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EFFECT OF APPLICATION OF DIFFERENT NUTRIENTS ON GROWTH AND YIELD PARAMETERS OF MAIZE (*Zea mays*), CASE OF KANDARA MURANG'A COUNTY

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ABSTRACT

Soil fertility is a major challenge depressing yields in small hold farms of Sub-Saharan Africa. Growth and yield parameters are key indicators of soil fertility status in most agro ecosystems. A study was conducted in Murang'a County Kandara Sub-County in Kenya. This was to determine the effects of applying different nutrients on growth and yield of maize. The study was done in 2013 during the long rains season (LR13) and the short rains season (SR13). Twenty-three farmers were randomly selected for the study. The experiment was laid out in randomized complete block design (RCBD) with 8 treatments (control, NPK+ CaMgS micronutrient fertilizer (Ca, Mg, S, B, Mn, Cu, Zn,), NPK+ Manure, NPK+ Lime, NPK, NP, NK, and PK). Soil was sampled before establishment of the trials at a depth of 0–20 cm. The soil samples were analyzed for pH, total carbon, macro, and secondary nutrients. Treatment inputs were applied at rates of 100 kg ha^{-1} N, 30 kg ha^{-1} P, 60 kg ha^{-1} K, 10 kg ha^{-1} Ca, 10 kg ha^{-1} Mg, 5 kg ha^{-1} S, 10 t ha^{-1} manure and 1 t ha^{-1} lime. Data on maize plant height, leaf number, and basal diameter was collected at 14, 28, 42, 56 and 70 days after planting (DAP). Grain and stover yield was collected at physiological maturity. The results showed that control, PK and NK treatment achieved means that were significantly different ($p<0.05$) for leaf number and bio-volume during the 2 cropping seasons. The grain and stover yields for control, NK and PK showed significant differences ($p<0.05$) during the two cropping seasons. Simple linear regression analysis between grain yield and leaf number achieved a coefficient of determination (R^2) of 0.9 during both seasons. The coefficient of determination (R^2) between bio-volume and grain yield at 42 DAP was 0.8 for LR13 season and 0.9 for SR1, respectively. The yield response to nitrogen application was 1.87 Mg ha^{-1} in the LR13 season and 1.90 Mg ha^{-1} during the SR13 season. The yield response (yield loss) for phosphorus was 0.84 Mg ha^{-1} in the LR13 season and 0.81 Mg ha^{-1} during the SR13 season. It was concluded that absence of N and P nutrients significantly affects maize leaf number and bio-volume and eventually these effects influence the achieved grain yield. The results of the study show the need to adopt specific nutrient application instead of the former use of blanket recommendation for whole regions.

Keywords: limiting nutrients, nutrient amendments, crop bio-volume, grain yield.

1. INTRODUCTION

The dominant food crop in Kenya is maize (Lelei *et al*., 2009). It is grown across a wide range of agro-ecological zones (Ngome *et al*., 2012; Romney *et al*., 2003). About 1.6 million hectares of land are under maize and 80% is grown by smallholder farmers (Mureithi *et al*., 2006). However, declining soil fertility has led to reduction in maize production (Karaya *et al*., 2012) with an average grain yield estimated at 1 Mg ha^{-1} (Mugwe *et al*., 2008; Ngome *et al*., 2011b). Studies have reported yield gaps of more than 3 Mg ha^{-1} from different localities in Kenya (Rutunga *et al*., 2003). The decline in soil fertility is a major biophysical cause of depressed maize yields in Central Kenya (Bationo *et al*., 2004; Kimani *et al.,* 2007).

The yields achieved by smallholder farmers in Central Kenya are estimated at 0.5 Mg ha^{-1} yr^{1} to 1.5 Mg ha^{-1} yr^{-1} (Ouma *et al*., 2002) compared to the potential of 7-12 Mg ha^{-1}. Central highlands of Kenya are associated with significant soil degradation caused by cultivation of fragile ecosystems and continuous cropping without soil replenishment (Mugendi *et al*., 2003). Severe nutrient depletion has threatened the agricultural productivity of smallholder farmers and thereby hindering efforts to reduce poverty (Lufumpa, 2005). Decreasing soil fertility is a result of imbalance between nutrient inputs and nutrient removals through harvesting, erosion, and leaching (Lynam *et al.,* 1998; Zingore *et al.,* 2005; Lal, 2007). The depletion rates of specific nutrients depend on a number of factors including management, soil type, and climate (Wopereis *et al.,* 2006; Zingore *et al.,* 2007).

Nitrogen is one of the key nutrients needed for crop production; however, it is the most mobile and volatile and the most exhausted nutrients due to its ability to exist in different forms and its easy leach ability (Palm *et al*., 1997; Mugendi *et al*., 2003; Mucheru-Muna *et al*., 2009). In the absence of site-specific recommendations, N management poses a serious challenge in the highlands (Shanahan *et al.,* 2008). Nitrogen management in agro-ecosystems has been extensively studied due to its importance in improving crop yield and quality (Hillin and Hudak, 2003; De Paz and Ramos, 2004; Alam *et al.,* 2006; Dambreville *et al.,* 2008; Mugwe *et al.,* 2009; Mucheru-Muna *et al*., 2010; Mucheru-Muna *et al*., 2014). According to Lungu and Dynoodt (2008), one of the ways of addressing nitrogen limitation, is use of inorganic fertilizers. However, there exists inadequate use of fertilizers to replenish the mined nutrients (Makokha *et al*., 2001).

Phosphorus is a limiting nutrient in maize agro ecosystems due to the low native soil P and high P fixation (Kwabiah *et al*., 2003). In addition, Fairhurst *et al*. (1999) observed that phosphorus unlike nitrogen couldn't be replenished through biological fixation. For many cropping systems, application of P from organic and inorganic sources is essential to sustain high crop yield (Jones, 2003). Enhanced early-season P nutrition in maize increased the dry matter partitioning to the grain at later development stages (Plénet *et al*., 2000).

Secondary nutrients play an active role in the plant metabolism process starting from cell wall development to respiration, photosynthesis, chlorophyll formation, enzyme activity and nitrogen fixation (Das, 2000).

The importance Ca and Mg soils cannot be understated for their role in plant nutrition is crucial since they constitute plants protoplasm (Szulc *et al*., 2008). Sulfur (S) is often the third limiting nutrient in soils after N and phosphorus (P) (Randhawa and Arora, 2000), yet it is seldom included in the fertilizers commonly available.

Micronutrient deficiencies occur not only due to low contents of these elements in the soil but also nutrient mining by growing plants (Brady and Weil, 2002). Studies across SSA indicate that many soils become deficient in Zn, Fe, and S though macronutrient status is corrected (Lipinski, 2005). Sustained removal of micronutrients means they need to be replaced after some time (Giller *et al.,* 2006).

The use of organic resources in combination with mineral fertilizers offers potential for improving soil fertility and crop yields (Vanlauwe *et al*., 2002b). The release of nutrients and the efficiency of nutrient availability to the plant can be manipulated by controlling the quality and quantity of organic resources. Research by Nyamangara *et al*. (2003), Mtambanengwe *et al*. (2006) Mugwe *et al*. (2009) and Mucheru-Muna *et al*. (2014) showed that combinations of organic resources and mineral fertilizers result in greater crop yields. This increase in grain yield has been attributed to improved N synchrony with combined inputs through direct interactions of the organic resources and N fertilizers as observed by Vanlauwe *et al*. (2002b).

The objective of this study was therefore to establish which nutrients limit growth and yield of maize in Kandara Murang'a County.

2. MATERIALS AND METHODS

2.1. Study area

The study was conducted in Kandara Sub-county in Murang'a County which covers an area of 235 km^2 of which 193 km^2 has been put under agricultural production. Kandara geographical coordinates are 0° 54' 0" South, 37° 0' 0" East. Kandara lies in upper midland 2 (UM2) agro-ecological zones (AEZ), which support maize production (Jaetzold *et al*., 2006). Average annual rainfall is variable and ranges 1400- 2000 mm (Jaetzold *et al*., 2006). The rainfall pattern is bimodal and rainy seasons are clearly separated with long rains season in March – May and short rains season in October - December. According to Jaetzold *et al*. (2006), Kandara area has medium to long cropping days (155 - 174 days) and medium to short cropping days (115 - 134 days) in a cropping season. Kandara has mean annual temperatures ranging from of 18 - 21^{0}C. The soils are deep, well drained; weathered Humic Nitisols (locally known as red Kikuyu loams) with moderate to high inherent fertility (Jaetzold *et al*., 2006).

2.2. Experimental design and treatment layout

This experiment was carried out during the long rains season (LR13) and short rains season (SR13). The treatments were laid out in a randomized complete block design. Trials were established on-farm in 23 selected fields. Choice of experimental fields was limited to farmer fields currently in crop production. Each field was divided into eight plots measuring 5 m by 5 m. The 23 fields were treated as replicates. Land preparation was done by hand ploughing at a depth of 15-20 cm using hoes.

The trial consisted of eight treatments, which were; control, PK, NK, NP, NPK, NPK+ CaMgS micronutrients fertilizer, NPK+ manure and NPK+ lime. Straight fertilizers were used to supply N, P, and K. The source of Nitrogen (N) was Urea, of Phosphorus (P) was Triple Super Phosphate (TSP), and of Potassium (K) was Muriate of Potash (MOP). The source of secondary nutrients was Mavuno fertilizer, which is locally available as a multi-nutrient fertilizer. It contains N, P and K, and Calcium (Ca), Magnesium (Mg) and Sulphur (S) and micro nutrients. Mavuno contains; N10+26P+10K+10Ca+4Mg+4S+ micronutrients. The application rates of Urea, TSP, and MOP in the NPK+ CaMgS and micronutrients treatment were adjusted to factor in the amount of N, P, and K supplied by Mavuno fertilizer. Lime and manure were applied at pre-planting, by broadcasting in the 5 m x 5 m plot by incorporation into the surface soil by digging. Basal fertilizer was applied in the planting holes at sowing. Top dressing using urea was done by spot-application in two equal splits, at three and six weeks after emergence. This was done for all treatments requiring nitrogen. Weeding was done using a hoe. The rate of nutrient application for each treatment is indicated in Table-1.

Two seeds of maize variety H513 were sowed per hill at a spacing of 75 cm (inter-row) and 25 cm (intra-row). Thinning to one plant per hill was done 10 days after emergence. Gapping was done 5 days after emergence. Other agronomic procedures were followed appropriately.

2.3. Data collection

2.3.1. Soil sampling and analysis

Soil samples were collected before planting at 0 - 20 cm depth using a soil auger. Soil pH was determined using potentiometric method i.e. soil: water at a ratio of 1:2 (Miller and Kissel, 2010). For soil nutrients (P, K, S, Ca, Mg), ICP-AES instrumentation was used with Mehlich 3 reagent, which estimates most macro nutrients and micronutrients in, soils with acidic to neutral pH using a dilute acid-fluoride-EDTA solution of pH 2.5 (Schroder *et al*., 2010; Pittman *et al*., 2005). Total nitrogen was analyzed by the modified Kjeldahl oxidation method where salicylic acid was added during digestion to include nitrate-N and nitrite-N (Okalebo *et al*., 2002). Soil organic carbon was determined by the Walkley Black combustion method (Nelson and Sommers, 1996).

2.3.2. Maize plant height, leaf number, and basal diameter

Data on plant height, leaf number and basal diameter of 8 random maize plants per plot from the net plot area of 3 m x 3 m was obtained at 14, 28, 42, 56 and 70 days after planting. The measurement for basal diameter was obtained at about 1 cm from the soil surface using vernier calipers. Plant height was taken from the soil surface to the highest tip of the emerging leaf or the highest tip of the tassel. For each of the growth stages for which height and basal diameter were measured, the number of leaves on the 8 selected plants was counted. All leaves were counted including those that were senesced as long as they were identifiable.

2.3.3. Grain and crop residue yield

Harvesting was done after the crop had reached physiological maturity. Grain yields in each treatment were determined from a net plot of 3 m x 3 m. The cobs were removed, counted, and recorded. The grain sub sample was oven dried (at 60 ºC for 48 hours) and reweighed to determine moisture content. After drying to 12.5% moisture content, the final dry weight was determined and recorded.

2.4. Statistical analysis

Plant height and stem diameter were used to calculate plant bio-volume. The leaf number and plant bio-volume was analyzed using statistical analysis software (SAS) 9.2 (SAS Institute, 2009). Analysis of variance (ANOVA) was carried out to determine whether there were significant differences among treatments on plant growth parameters. Fisher's LSD was used to separate means at ($P<0.05$) significance level. Simple linear regression analysis was done to establish the relationship between leaf number, bio- volumes and grain yield at 42 DAP. Further, analysis was carried out on grain yield to deduce the average nutrient responses.

3. RESULTS

3.1. Average precipitation of Kandara

The rainfall pattern is bimodal. The long rains (LR) last from March to June, while the short rains (SR) commence in October through December (Figure-1). The rainfall amount during the two cropping systems was adequate. Rainfall was well distributed across the entire crop establishment period over the two growing seasons. There was no rainfall failure at critical physiological stages of the crop.

3.2. Soil characterisation

The results from soil analysis indicated the pH ranges from extremely acidic (4.57) to slightly acidic (6.87) (Table 2). About 65% of the sampled fields had soil pH ranging between 5 -8, which is optimum for maize production. However, 17% fields were below the recommended pH levels for maize production. Total C and N were found to be inadequate in most of the fields (Table 2). A high percentage (87%) of the fields recorded low levels of total N whose critical level was ≥2.4% and 91% had inadequate levels of total C whose critical level was ≥9.5%. P (ppm) was low in 34% fields whose critical level was ≥ 30 ppm while, K (ppm) deficiency was not observed in any of the sampled fields (Table 2). The fields that recorded low levels of Ca whose critical level was ≥ 513 ppm were 17% (Table 2). No magnesium and sulphur deficiencies were recorded in the sampled fields (Table 2).

3.3. Effect of nutrient application on leaf number

Table-3 indicates significant differences ($p<0.05$) among different treatments for leaf number during both seasons of crop growth. Significant differences were observed in the control, NK and PK treatments for the entire growth period over the two seasons. During the LR13, NPK+ manure (6.9) had the highest leaf count while the control (5.3) treatment had the lowest leaf count at 14 DAP (Table 3). During the SR13 season, the treatment that recorded the highest leaf number was NPK (7.3) and control recorded the lowest leaf count (6.6) at 14 DAP. At 28 DAP; during the LR13 season, NPK+ CaMgS recorded the highest leaf number (9.7) while control recorded the lowest (7.8) (Table 3).

During the LR13 season of crop establishment, coefficient of determination (R^2) for grain yield and leaf number simple linear regression was 0.9 at 42 DAP (Figure 2). This indicates a strong positive relationship between the number of leaves in maize and the achieved grain yields. Similarly, during SR13 season, coefficient of determination (R^2) was 0.9 (Figure 3) indicating a strong linear relationship between leaf numbers and the achieved yield.

3.4. Effect of nutrient application on plant bio volume

At 14 DAP, bio-volume was significant ($p<0.05$), in control and NPK treatment (Table 4). The other treatments showed no significant differences during the LR13 season (Table-4). During the SR13 season, the treatments that indicated significance differences were control, PK and NK (Table 4). During the two seasons, control, PK and NK indicated significant differences in bio volumes. These significant differences were consistent in 28, 42, 56 and 70 DAP (Table 4). The other notable observation was treatment NP, performed as well as other full fertilizer treatments. A large bio-volume was observed in NPK treatments across both seasons of crop establishment. Moreover, full fertilizer treatments with amendments, i.e. NPK +manure, NPK +lime; NPK +CaMgS achieved relatively high bio-volumes over the two seasons of crop growth. In this experiment, NP treatment, recorded high bio volumes.

Simple linear regression results indicated that bio-volumes achieved by specific treatments directly impacted on the yields realised at the end of the season. There was strong linear relationship between mean bio-volume at 42 DAP and grain yield achieved for both LR13 and SR13 seasons of crop establishment (Figures 4 and 5), the coefficient of determination (R^2) for LR13was 0.8 while R^2 for SR13 was 0.9.

3.5. Effect of nutrient application on grain and stover yield

The mean grain yield was significantly different ($p <0.05$) in both cropping season (Table-5). Control, PK, and NK treatments indicated significant differences in grain yields during SR13 and during cropping LR13 season, the treatments, which showed significant differences in grain yield were; control, PK, NK, and NPK +CaMgS (Table 5). During the LR13 season, the treatment that achieved the highest mean grain yield was NP at 5.5 Mg ha^{-1} while the control had the lowest mean grain yield of 2.6 Mg ha^{-1}. During the SR13, NPK+ CaMgS achieved the highest grain yield (5.9 Mg ha^{-1}), while control treatment achieved the lowest grain yield (2.8 Mg ha^{-1}) (Table 5). There was no wide variation in harvest index over the two cropping seasons. The range of harvest indices achieved for both cropping seasons was between 0.43- 0.50. The harvest index is around 0.50 for a normal cropping season. Further analysis indicated that absence of N in PK treatment led to a yield loss of 2 Mg ha^{-1} over the two seasons (Figure-6). The net yield loss recorded in the NK treatment was about 1 Mg ha^{-1} for both seasons. The yield loss recorded by absence of CaMgS secondary nutrients was about 0.5 Mg ha^{-1}. The rest of the treatments had yield losses below 0.5 Mg ha^{-1} (Figure-6)

4. DISCUSSIONS

4.1. Effect of nutrient applications on leaf number

Results indicate that all treatments, which received full NPK fertilizer achieved good leaf establishment throughout the two growth seasons. This was in agreement with the observations of Stefano *et al*. (2004) who reported that fertilizer application resulted in luxuriant growth of leaves. Good leaf establishment is a precursor to high yields as indicated by the positive correlation between the leaf numbers of different treatments and the achieved yields. This observation was affirmed by Bray and Bailey-Serres (2000) who indicated that high number of leaves on fertilizer treated plants contributed to high yields. The omission treatments (NK and PK) showed reduced number of leaves across both seasons. In existing literature, nitrogen deficiency is known to effectively interfere with metabolic process in plants; for instance, Reddy and Dakota (2007) recognized that nitrogen deficiency leads to disruption of the fine structures of chlorophyll and instability of the pigment protein complex. Graham and Vance (2000) observed that an increase in the nitrogen supply stimulates growth as observed in NPK, NP, NPK + manure, NPK +CaMgS and NPK + lime. Gastal (2002) reported that an increase in number of leaves is brought about by a large effect of nitrogen supply on the expansion of individual leaves and on branching, or tillering in grasses. In all instances, the impact of nitrogen on leaf development is related more to the effect of nitrogen on cell production than cell elongation rate (Drew and Morgan, 2000).

High N has shown higher leaf numbers (Sumi and Katayama, 2000) as observed in; NPK, NPK+ manure, NPK+ Lime, NPK+ CaMgS and NP treatments. According to Bonhomme (2000), light interception by crop leaves is a major factor influencing dry matter productivity where leaves contribute more than 80%. Therefore, negative N deficits in maize fields could lead to depressed yields, since leaf growth is highly dependent of availability of N in adequate levels.

Phosphorus deficiency is invariably a common crop growth and yield-limiting factor in unfertilized soils (Ibrikci *et al*., 2005). According to Rehman *et al*. (2011), nutrient P affects leaf growth dynamics in maize; this was observed in NK treatment, which recorded reduced number of leaves for both seasons of growth. Amanullah *et al*. (2009) observed that P is one of the most important factors affecting crop growth and yield of maize. This was corroborated by NPK, NP, NPK, + manure, NPK +CaMgS and NPK + lime treatments which showed robust growth with adequate leaf numbers. Alias *et al*. (2003) reported that leaf number was significantly increased by increasing dose of phosphorous by 125 kg ha^{-1}.

4.2. Effect of nutrient application on plant bio volume

Studies have shown that application of balanced fertilizer accelerate plant growth resulting in taller and greener plants (Zhang *et al*., 2007; 2008a; 2010a, b). According to Fashina *et al*. (2002), the availability of sufficient growth nutrients from inorganic fertilizers leads to improved cell activities, enhanced cell multiplication, enlargement, luxuriant growth, and eventually high yields. This was observed in NPK, NPK + manure, NPK, +CaMgS and NPK + lime and NP treatments. PK and NK achieved low bio volumes across both seasons. This agrees with the observation by Adediran and Banjoko (2003) who indicated that the absence of N and P nutrients resulted in stunted growth and depressed yields. Nitrogen is typically the most limiting nutrient in maize production (Joern and Sawyer, 2006). This observation was confirmed by the poor performance of PK treatment in both seasons. Further, Uyovbisere *et al*. (2001) reported that there was substantial reduction of growth when nitrogen was omitted in smallholder cropping systems of South-western Nigeria. NK, achieved low bio volumes in both cropping seasons. This is enhanced by, Busman *et al*. (2002) and Sahoo and Panda (2001) who indicated that the availability of adequate phosphorous improves plant growth and hastens maturity. This was evident in NPK, NPK + manure, NPK, +CaMgS, NPK + lime and NP treatments which achieved improved bio-volume. Plant growth parameters such as bio-volume increased by application of the phosphorous alone or in combination with the nitrogen (Saeed *et al*., 2001). This observation was further affirmed by Ayub *et*

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al. (2002), who indicated that growth and yield increased with increase in the rate of phosphorous application.

Nitrogen internal efficiency does not only depend on its total amount taken up by the crop, but also on the concomitant supply of secondary nutrients (Jones and Huber, 2007; Potarzycki and Grzebisz, 2009). Although NPK +CaMgS had no significant differences from other full fertilizer treatments; observations show the treatment achieved high bio-volume. Nitrogen metabolism is related to the presence of magnesium in the chlorophyll and its role as a cofactor of the activity of enzymes responsible for the remobilization and transportation of metabolites (nitrogen among others) from the vegetative plant parts to the developing kernels (Rasheed *et al*., 2004). Moreover, since magnesium activates a large number of enzymes in the plant, its simultaneous supply increases the rate of mineral nitrogen transformation into proteins (Pessarakli, 2002).

NPK + manure treatment showed a high bio-volume throughout the growth season. Manure temporarily immobilizes nutrients from mineral fertilizers and may release them in synchrony with crop nutrient uptake (Vanlauwe *et al*., 2002a). N mineralization of manure is improved with the combined application of manures and nitrogenous fertilizers (Sakala *et al*., 2001; Mucheru-Muna *et al*., 2014). Indirect interactions may also enhance crop growth by improving the soil environment for root growth through increased SOM (Vanlauwe *et al.,* 2002b).

4.3 Effects of nutrient application on grain and stover yields

The average yield findings are in line with the results of Adediran and Banjoko (2003) who reported high yields in treatments with balanced fertilizer treatment. Treatments, NPK, NPK +manure, NPK +CaMgS and, NPK + lime achieved high yields because they had adequate supply of all 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 by treatment PK. This is in agreement with Sangoi *et al*. (2007) who found that lack of N before or at sowing results in 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.

Treatment NK achieved low yields, this observation was in line with Kogbe and Adediran (2003) who found that the application of inadequate P depressed maize yield. Another study by Grant *et al*. (2001) found that plants require adequate P from the very early stages of growth for optimum crop production. Further studies that corroborate the observations made in this study were done by Tang *et al.* (2007), Blake *et al*. (2000), Krishna (2002), and Bunemann *et al*. (2004) who reported depressed maize yields when P supply was inadequate over the entire maize growth period. Studies in Ontario have shown that maize grain yield was strongly affected by P supply and tissue P concentration in the V4 to V5 stage, rather than by P concentration later in growth (Barry and Miller, 1989; Lauzon and Miller, 1997). Enhanced early-season P nutrition in maize increased the dry matter partitioning to the grain at later development stages (Gavito and Miller, 1998). 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). The spectacular effect of P deprivation on early reduction in shoot growth is explained by a slight although rapid stimulation of root growth (Mollier and Pellerin, 1999). Phosphorus deficiency results in plants that grow slowly with poorly developed root systems and small leaves of greyish-green color (Plénet *et al*., 2000).

Research has shown that combinations of manure and mineral fertilizers result in higher crop yields compared with sole use of manure or sole use mineral fertilizers (Mucheru-Muna *et al*., 2014; Mucheru-Muna *et al*., 2009; Mtambanengwe *et al.,* 2006; Nyamangara *et al.,* 2003). NPK+ manure had grain yield response of 0.4 Mg ha^{-1}. This increase in grain yield could be attributed to improved N synchrony with combined inputs through direct interactions of the manure and N fertilizers (Vanlauwe *et al*., 2002b). The results agree with the findings by Nziguheba *et al.* (2000), Kimetu *et al.* (2004), Mucheru-Muna *et al.* (2007) and Mucheru-Muna *et al*. (2014) who observed improved maize grain yields because of applying organic inputs with combination mineral fertilizers as compared to sole application of mineral fertilizers.

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Table-1. Rate of nutrient application.

Treatment	Rate of nutrient application (kg ha^{-1})
Control	No fertilizer inputs
NPK	100N+30P+60K
NPK+ lime	100N+30P+60K+1,000 Lime
NPK+ manure	100N+30P+60K+10,000 Manure
NPK+ CaMgS	100N+30P+60K+10Ca+10Mg+3S+Micronutrients
NP	100N+30P
NK	100N+60K
PK	30P+60K

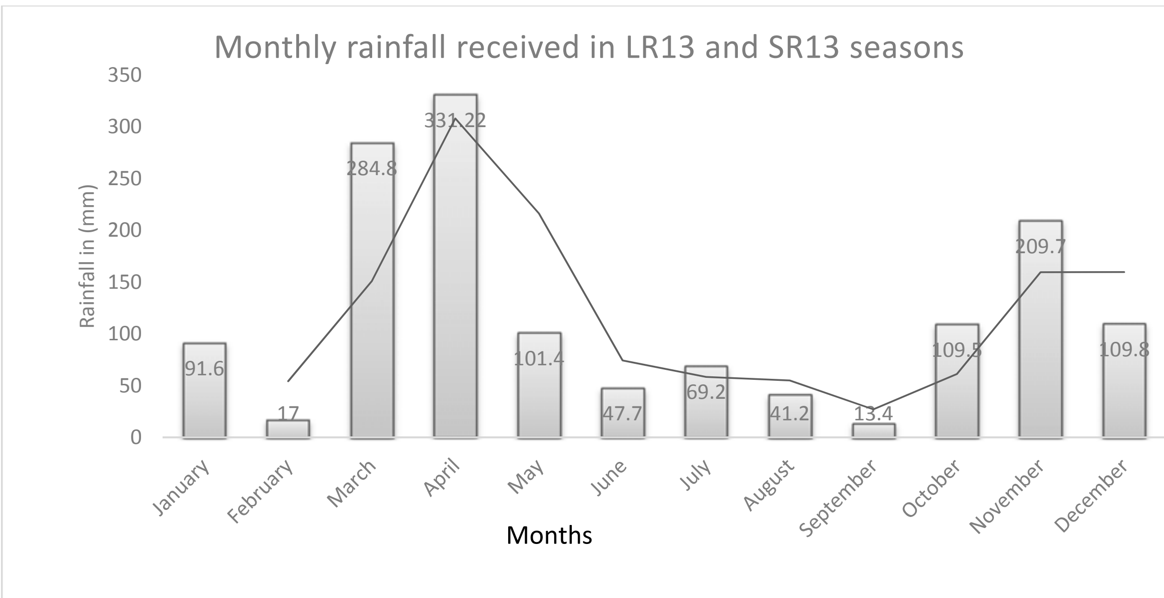

Figure-1. Average monthly precipitation in Kandara during the long rains (LR13) season and short rains season (SR13) of 2013.

Table-2. Soil chemical properties determined at the start of the experiment in 2013 (top soil 0 - 20 cm).

Results for soil chemical analysis at the start of the trials							
Soil parameter	**Max**	**Min**	**Nutrient critical levels**	**Fields with below critical levels**	**Fields with optimum levels**	**Fields with above critical levels**	**% of 23 samples with below critical levels**
pH	6.87	4.57	≥5.5	8	15	-	34
Total N (%)	4.1	1.2	≥2.4	20	3	-	87
Total C (%)	9.7	4.9	≥9.5	21	2	-	91
P (ppm)	208	5.22	≥30	8	12	3	34
K (ppm)	1170	126	≥126	-	13	10	-
Ca (ppm)	3600	334	≥513	4	16	3	17
Mg (ppm)	517	119	≥216	-	16	7	-
S (ppm)	86.7	10	≥14.4	-	17	6	-

Source of critical levels: Soil Suitability Evaluation for Maize Production in Kenya. A Report by NAAIAP in Corroboration with KARLO Department of Soil Survey, Feb 2014.

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Table-3. Effect of nutrient application on leaf numbers.

Leaf number										
	14 DAP		28 DAP		42 DAP		56 DAP		70 DAP	
Treatment	LR13	SR13	LR13	SR13	LR13	SR13	LR13	SR13	LR13	SR13
Control	5.3[e]	6.6[b]	7.8[d]	8.9[d]	8.6[e]	10.0[f]	11.6[d]	12.4[d]	11.7[c]	12.6[c]
PK	6.8[ab]	7.2[a]	8.4[c]	9.3[cd]	9.2[d]	10.5[e]	11.7[d]	12.7[d]	11.7[c]	12.9[bc]
NK	6.1[d]	7.2[a]	8.1[cd]	9.8[c]	9.9[c]	11.4[d]	12.7[c]	13.5[c]	12.4[b]	13.3[b]
NP	6.6[bc]	7.2[a]	9.2[b]	10.9[a]	10.8[ab]	12.1[bc]	13.7[a]	14.5[a]	13.3[a]	14.2[a]
NPK	6.7[abc]	7.3[a]	9.1[b]	11.0[a]	11.0[a]	12.6[a]	13.8[a]	14.6a	13.4[a]	14.3[a]
NPK+ lime	6.8[ab]	7.2[a]	9.2[b]	11.0[a]	10.8[ab]	12.1[bc]	13.4[ab]	14.4[ab]	13.5[a]	14.4[a]
NPK+ manure	6.9[a]	7.2[a]	9.4[ab]	10.3[b]	10.8[ab]	11.7[cd]	13.1[bc]	14.1[b]	13.4[a]	14.3[a]
NPK+ CaMgS	6.5[c]	7.2[a]	9.7[a]	11.0[a]	10.4[bc]	12.3[ab]	13.7[a]	14.7[a]	13.4[a]	14.3[a]
LSD. 5%	0.2024	0.1186	0.4807	0.4668	0.5066	0.5001	0.4433	0.4434	0.4717	0.4721

Same superscript letters appearing in the same column indicate no significant difference between the treatments

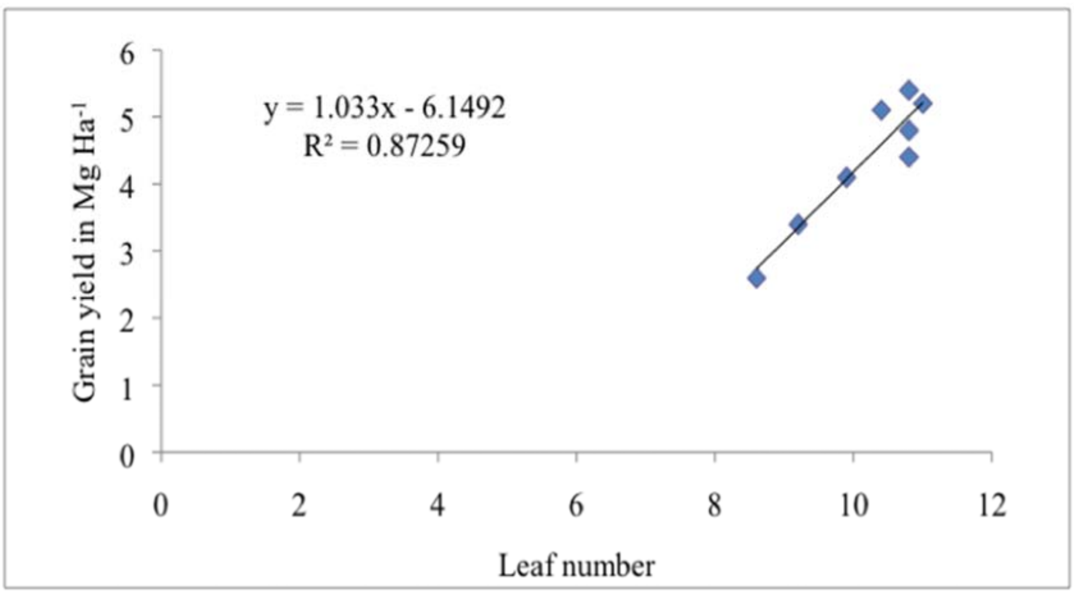

Figure-2. Linear regression analysis for grain yield and leaf number at 42 DAP in LR13.

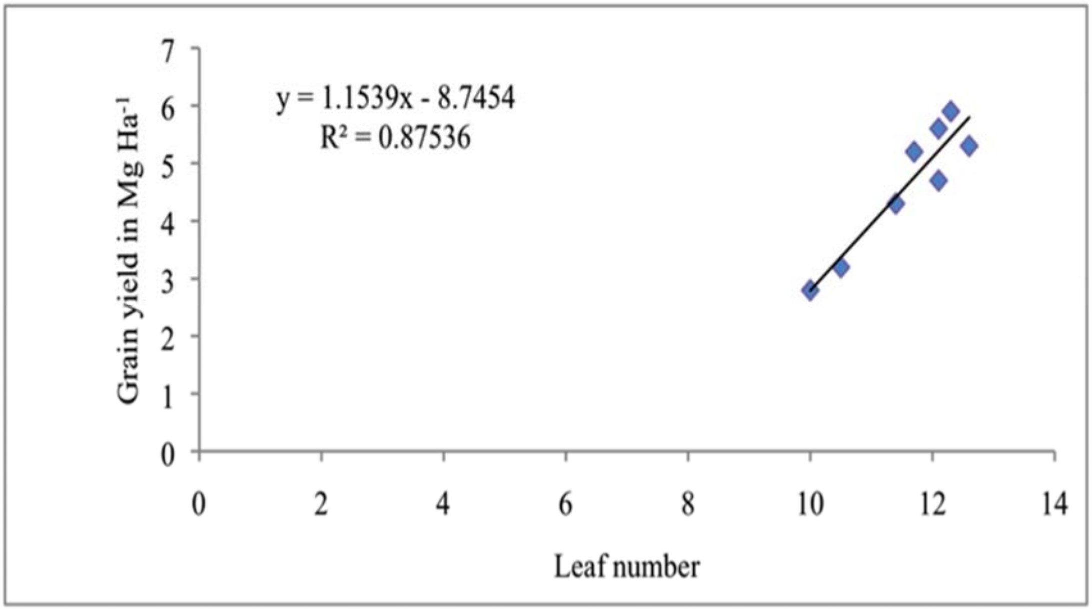

Figure-3. Linear regression for grain yield and leaf number at 42 DAP in SR13.

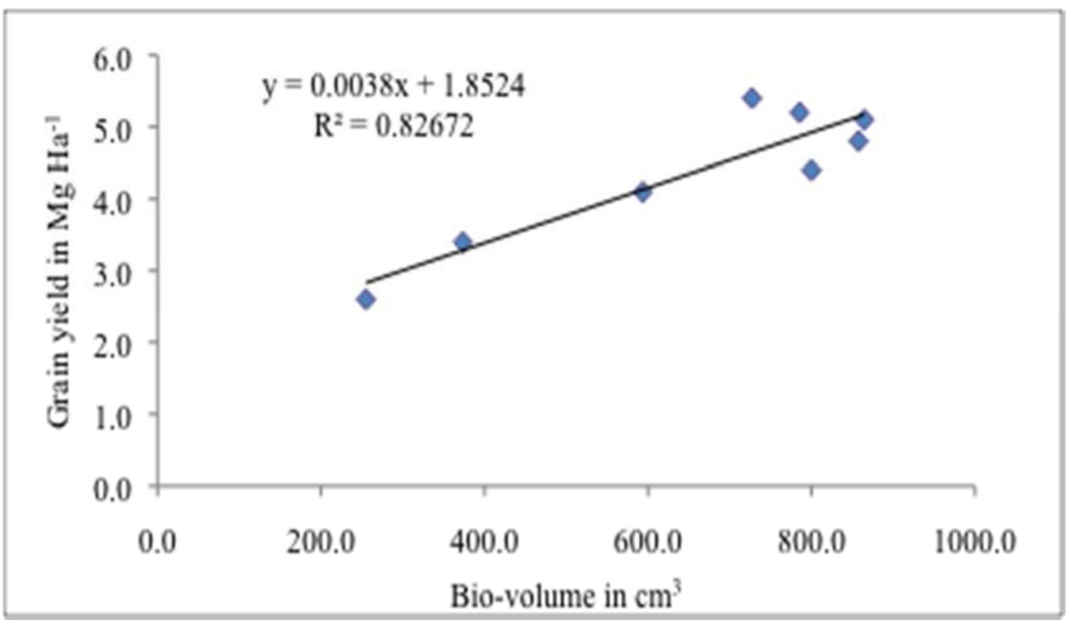

Figure-4. Linear regression for grain yield and bio-volume at 42 DAP in LR13.

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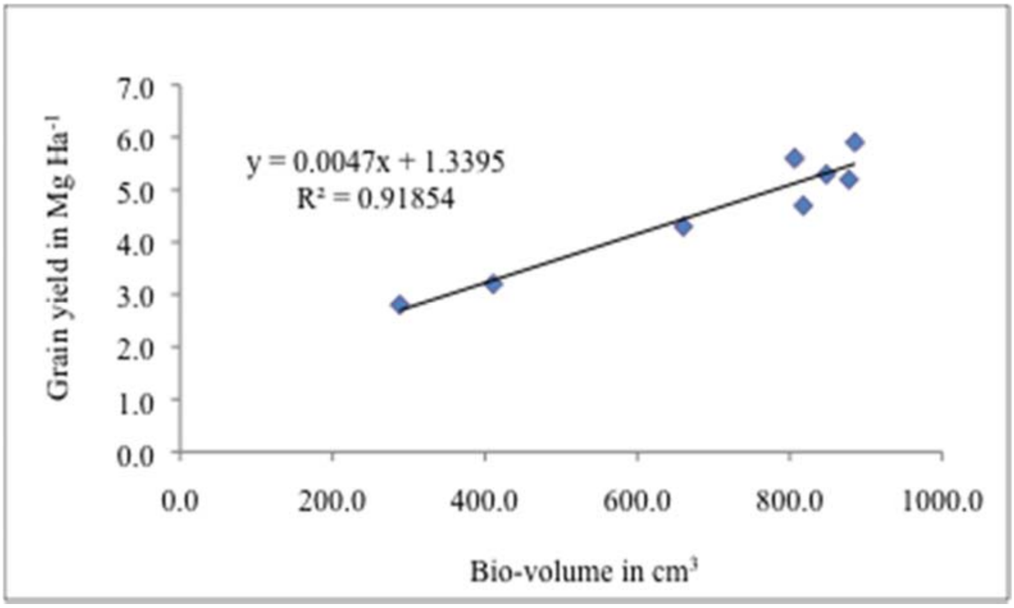

Figure-5. Linear regression of grain yield and bio-volume at 42 DAP in SR13.

Table-4. Effect of nutrient application on plant bio volume.

Biovolume (cm^3)										
	14 DAP		**28 DAP**		**42 DAP**		**56 DAP**		**70 DAP**	
Treatments	**LR13**	**SR13**	**LR13**	**SR13**	**LR13**	**SR13**	**LR13**	**SR13**	**LR13**	**SR13**
Control	19.5^{c}	22.6^{d}	126.4^{c}	128.4^{b}	255.0^{c}	288.3^{c}	435.7^{c}	506.5^{c}	437.2^{c}	565.0^{c}
PK	29.3^{b}	30.9^{c}	180.6^{bc}	201.4^{b}	373.6^{c}	411.0^{c}	547.9^{c}	585.4^{c}	588.1^{c}	679.7^{c}
NK	30.6^{ab}	31.6^{bc}	220.1^{b}	219.9^{b}	593.7^{b}	660.3^{b}	816.3^{b}	928.6^{b}	958.1^{b}	1003.9^{b}
NP	30.0^{ab}	34.5^{ab}	327.8^{a}	361.2^{a}	727.3^{ab}	806.5^{ab}	1057.1^{a}	1161.3^{a}	1159.1^{ab}	1209.1^{ab}
NPK	32.2^{a}	35.9^{a}	348.4^{a}	373.4^{a}	785.5^{a}	848.1^{a}	1143.7^{a}	1185.4^{a}	1119.6^{ab}	1190.4^{ab}
NPK+ Lime	28.1^{b}	34.6^{a}	332.7^{a}	347.7^{a}	800.0^{a}	817.7^{ba}	1134.6^{a}	1157.6^{a}	1181.6^{ab}	1142.9^{ab}
NPK+ Manure	28.5^{b}	35.0^{a}	354.9^{a}	349.3^{a}	857.5^{a}	877.7^{a}	1166.5^{a}	1190.5^{a}	1291.2^{a}	1314.4^{a}
NPK+ CaMgS	28.2^{b}	35.2^{a}	412.3^{a}	427.3^{a}	864.6^{a}	885.6^{a}	1236.4^{a}	1260.7^{a}	1273.7^{a}	1300.2^{a}
LSD. 5%	2.32	2.98	93.31	103.99	167.30	179.18	185.12	201.66	202.91	224.72

Same superscript letters appearing in the same column indicate no significant difference between the treatments.

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Table-5. Effects of nutrient application on grain and stover yields.

	LR13			SR13		
Treatments	**Grain yields Mg ha^{-1}**	**Stover yields Mg ha^{-1}**	**HI**	**Grain yields Mg ha^{-1}**	**Stover yields Mg ha^{-1}**	**HI**
Control	2.6^{f}	2.8^{e}	0.48	2.8^{d}	3.4^{c}	0.50
PK	3.4^{e}	3.9^{d}	0.47	3.2^{d}	4.2^{c}	0.43
NK	4.1^{d}	4.5^{c}	0.48	4.3^{c}	4.4^{c}	0.49
NP	5.5^{a}	5.6^{ba}	0.50	5.6^{a}	6.0^{b}	0.48
NPK	5.2^{ba}	6.0^{a}	0.46	5.3^{b}	6.1^{b}	0.46
NPK+ Lime	4.4^{dc}	5.3^{b}	0.45	4.7^{ba}	6.1^{b}	0.44
NPK+ Manure	4.8^{bc}	6.1^{a}	0.44	5.2^{b}	6.5^{a}	0.44
NPK+ CaMgS	5.1^{ba}	5.7^{ba}	0.47	5.9^{a}	6.4^{a}	0.48
LSD. 5%	0.6411	0.7032		0.6984	0.8549	

HI: Harvest index. Same superscript letters appearing in the same column indicate no significant difference between the treatments

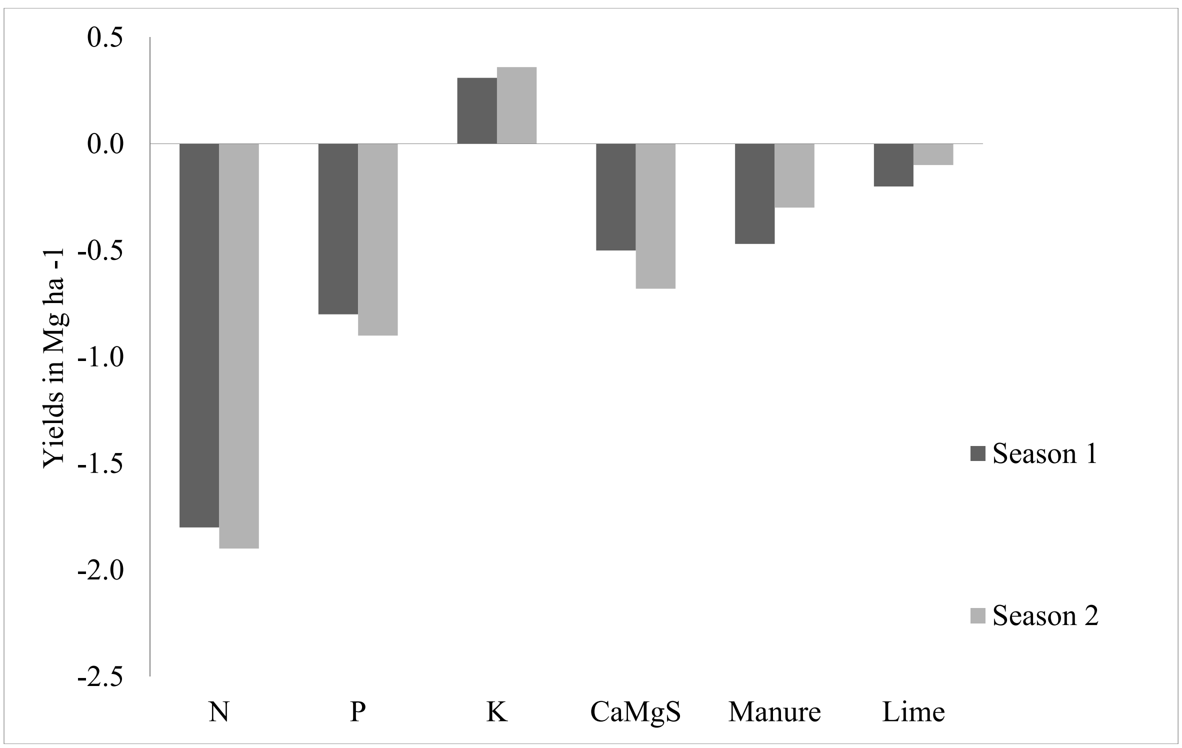

Figure-6. Grain yields response (loss) for different nutrient omissions.

5. CONCLUSIONS

From the results of the experiment, it is evident that absence of N and P nutrients significantly affects maize leaf number and bio-volume and eventually these effects influence the achieved grain yield. Therefore, the limiting nutrients in the study area are nitrogen and phosphorus. The yield response to nitrogen application was 1.87 Mg ha^{-1} in the LR13 season and 1.90 Mg ha^{-1} during the SR13 season. The yield response (yield loss) for phosphorus was 0.84 Mg ha^{-1} in the LR13 season and 0.81 Mg ha^{-1} during the SR13 season. The results of the study show the need to adopt specific nutrient application in smallholder farming systems. This can be achieved if soil test is done before fertilizer recommendations are made. The use of blanket recommendations on fertilizer use in some regions needs stop and studies done to ascertain the specific nutrients needed to improve maize yields.

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REFERENCES

Adediran, J.A., and Banjoko, V.A. 2003. Comparative effectiveness of some compost fertilizer formulations for maize in Nigeria. Nig. J. Soil Sci. 13: 42-48.

Alam M.M., Ladha J.K., Foyjunnessa. Rahman Z., Khan S.R., Harun-ur-Rashid. Khan, A.H. and Buresh R.J. 2006. Nutrient management for increased productivity of rice wheat cropping system in Bangladesh Field Crop. Res. 96, 374-386.

Alias A., Usman M., Ullah E. and Waraich E.A. 2003. Effects of different Phosphorus levels on the the growth and yield of two cultivars of maize (*Zea mays* L.) Int. J. Agric. and Bio. 4: 632-634.

Amanullah R.A., Khattak. and Khalil S.K. 2009a. Effects of plant density and N on phenology and yield of maize. J. Plant Nutr. 32: 245-259.

Amanullah M., Asif S., Malhi S. S. and Khattak R.A. 2009b. Effects of P-fertilizer source and plant density on growth and yield of maize in Northwestern Pakistan. J. Plant Nutr. 32: 2080-2093.

Ayub M., Nadeem M.A., Sharar M.S. and Mahmood, N. 2002. Response of Maize (*Zea mays* L.) Fodder to Different Levels of Nitrogen and Phosphorus. Asian Journal of Plant Sciences. 1: 352-354. http://dx.doi.org/10.3923/ajps.2002.352.354.

Barry D.A.J. and Miller M.H. 1989. The phosphorus nutritional requirement nutritional requirement of maize seedlings for maximum yield. Agron. J. 81: 95-99.

Bationo A., Kimetu J., Ikerra S., Kimani S., Mugendi D.N., Odendo M., Silver M., Swift M.J. and Sanginga N.H. 2004. The African network for soil biology and fertility: new challenges and opportunities. In: Bationo A (eds) Managing nutrient cycles to sustain soil fertility in Sub-Saharan Africa. AfNet-CIAT. Academy Science Publishers, Nairobi, Kenya. pp. 1-23.

Blake L. S., Merciks M., Koerschen S., Moskal P. R., Poulton K. W. T., Goulding A., Weige D. and Powlson S. 2000. Phosphorus content in soil, uptake by plants and balance in three European long - term field experiments, Nutr. Cycle, Agro-ecosyst. 56:263-275.

Bonhomme R. 2000. Beware of comparing RUE values calculated from PAR VS. Solar radiation or absorbed VS. Intercepted radiation. *J. Field Crops Res*. 68: 247-252.
Brady N C. and Weil R. R. 2002 Micronutrient and other trace elements. The Nature and Property of Soil (13th ed.). Pearson Education Publisher, Singhapur. pp. 638-668.

Bray E.A., Bailey-Serres J. 2000. Responses to abiotic stress, 1158-1203 p. In: Biochemistry and Molecular Biology of Plant. American Society of Plant Physiologists, Rockville, MD.

Bunemann E.K., Steinebrunner F., Smithson P.C., Frossand E. and Oberson A. 2004. Phosphorus dynamics in a highly weathered soil as revealed by isotopic labeling techniques. Soil Sci. Soc. 125: 49-54.

Busman L., Lamb J., Randall G., Rehm G. and Schmitt M. 2002. The nature of phosphorus in soils. University of Minnesota Extension Service, Available at http://www.extension.umn.edu/distributution/cropsystems/DC6795.html.

Dambreville C., Morvan T. and Germon J.C. 2008. N_2O emission in maize-crops fertilized with pig slurry, matured pig manure or ammonium nitrate in Brittany. Agr. Ecosyst. Environ. 123: 201-210.

Das D.K. 2000. Micronutrients: their behavior in soils and plants. Kalyani Puiblishers, New Delhi, India. p. 307.

De Paz J.M. and Ramos C. 2004. Simulation of nitrate leaching for different nitrogen fertilization rates in a region of Valencia (Spain) using a GISGLEAMS system. Agr. Ecosyst. Environ. 103: 59-73.

Derby N.E., Casey F.X.M. Casey, Knighton R.E, Knighton and Steel D.D. Steel. 2004. Midseason nitrogen fertility management for corn based on weather and yield prediction. Agron. J. 96: 494-501.

Drew M.C. and Morgan P.W. 2000. Programmed cell death and aerenchyma formation in roots. Trends in Plant Science. 5: 123-127.

Fairhurst T., Lefroy R., Mutert E. and Batjes N. 1999. The importance, distribution and causes of phosphorus deficiency as a constraint to crop production in the tropics. Agroforest For. 9: 2-8.

Fashina A. S., Olatunji K. A and Alasiri K. O. 2002. Effects of different plant population and poultry manure on yield of Ugu (*Telfairia occidentalis*) in Lagos State, Nigeria in Proceedings of the annual Conference of Horticultural Society of Nigeria (HORTON). pp. 123-127.

Gastal T.R. 2002. Effect of alfalfa leaf extracts and phenolic allelochemicals on early seedling growth and root morphology of alfalfa and barynarg grass. Crop Prot. 5: 1077-1082.

Gavito M.E. and Miller M.H. 1998b. Early phosphorus nutrition, mycorrhizae development, dry matter partitioning and yield of maize. Plant and Soil. 199: 177-186.

Gavito M. E. and Miller M. H. 1998a. Early phosphorus nutrition, mycorrhizae development, dry matter partitioning and yield of maize. Plant Soil. 1999: 177-186.

Giller K.E., Rowe E., de Ridder N. and van Keulen H. 2006. Resource use dynamics and interactions in the tropics: Scaling up in space and time. Agricultural Systems, 88, 8-27. Scaling up in space and time. Agric. Syst., in press.

Graham S.J. and Vance Y.R. 2000. The Glycine-Glomus-Rhizobium symbiosis IV. Interactions between mycorrhizal and nitrogen-fixing Endophytes. Plant Cell Envir. 10: 607-617.

Grant C. A., Flaten D. N., Tomasiewicz D. J and Sheppard S. C. 2001. The importance of earl season P nutrition. Can. J.Plant Sci. 81: 211-224.

Hillin C.K. and Hudak P.F. 2003. Nitrate contamination in the seymour aquifer, northcentral texas, USA. Bull. Enviro. Contam. Tox. 70: 674-679.

Ibrikci H., Ryan J., Ulger A.C., Buyuk G., Cakir B., Korkmaz K., Karnez E., Ozgenturk G and Konuskan O. 2005. Maintenance of P fertilizer and residual P effect on corn production. Nigerian J. Soil Sci. 2: 1279-286.

Jaetzold, R., Schmidt H., Hornetz B. and Shisanya C. 2006. Farm Management Handbook of Kenya.Natural Conditions and Farm Management.2nd Edition. MoA/GTZ, Nairobi, Kenya.

Joern B and Sawyer J. 2006. Nitrogen and Corn Use.*In* Concepts and rationale for regional nitrogen rate guidelines for corn. M. Loukianenko and J. McGuire, eds. Iowa State University Extension. Available on-line at: www.extension.iastate.edu/Publications/2015.pdf. Accessed November 11, 2011.

Jones (Jr) J.B. 2003. Agronomic handbook: management of crops, soils, and their fertility. New York, USA: CRC Press.

Jones J. and Huber D. 2007. Magnesium and plant disease. In. Datnoff, L., Elmer, W., Huber, D. (Eds.): Mineral nutrition and plant disease. APS Press, St. Paul, USA. pp. 95-100.

Karaya H., Njoroge K., Mugo S., Ariga E.S., Kanampiu F., Nderitu J.H. 2012. Determination of levels of *Striga* germination stimulants for maize gene bank accessions and elite inbred lines. Int. J. Plant Prod. 6: 209-224.

Kimani S.K., Macharia J.M., Gachengo C., Palm C.A. and Delve R.J. 2004. Maize production on the central highlands of Kenya using cattle manures combined with modest amounts of mineral fertiliser. Uganda Journal of Agricultural Sciences. 9: 480-490.

Kimetu J.M., Mugendi D.N., Palm C.A., Mutuo P.K., Gachengo C.N., Bationo A., Nandwa S. and Kung'u J. 2004. Nitrogen fertilizer equivalences by organics of differing quantity and optimum combinations with organic nitrogen source in central Kenya. Nutrient Cycling in Agroecosystems. 68: 127-135.

Kogbe J.O S. and Adediran J.A. 2003. J.A. Influence of Nigeria, Phosphorus and Potassium application on the yield of maize in the savannah zone of Nigeria. Africa Academic. 2(10): 345-349.

Krishna K.R. 2002. Soil phosphorus, its transformation, and their relevance to crop productivity. In: Krishna Enfield (NH), USA, Plymouth, UK. pp. 109-140.

Kwabiah A.B., Stoskopf N.C., Palm C.A., Voroney R.P., Rao M.R. and Gacheru E. 2003. Phosphorus availability and maize response to organic and inorganic fertilizer inputs in a short term study in Western Kenya. Agric Ecosyst Environ. 95: 49-59.

Lal R. 2007. Anthropogenic influences on world soils and implications to global food security. Advances in Agronomy. 93: 69-93.

Lauzon J. D. and Miller M. H. 1997. Comparative response of corn and soybean to seed-placed phosphorus over a range of soil test phosphorus. Commun. Soil Sci. Plant Anal. 28: 205-215.

Lelei J.J., Onwonga R.N. and Freyer B. 2009. Organic based nutrient management strategies: Effect on soil nutrient availability and maize (*Zea mays* L.) performance in Njoro, Kenya. Africa Journal of Agricultural Research. 4(2): 092-099.

Lipinski W. 2005. The content of available magnesium in soils of Poland. Fertilizers and Fertilization. 23: 61-66 (in Polish).

Lufumpa C. 2005. The poverty-environment nexus in Africa. African Development Review. 17: 366–381.

Lungu O.I.M and Dynoodt R.F.P. 2008. Acidification from long-term use of urea and its effect on selected soil properties. African Journal of Food Agriculture Nutrition and Development. 8(1).

Lynam J. K., Nandwa S. M. and Smaling. E. N. A. 1998. Nutrient balances as indicators of productivity and substainability in Sub-Saharan African agriculture. Agriculture Ecosystems & Environment. 71: 1-4.

Makokha S., Kimani S., Mwangi S., Verkuijil H. and Musembi F. 2001. Determination of fertilizer and manure use in maize production in Kiambu District Kenya. Mexico, D.F: International Maize and Wheat Improvement Centre (CIMMYT) and Kenya Agricultural Research Institute (KARI).

Miller R.O. and Kissel D.E. 2010. Comparison of soil pH methods on soils of North America. Soil Science Society of America Journal. 74: 9754645.

Mollier A. and Pellerin S. 1999. Maize root system growth and development as influenced by phosphorus deficiency. J. Exp. Bot. 50: 487-497.

Mtambanengwe F., Mapfumo P. and Vanlauwe B. 2006. Comparative short term effects of diff erent quality organic resources on maize productivity under two diff erent environments in Zimbabwe. Nutr. Cycling Agroecosyst. 76: 271-284.

Mucheru-Muna M.W., Mugendi D., Kung'u J., Mugwe J. and Bationo A. 2007. Effects of organic and mineral fertilizer inputs on maize yield and soil chemical properties in a maize cropping system in Meru South District, Kenya. Agroforestry Systems. 69: 189-197.

Mucheru-Muna,M.W., Mugendi, D., Pypers, P., Mugwe, J., Kung'u, J., Vanlauwe, B., and Merckx, R. (2014). Enhancing maize productivity and profitability using organic inputs and mineral fertilizer in central Kenya small- hold fields. Experimental Agriculture. 50: 250-269.

Mucheru-Muna MW, Mugendi D, Mugwe J, and Kung'u J 2009. Soil mineral N dynamics in a maize crop following different soil fertility amendments in different soil fertility status in sub-humid and semi-arid regions in Central Kenya. Research Journal of Agriculture and Biological Sciences. 5 (6): 978-993

Mucheru-Muna,M.W., Pypers, P., Mugendi, D., Kung'u, J., Mugwe, J., Merckx, R., and Vanlauwe, B. 2010. A staggered maize- legume intercrop arrangement robustly increases crop yields and economic returns in the highlands of Central Kenya. Field Crops Research. 115: 132-139.

Mugendi D.N., Kanyi M.K., Kung'u J.B., Wamicha W. and Mugwe J.N. 2003. Mineral-N movement and management in an agroforestry system in central highlands of Kenya. In: Proccedings for soil science society of East Africa Conference, Mombasa ,4 Mombasa, 4-8 December 2000, pp. 287-297.

Mugwe J., Mugendi D., Kungu J. and Mucheru-Muna M.M. 2009. Maize yields response to application of organic and inorganic input under on-station and on-farm experiments in central Kenya. Expl. Agric. 45: 47-59.

Mureithi J. G., Macharia P. N., Kiiya W. W., Gitahi F. M. and Nekesa C. O. 2006. Identifying suitable green manure legumes for the major agro-ecological zones in Kenya: Legume screening and database development. In: Development and up-scaling of green manure legume technologies in Kenya. Ed. Mureithi, J. G., Gachene, C.K.K., Wamuongo, J. W. and Eilitta, M. Kenya Agricultural Research Institute. pp. 9-42.

Nelson D.W. and Sommers L.E. 1996. Total carbon, organic carbon, and organic matter. p. 961-1010. In D.L Sparks et al. (eds.) Methods of soil analysis. Part 3. Chemical Methods. SSSA Book Series No. 5, SSSA and ASA, Madison.

Ngome A.F., Becker M., Mtei K.M., Mussgnug M. 2011a. Fertility management for maize cultivation in some soils of Kakamega, Western kenya. Soil Tillage Res. 117: 69-75.

Ngome A.F., Becker M., Mtei M.K., Mussgnug F. 2012. Management options and soil types differentially affect weeds in maize fields of Kakamega, Western Kenya. J. Agric. Sci. Technol. 2: 104-114.

Ngome A.F., Mtei M.K., Becker M. 2011b. Leguminous cover crops differentially affect maize yields in Western kenya. J. Agric. Rural Dev. Trop. 112: 1-10.

Niehues B.J., Lamond R.E., Godsey C.B. and Olsen C.J. 2004. Starter nitrogen fertilizer management for continuous n0-till corn production.Agron. J. 96: 1412-1418.

Nyamangara J., Piha M.I. and Giller K.E. 2003. Effect of combined cattle manure and mineral nitrogen on maize N uptake and grain yield. African Crop Sci. J. 11: 289-300.

Nziguheba G., Merckx R., Palm C.A. and Rao M.R. 2000. Organic residues affect phosphorous availability and maize yields in Nitisol of Western Kenya. Biol. Fert. Soils. 32: 328-339.

Obi C. O., Nnabude P. C., Nnabude and Onucha, E. Onucha. 2005. Effects of kitchen waste compost and tillage on soil chemical properties and yield of Okra (*Abelmuschus esculentus*), Soil Sci. 15: 69-76.

Okalebo J.R., Gathua K.W. and Woomer P.L. 2002. Laboratory methods of soil and plant analysis: A working manual. 2nd Edn. TSBFCIAT and SACRED Africa, Nairobi, Kenya. p. 128.

Palm C. A., Myers R. J. K. and Nandwa S. M. 1997. Combined Use of Organic and Inorganic Nutrient Sources for Soil Fertility Maintenance and Replenishment. In: Buresh, R. J., and Sanchez, P. A., (Eds). Replenishing soil fertility in Africa. Soil Science Society of America and American Society of Agronomy, Madison, Wisconsin, U.S.A. pp. 193-217.

Pessarakli M. (ed.) 2002. Handbook of Plant and Crop Physiology. Eastern Hemisphere Distribution, Marcel Dekker Inc., New York, Basel, 940.

Pittman J., Zhang H., Schrode,r J.L. and Payton M.E. 2005. Differences of phosphorus in mehlich 3 extracts determined by colorimetric and spectroscopic methods. Commun. Soil Sci. and Pl. Anal. 36: 1641-1659.

Plénet D., Mollier A. and Pellerin S. 2000. Growth analysis of maize field crops under phosphorus deficiency. II. Radiation use efficiency, biomass accumulation and yield components. Plant Soil. 224: 259-272.

Potarzycki J and Grzebisz W. 2009. Effect of zinc foliar application on grain yield of maize and its yielding components. Plant, Soil and Environment. 55: 519-527 pp. 9-42.

Randhawa P.S and Arora C.L. 2000. Phosphorus-sulfur interaction effects on dry matter yield and nutrient uptake by wheat. Journal of Indian Society of Soil Science. 48(3): 536-540.

Rasheed M., Mahmood T., Nazir M.S., Bhutta W.A., Ghaffar A. 2004. Nutrient Efficiency and Economics of Hybrid Maize Under Different Planting Methods and Nutrient Levels. Int. J. Agri. Biol. 6(5): 922-925.

Reddy, M.A., and Dakota, F.D. (2007). Yield components of nodulated cowpea (*Vigna unguiculata*) and maize (*Zea mays*) plants grown with exogenous phosphorus in different cropping systems. Australian J Exp Agric 47:583-589.

Rehman A., Saleem M.F., Safdar M.E., Hussain S. and Akhtar N. 2011. Grain quality, nutrient use efficiency, and bio-economics of maize under different sowing methods and NPK levels. Chilean J. Agric. Res. 71(4): 586-593.

Romney D.L., Thorne P., Lukuyu B., Thornton P.K. 2003. Maize as food and feed in intensive smallholder systems: management options for improved integration in mixed farming systems of East and Southern Africa. Field Crops Res. 84: 159-168.

Roy R.N., Misra R.V., Lesschen J.P. and Smaling E.M.A. 2003. Assessment of soil nutrient balance, approaches and methodologies. FAO fertilizer and plant nutrition bulletin 14. FAO, Rome, Italy.

Rutunga V., Gachene C.K.K., Karanja N.K., Palm C.A. 2003. Grain maize yield improvement using *Tephrosia vogelii* and *Tithonia diversifolia* biomass at Maseno, Kenya. Trop. Subtrop. Agroecosyst. 2: 1-11.

Saeed I. M., Abbasi R., Abbasi and Kazim M. Kazim. 2001. Response of maize (*Zea mays*) to nitrogen and phosphorus fertilization under agro-climatic condition of Rawalokol, Azad Jammu and Kaslim and Kashmir, Pak. J. Biological Sci. 4: 949-952.

Sahoo S.C., and Panda M. 2001. Effect of phosphorus and de-tasseling on yield of baby-corn. Indian J. Agric. Sci. 71: 21-22.

Sakala W.D., Kumwenda J.D., Saka A.R., and Kabambe V.H. 2001. The potential of green manures to increase soil fertility and maize yields in Malawi. Soil Fertility Network Research Results.Working paper No. 7. CIMMYT and Kenya Agricultural Research Institute, Nairobi, Kenya.

Samira M., Hussein M.A., Haikel M and El-Masry M.A. 1998. Effect of some preceding crops, hill spacing and nitrogen fertilization on yield attributes and grain yield of maize under reclaimed sandy soil conditions in East Delta. Proc. 8th Conf. Agron., Suez Canal Univ., Ismailia, Egypt, 28-29 November. pp. 174-181.

Sangoi L., Rernani P. and Silva P. R.F. 2007. Maize response to nitrogen fertilization timing in two tillage systems in a soil with high organic matter content. Rev. Bras. Ciênc. Solo. Vol. 31: 507-517.

SAS Institute Inc. 2009. SAS®9.2 Macro Language: Reference. Cary, NC: SAS Institute Inc.

Schroder J.L., Zhang H., Richards J.R. and Payton M.E. 2010. An inter-laboratory validation of Mehlich 3 as a universal extractant for plant nutrients. J. AOAC International.

Shanahan J. F., Kitchen N. R., Raun W. R. and Schepers J. S. 2008. Responsive in-season nitrogen management for cereals Computers and Electronics in Agriculture. 61(1): 51-62.

Shepherd K.D., Ndufa J.K., Ohlsson E., Sjogren H. and Swinkels R. 1997. Adoption potential of hedgerow intercropping in maize-based cropping systems in the highlands of western Kenya. I. Background and agronomic evaluation. Exp. Agric. 33: 197-223.

Sumi A. and Ketayama T.C. 2000. Effect of nitrogen fertilizer application and solar radiation on the growth response of sorghum seedling to soil moisture. Crop Sci. 69: 513-519.

Tang D.T., Vu T. and Amstron R.D. 2007. Changes and availability of P fraction following 65 years' application to a calcareous soil in a Mediterranean climate. Plant soil. 304: 21-33.

Torbert H.A., Potter K.N. and Morrison J.E. 2001. Tillage system, fertilizer nitrogen rate and timing effect on corn yields in the Texas Blackland prairie. Agron. J. 93: 1119-1124.

Vanlauwe B., Diels J., Aihou K., Iwuafor E.N.O., Lyasse O., Sanginga N. and Merckx R 2002b. Direct interactions between N fertilizer and organic matter: Evidence from trials with 15N-labelled fertilizer. pp. 173-184. *In* B. Vanlauwe *et al*. (ed.) Integrated plant nutrient management in Sub- Saharan Africa. CABI, Wallingford, UK.

Vanlauwe B., Diels J., Lyasse O., Aihou K., Iwuafor E. N. O., Sanginga N., Merckx R. and Deckers J. 2002a. Fertility status of soils of the derived savanna and northern guinea savanna and response to major plant nutrients, as influenced by soil type and land use management. Nutrient Cycling in Agro ecosystems. 62: 139-150.

Wang Y., Wang E., Wang D., Huang S., Ma Y., Smith C.J., Wang L. 2010. Crop productivity and nutrient use efficiency as affected by long-term fertilization in North China Plain. Nutr. Cycl. Agroecosyt. 86, 105-11.

Wopereis M. C. S., Tamelokpo A., Ezui K., Gnakpenou D., Fofana B. and Breman H. 2006. Mineral fertilizer management of maize on farmer fields differing in organic inputs in the West African savanna. Field Crops Research. 96: 235- 362.

Zhang J., Blackmer A.M. Ellsworth J.W. and Koehler K.J. 2008a. Sensitivity of chlorophyll meters for diagnosing nitrogen deficiencies of corn in production agriculture. Agron. J. 100: 543-550. doi:10.2134/agronj2006.0153.

Zhang J., Blackmer A.M., Blackmer P.M., Van De Woestyne, Kyveryga B.W. Van D. W. and Blackmer T.M. 2008b. Fertilizer-induced advances on corn growth stage and quantitative definitions of nitrogen deficiencies. Pedosphere. 18: 60-68. Doi: 10.1016/S1002-0160(07)60103-9.

Zhang J., Blackmer A.M., Blackmer T.M. 2007. Check for differences in physiological age when diagnosing deficiencies of nitrogen in corn-fields, J. Agron. (in press). http://www.ansijournals.com/ja/o/166-JA-2k6.pdf.

Zhang J., Blackmer A.M., Blackmer T.M. and Kyveryga P.M. 2010a. Fertilizer bands and dual effects of nitrogen on young corn plants. Better Crops. 94(2):17-19.

Zhang J., Blackmer A.M., Blackmer T.M. and Kyveryga P.M 2010b. Fertilizer bands affect early growth of corn. Commun. Soil Sci. Plant Anal. 41:1306–1314. doi:10.1080/00103621003759312

Zingore S., Manyame C., Nyamugafata P. and Giller K. E. 2005. Long-term changes in organic matter of woodland soils cleared for arable cropping in Zimbabwe. European Journal of Soil Science. 56:727-736.

Zingore S., Murwira H. K., Delve R. J. and Giller K. E. 2007. Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. Agriculture Ecosystems & Environment. 119: 112- 126.