made. In addition, nitrogen is also found in chlorophyll, the green colouring matter of leaves. Chlorophyll enables the plant to transfer energy from sunlight by photosynthesis. Therefore, the nitrogen supply to the plant will influence the amount of protein, protoplasm and chlorophyll formed. In turn, this influences cell size, leaf area and photosynthetic activity (Evert, 2006). Maize is very sensitive to insufficient nitrogen and very responsive to nitrogen fertilization. Insufficient N availability to maize plants results in low yields and significantly reduced profits compared to a properly fertilized crop (Singh *et al.,* 2003).

The nitrogen nutrient has synergistic effect on growth and yield attributes resulting in greater translocation of photosynthesis from source to sink, beneficial effect on physiological process, plant metabolism, growth and the major ingredient of proteins, enzymes, amino acids, amides and nucleic acids (Yayock *et al*.,1988) and there by leading to higher grain yield. The P supply is particularly important for stimulating early root formation and growth, functions in plant macromolecular structures as a component of nucleic acids and phospholipids, with crucial roles in energy metabolism, participation in signal transduction path ways via phosphorylation and controlling key enzyme reactions (Marschner, 2012). Application of potassium fertilizer in adequate amount is essential for obtaining optimal crop yields. Many other researchers also have reported that the application of potassium fertilizer along with N and P fertilizers increased maize grain yield (Fageria *et al.,* 2010). Generally, the application of balanced N, P and K nutrient is useful to enhance crop productivity and nutrient use efficiencies.

Biomass yield

Biomass yield was also significantly influenced by the fertilizer treatment ($p<0.05$). The highest biomass yield was obtained with the application of NPK fertilizer, while the lowest biomass yield was obtained from the unfertilized control. N, P and K omission significantly reduced biomass yield over NPK application. The omission of N, P and K suppressed biomass yield (Table 2). However, the biomass yield from the unfertilized control and N omitted treatments were significantly lower as compared to any of the other treatments (Table 2).Biomass yield is strongly correlated with K supply and was reduced significantly due to its omission by 21.5% in comparison to NPK. Omission of secondary and micronutrients had no significant effect on biomass production.

Harvest index

Harvest Index of maize was significantly affected ($p<0.05$) by the fertilizer treatments (Table 3). The highest harvest index (47.36%) was obtained by the application of NPK+ treatment compared to all the other treatments followed by the application of NPK (47.15%), while the lowest harvest index was recorded from the control (33%) and N-omitted treatment (34%).

On average, maximum leaf area index was observed when balanced NPK was applied. In addition to its effect in promoting photosynthetic activity, potassium increases cell expansion by regulating solute potential that may increase the rate of leaf expansion and the leaf area (Rao and Madhava, 1983; Yahiya *et al*., 1996).The treatments that promoted better growth of the maize crop had a positive influence on HI, presumably due to faster growth and partitioning of more carbohydrates into the grain. All treatments had higher HI compared to the control, reflecting poor plant growth in the control. The results suggest that an application of NPK supply is essential for optimized partitioning of dry matter between grain and other parts of the maize plant.

Relationship between Grain Yield and Yield Components of Maize

All the independent variables showed a significant positive and linear relationship with grain yield (Table 3).The correlation analyses revealed that, there was a significant ($P < 0.001$) positive correlation between grain yield and yield related agronomic parameters of maize. Grain yield was significantly and positively correlated with biomass yield ($r = 0.962^{**}$), leaf area index ($r = 0.871^{**}$) and harvest index ($r = 0.931^{**}$). Biomass yield was positively correlated with almost all agronomic parameters of maize crop. This indicates increasing grain yield could increase yield components of maize and vise versa. This pattern agrees with the findings that most of the variation in grain yield could be explained by above-ground dry matter (Haefele *et al*., 2003; Katsura *et al*., 2008). All these indicated that the improvement in above-ground plant biomass with maintenance of high harvest index could be of great benefit for an additional increase in maize grain yield. Similar findings were reported by Yihenew (2015) and Habtamu *et al*. (2015) that grain yield of maize was positively and significantly correlated with yield components.

Table 3: Correlation among growth parameters, yield and Yield Components of Maize at Kersa

Variables	GY	BM	HI	PHT	LAI
GY	1.00	0.962**	0.931**	0.701**	0.871**
BM		1.00	0.818**	0.697**	0.875**
HI			1.00	0.651*	0.777**
PHT				1.00	0.873**
LAI					1.00

GY= Grain Yield; BMY= Biomass Yield; HI= Harvest Index; LAI=Leaf Area Index; PH= Plant Height; ** and * indicate significant at $P < 0.001$ and $P < 0.05$ level, respectively.

Agronomic efficiency of NPK

The agronomic efficiency of the nutrients was significantly influenced by the fertilizer treatments (Table 4). The results showed that the highest agronomic efficiencies of all N, P and K were observed for the NPK treatment followed by the NPK+ treatments.

Table 4: Agronomic and Apparent Recovery efficiency of N, P and K as affected by nutrients in 2017

Treatments	Agronomic Efficiency (kg grain kg^{-1} Nutrient applied)		
	AE_N	AE_P	AE_K
Control	-	-	-
PK(-N)	-	11.13c	17.25d
NK(-P)	20.08d	-	50.02c
NP(-K)	50.81c	55.48b	-
NPK	61.03a	68.81a	152.58a
NPK+	54.17b	64.78a	135.43b
Mean	46.52	50.05	88.83
LSD(0.05)	2.74	6.36	6.76
CV (%)	4.78	10.32	6.18

The AE_N ranged from 20.08(for NK treatment) to 61.03 kg grain $kg^{-1}$of applied N (for NPK treatment).Dobermann (2007) reported that the AE_N for cereals in developing countries could reach >30kg/kg under optimum crop management. The AE_P ranged from 11.13(for PK treatment) to 68.81(for NPK treatment) kg of grain kg^{-1} applied P. Omission of N (i.e. PK treatment) extraordinarily reduced AE_P, suggesting that P application in the absence of N cannot improve the agronomic efficiency of P. The AE_K ranged from 17.3(for PK treatment) to 152.6(for NPK treatment) kg of grain kg^{-1} K.

Xu *et al*. (2014) also reported higher AE of N, P, and K with lower doses. The application of NPK fertilizers improved N use efficiency by about 200% as compared to NK treatment. Similarly, the same trend was observed with P and K use efficiencies. High agronomic efficiency would be obtained if the yield increment per unit applied is high (Obreza and Rhoads, 1988). A lower yield response to any of the nutrients indicates higher soil indigenous nutrient supply or higher soil fertility, resulting in lower agronomic efficiency. In contrast, a larger yield response means lower soil nutrient supply and relatively higher agronomic efficiency.

Conclusions

Higher mean grain yield of 9185.1 kg ha^{-1} and biomass yields of 10307.8 kg ha^{-1} were recorded with the application of balanced NPK fertilizers whereas the lowest was recorded from the control and N-omitted treatments indicating that N was the most yield limiting nutrient for maize production than any other nutrient in the study areas. The yield response to K fertilizer was also not nil although it was lower compared to N or P fertilizers. Grain yield was strongly correlated with biomass yield (r = 0.962**), leaf area index (r = 0.871**) and harvest index (r = 0.931**).The highest AE_N was obtained from the application of NPK (61.03 kg of grain kg^{-1}N applied) treatment, while the lowest AE_N was recorded from the application of NK (20.08 kg/kg). The highest AE_P was obtained from the application of NPK (68.81kg grain kg^{-1}applied P) while the lowest AEP was recorded from the PK treatment (11.13 kg grain kg^{-1}applied P). Omission of N (i.e. PK treatment) extraordinarily reduced AE_P, suggesting that P application in the absence of N cannot improve the agronomic efficiency of P.

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