Growth and Yield of Maize (*Zea Mays* L.) as Affected by Application Rates of Different NPK Fertilizer Formulations in Northern Ghana

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Abstract

Most farmers in the Northern Region of Ghana are unaware of the existence and role of NPK formulations such as NPK 20-10-10, NPK 20-20-20, NPK 17-17-17, NPK 23-10-10 and NPK 23-10-5. The most commonly used formulation in Ghana is NPK 15-15-15. Pot and field studies were conducted at the University for Development Studies, located in the Guinea Savannah agroecology of Ghana from January to April (Dry season pot experiment) and from June to October (Rainy season field studies) of the year 2015, to study the growth and yield response of maize to the various application rates of NPK fertilizer formulations. Four NPK formulations: 15-15-15, 23-10-5, 23-10-10 and 20-10-10 were applied at 0, 350, 375 or 400 kg/ha to maize. The treatment combinations were replicated four times in a randomized complete block design for the field studies. The pot study however, was laid out using completely randomized design. Results indicated that the application of 375 and 400 kg NPK/ha gave the best performance in all fertilizer formulations, and in all instances did not differ significantly ($P > 0.05$) from each other. Grain yield increased linearly with chlorophyll content, leaf area, stem girth, cob length, cob weight, stover weight, number of seeds per cob and thousand seed weight. Benefit - cost analysis revealed that all control plots recorded losses, whilst all treated plots recorded profits. The application at 375 kg/ha provided the most profit in almost all fertilizer formulations.

Keywords: Maize, Northern Ghana, NPK formulations, NPK application rates, productivity.

Introduction

Maize is the largest staple crop in Ghana and contributes significantly to consumer diets (FAO, 2008). It is the number one crop in terms of area planted and accounts for 50-60% of total cereal production (MoFA, 2010). Most people regard maize as a breakfast cereal. However, in a processed form it is also utilized as fuel (ethanol) and starch. As a source of starch, it involves enzymatic conversion into products such as sorbitol, dextrine, sorbic and lactic acid, and appears in household items such as beer, ice cream, syrup, shoe polish, glue, fireworks, ink, batteries, mustard, cosmetics, aspirin and paint (Du-Plessis, 2003).

Several decades of nutrient depletion has transformed the originally fertile arable lands that yielded 2-4 t/ha of cereal grain, into infertile ones where cereal crop yields of less than 1 t/ha are common (Bekunda *et al*., 1997). Low soil fertility has been identified as one of the major biophysical constraints adversely affecting maize production in the tropics (Sanchez *et al*., 1997). As soil is continuously cropped over long periods of time, soil conditions have changed over the years and the old fertilizer recommendations are becoming less efficient hence the need to update fertilizer recommendations for maize production. Low fertility status of most tropical soils hinders maize production because maize has a strong demanding effect on the soil. The availability of sufficient growth nutrients from inorganic fertilizers led to improved cell activities, enhanced cell multiplication and enlargement and luxuriant growth (Fashina *et al.*, 2002). Regardless of the availability of numerous fertilizer formulations in the Ghanaian market, the use of adequate fertilizer remains low primarily due to poverty among farmers, coupled with the unawareness of different fertilizer formulations (*Bänziger et al*., 1997). In recent times, there has been an increase in the use of fertilizer by farmers in Sub- Saharan Africa but crop yield is still low (Adjognon *et al.,* 2017). Therefore, it is glaring that high productivity is the function of the use of new innovations like fertilizer technology. Farmers are unaware of other NPK formulations such as NPK 20-10-10, 20-20-20, 17-17-17, 23-10-10 and 23-10-5. For these reasons, studies were conducted to determine growth and yield response of maize to the rate of application of the various NPK fertilizer formulations.

Materials and Methods

Description of study area

Pot and field experiments were conducted at the University for Development Studies, Tamale, Ghana, during the dry season (January to April) and wet season (June to October) of the year 2015. The experimental location lies on an altitude of 183 m, latitude 09° 25' N and longitude 0° 58'W. The selected area is within the interior Guinea Savannah agroecological zone and is subjected to marked wet and dry season with a unimodal total annual rainfall approximately 1022 mm which is evenly distributed from May to October, reaching a peak in August and September. The average minimum temperature is 25˚C whilst the maximum average temperature is 35˚C (Lawson *et al*., 2013). Soils are moderately drained and are free from concretions; they are shallow with hardpan under the top few centimetres and were derived from Voltaian sandstone (FAO, 1988). Physico – chemical properties of soils at the experimental site prior to field studies were as shown in Table 1.

Soil sampling and analysis

Soil samples were taken using a soil auger along the two diagonals of the field prior to experimentation. Ten cores, taken at a 15 cm depth along each diagonal at a regular interval of 5.17 m were composited. The samples were air dried by placing them on a shallow tray in a well-ventilated area. The soil lumps were crushed and gravel, roots and organic residues were removed from the samples. Then, the soil was sieved using a 2 mm mesh prior to analysis at the soil chemistry laboratory of the Council for Scientific and Industrial Research (CSIR) - Savanna Agriculture Research Institute (SARI), Nyankpala.

Soil pH in 0.01 M $CaCl_2$ was determined using glass electrode whilst particle-size distribution was determined by the hydrometer method according to Ashworth *et al.* (2001). The Walkley and Black (1934) dichromate digestion method was used for the determination of organic matter content of the soil whilst total nitrogen was by the micro-kjeldahl technique according to Bremner and Mulvancy (1982). Available P was determined using the procedure of Murphy and Riley (1962). Ammonium acetate was used in the extraction of exchangeable K^+, Ca^{2+} and Mg^{2+}. Potassium was determined using the flame photo meter whilst calcium and magnesium ions were determined by the EDTA titration procedure.

Experimental layout and treatments

Both the pot and field studies were 4 x 4 factorial experiments. Four levels of NPK fertilizer formulations: 15-15-15, 23-10-5, 23-10-10 and 20-10-10 were applied at the following four rates: 0 kg/ha, 350 kg/ha (225 kg NPK/ha as basal and 125 kg Sulphate of ammonium/ha as top dressed), 375 kg/ha (250 kg NPK/ha as basal and 125 kg Sulphate of ammonium/ha as top dressed) or 400 kg/ha (275 kg NPK/ha as basal and 125 kg Sulphate of ammonium/ha as top dressed) to maize. The rates of NPK fertilizers used were in accordance with the recommendations on mineral fertilization for maize production in Ghana according to MoFA (1998). The 16 treatment combinations were laid out in randomized complete block (RCBD) and completely randomized designs (CRD) for the field and pot studies respectively, with four replications. In the case of the pot study, cylindrical plastic containers (7221.78 cm^3) were used as the experimental units. Holes were perforated underneath the containers to drain excess water during watering. Each container was filled with 11 kg of Nyankpala soil series and three seeds of maize were planted in each pot then thinned to two seedlings after emergence. For the field study, the experimental site was ploughed, harrowed and demarcated into plots, each measuring 12 m^2 with 1 m and 2 m alleys between plots and replications respectively. Planting was done at a spacing of 40 x 80 cm and at seeding rate of two per stand. The pots and field were cleared of weeds manually at 3, 6 and 9 weeks after planting. For the pot experiment, two liters of water was applied to each pot twice a day, that is morning and evening. In both experiments, basal application of the respective NPK fertilizer formulations at the various rates were carried out at 2 weeks after planting and top-dressed with sulphate of ammonia at 8 weeks after planting. Fertilizers were applied by side placement, 5 cm away from the plants.

Data collection

Chlorophyll meter (Minolta SPAD- 502) that measures the relative index of leaf chlorophyll concentration was used for leaf chlorophyll measurement. The instrument was first calibrated and clipped to three points: lower, middle portion and towards the top of the leaves. Three leaves (from top, middle and base of plant canopy) were selected for each plant for measurement and averages computed. The girth of stem was measured at the third internode from the soil surface using a micrometer screw gauge. Leaf lengths and widths were measured using a metre rule. The leaf length was measured from the origin of the leaf blade and leaf sheaths to the tip whilst leaf width was measured at the widest part of the leaf. The number of leaves per plant at the time of data collection was obtained by counting the leaves. The total leaf area was calculated according to the formulae developed by Stewart and Dwyer (1999) as follows:

total leaf area = LL x LW x K x N, where LL= leaf length, LW = leaf width, K = leaf area constant of maize of 0.73.

After harvest, the plants were chopped into pieces and placed in separate envelops then dried in an oven at 80°C for 24 hours. Cobs harvested from plants from each experimental unit were threshed and the seeds dried to 13% moisture content prior to weighing and thousand seeds counted from each treatment combination. The total weight of grains from each plot was recorded and converted to kilogrammes per hectare (kg/ha). Additionally, input, labour and total costs as well as service charges and total revenue for the various treatment combinations were computed on per one-hectare production. Benefit/cost ratios were computed using the formula Benefit/Cost (B/C) = Total Revenue/Total Cost (Adegede and Dittoh, 1985); where Total Cost = Labour Cost + Input Cost + Service Charges, and Total Revenue = Total income obtained after sale of produce.

Data analysis

Data collected on various parameters were subjected to analysis of variance using Genstat statistical package, 12th edition and means separated using LSD at 5 % probability level.

Results

Soil physico – chemical properties

The soils used for the study were essentially sandy and had low mineral retention capacity as shown in Table 1.

Table 1: Physico - chemical properties of the soil used for the study

Soil Parameters	Values
pH	5.26
Organic carbon (%)	0.51
CEC (cmol/kg)	2.10
Nitrogen (g/kg)	0.04
Phosphorus (mg/kg)	8.70
Potassium (mg/kg)	68.00
Calcium (cmol/kg)	1.40
Magnesium (cmol/kg)	0.40
Sand (g/kg)	536.00
Clay (g/kg)	3.60
Silt (g/kg)	460.40

Vegetative growth of maize plants with different NPK types and application rates

For the pot experiment, plants that received NPK 23-10-5 applied at 400 kg/ha recorded the highest chlorophyll content though similar to plots treated with NPK 23-10-5, 15-15-15 and 23-10-10 applied at 375 and 400 kg/ha (Figure 1a). The lowest chlorophyll content of plants was observed in plants from the control plots while the highest chlorophyll content of plants from the field experiment were recorded by plants that received 400 kg/ha fertilization in respective NPK formulations. In general, plants that received 400 kg/ha recorded similar chlorophyll content as those treated with 375 kg/ha. For NPK 23-10-5, similar content of chlorophyll were recorded among plants from plots that received 400 and 350 kg/ha (Figure 1b).

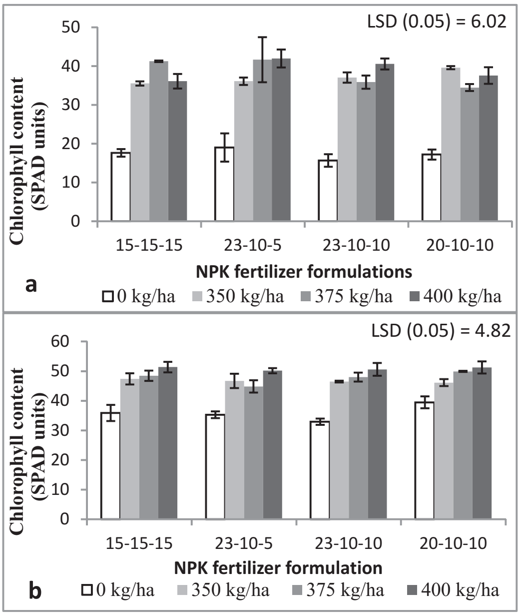

Figure 1: Effect of NPK fertilizer formulations and application rates on chlorophyll content of plants from pot (a) and field (b) studies.
Error bars indicate mean ± S.E.M (Standard error of means) of four replications.

The highest leaf area in the pot experiment was recorded by plants fertilized with NPK 23-10-10 and applied at 400 kg/ha. It was however, not significantly ($P > 0.05$) different to the leaf area recorded by the same fertilizer formulation at 375 and 350 kg/ha as well as 23-10-5 applied at 400 and 375 kg/ha and 15-15-15 applied at 375 kg/ha (Figure 2a). For the field study, the highest leaf area was recorded by plants treated with 400 kg/ha NPK from the various fertilizer formulations (Figure 2b). However, plants treated with 400 kg/ha NPK formulations recorded similar leaf area as those treated with 375 kg NPK/ha from all formulations, but varied significantly ($P < 0.05$) from plants treated with 350 kg/ha. The least leaf area was recorded by plants from the untreated control.

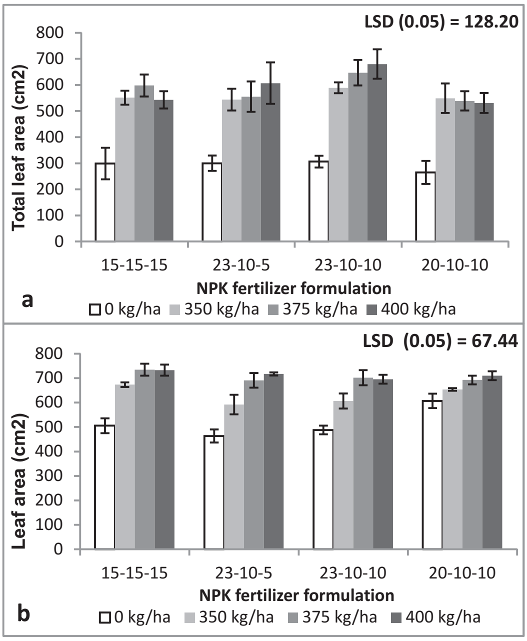

Figure 2: Effect of NPK fertilizer formulations and application rates on leaf area of plants in pot (a) and field (b) studies.

Error bars indicate mean ± S.E.M (Standard error of means) of four replications.

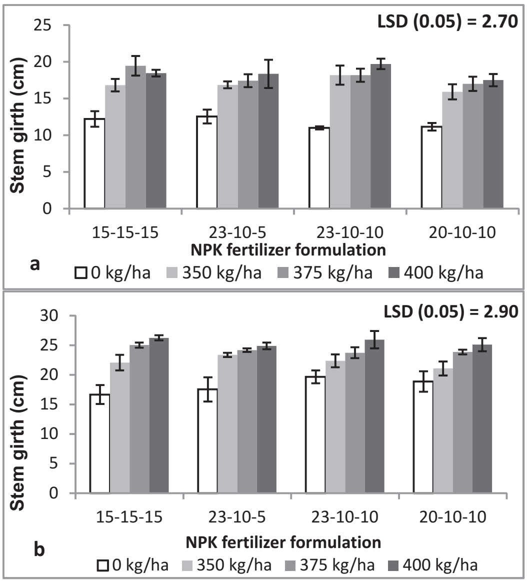

Figure 3: Effect of NPK fertilizer formulations and application rates on stem girth of plants in pot (a) and field (b) studies.
Error bars indicate mean ± S.E.M (Standard error of means) of four replications.

In general, plants fertilized with 400 kg/ha of NPK 23-10-10 recorded the widest stem girth in the pot experiment. It was however, not significantly different to the girth recorded by plants from the same fertilizer formulation at 375 and 350 kg/ha, as well as, NPK 23-10-5 and 15-15-15 applied at 400 and 375 kg/ha (Figure 3a). The widest stem girth in the field study was recorded by plants that received 400 kg NPK/ha in respective fertilizer formulations, and were significantly ($P > 0.05$) similar to values recorded by plants treated with 375 kg NPK/ha fertilization (Figures 3b). The highest stover weight was, however, recorded by plants treated with 400 kg/ha of NPK 23-10-10 but this value was similar to stover weights recorded for plants treated with 400 kg/ha of NPK 15-15-15 and 20-10-10; and 375 and 400 kg/ha of NPK 23-10-5 (Figure 4).

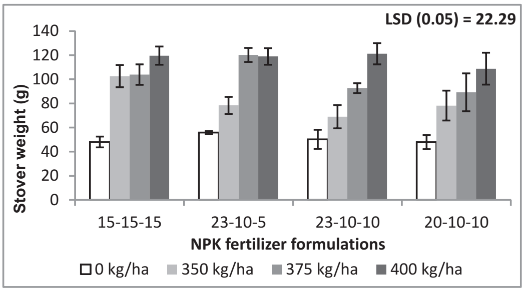

Figure 4: Effect of NPK fertilizer formulations and application rates on stover weight during field experimentation.

Error bars indicate mean ± S.E.M (Standard error) of means of four replications.

Yield components and yield of maize treated with different rates of NPK formulations

The cob length was greatest in plants treated with 375 kg/ha of NPK 23-10-5 (Figure 5a). This value was however, similar (P > 0.05) to the length recorded for plants treated with 400 kg/ha of NPK 23-10-5 and 23-10-10, as well as 375 and 400 kg/ha of NPK 15-15-15 and NPK 20-10-10. For NPK 15-15-15 and 20-10-10 formulations, however, plants that received 350 kg/ha fertilization obtained similar cob length as plants treated with 375 kg NPK/ha. Plants treated with 400 kg/ha of NPK 15-15-15 obtained the highest cob weight (Figure 5b). This was however not significantly (P > 0.05) different from the weight recorded by plants treated with 375 kg/ha from the other fertilizer formulations. Plants from the untreated control recorded the lowest cob weight and lowest number of seeds per cob. The highest number of seeds per cob was produced by plants treated with 400 kg/ha of NPK 15-15-15, and was not significantly (P > 0.05) different from the number of seeds produced by plants that received 375 kg/ha of NPK 15-15-15, as well as 375 and 400 kg/ha of NPK 23-10-5 (Figure 6a). Plants treated with 350, 375 and 400 kg/ha of the various NPK formulation produced the same values of 1000 seed weight (Figure 6a). The lowest seed weights were recorded in respective control plots for various fertilizer formulations. Plants treated with NPK 15-15-15 at 375 kg/ha recorded the highest total grain yield (Figure 7). This was however, significantly (P > 0.05) similar to the yield level obtained from plants treated with 400 kg/ha of NPK 15-15-15, as well as 375 and 400 kg/ha of NPK 23-10-5 and 20-10-10. Plants in the untreated control plots recorded the least grain yield.

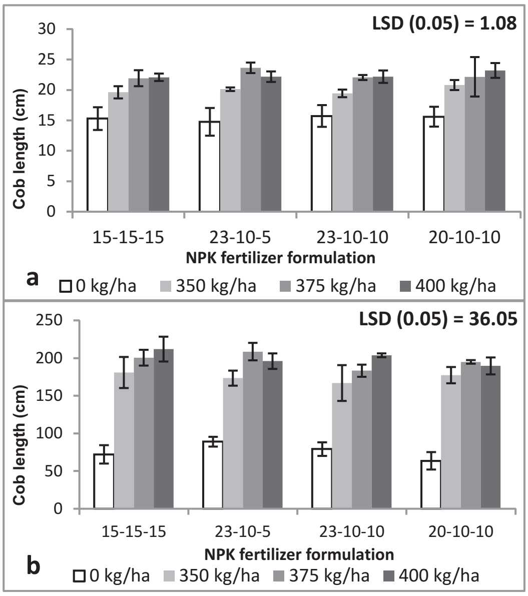

Figure 5: Effect of NPK fertilizer formulations and application rates on cob length (a) and cob weight (b) in field the experiment.

Error bars indicate mean ± S.E.M (Standard error) of means of four replications

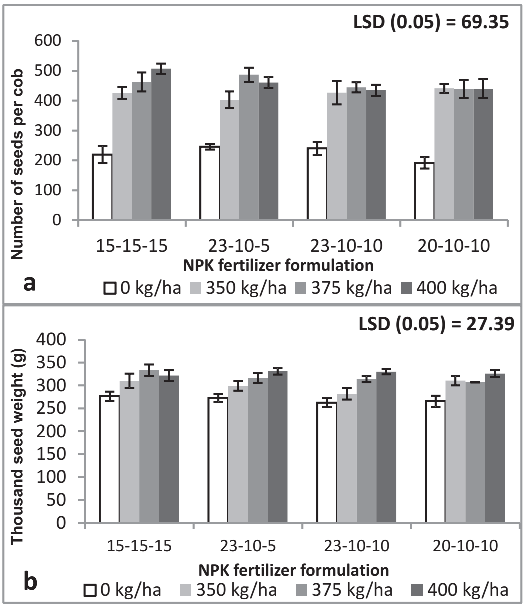

Figure 6: Effect of NPK fertilizer formulations and application rates on number of seeds per cob (a) and thousand seed weight (b) in the field experiment.

Error bars indicate mean ± S.E.M (Standard error of means) of four replications.

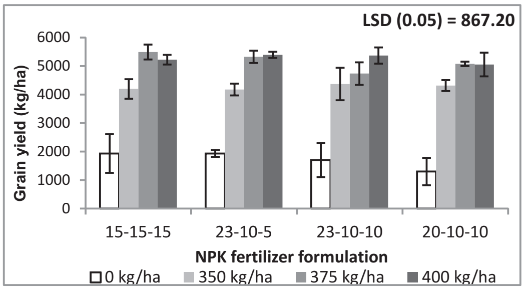

Figure 7: Effect of NPK fertilizer formulations and application rates on grain yield of maize during field experimentation.

Error bars indicate mean ± S.E.M (Standard error of means) of four replications.

Benefit/cost analysis

It was indicative from the results on benefit-cost (Table 2) that all control plots recorded losses, and all the treated plots recorded profits. Application at 375 kg/ha of the NPK from various formulations provided the maximum profit. For NPK 23-10-10, however, the maximum return was achieved by the application of the formulation at 400 kg/ha. Fertilizer NPK 15-15-15 at 375 kg/ha recorded the highest average return.

Table 2: Benefit – Cost (B/C) analysis* for the treatment combinations

NPK Fertilizer Formulation	Rates Kg/Ha	Service Charge (USD)	Input Cost (USD)	Labour Cost (USD)	Total Cost (USD)	Total Revenue (USD)	B/C Analysis
15:15:15	0	20.60	16.48	212.20	249.28	244.43	0.98
	350	27.81	98.68	217.35	343.84	532.39	1.55
	375	28.43	104.66	223.53	356.41	696.52	1.95
	400	28.84	110.42	228.68	367.94	662.42	1.80
23:10:5	0	20.60	16.48	212.20	249.28	245.06	0.98
	350	27.81	110.22	217.35	355.38	529.30	1.49
	375	28.43	117.02	223.53	368.77	674.72	1.83
	400	28.84	123.61	228.68	381.13	684.10	1.79
23:10:10	0	20.60	16.48	212.20	249.28	215.14	0.86
	350	27.81	105.89	217.35	351.05	554.02	1.58
	375	28.43	112.28	223.53	364.24	600.42	1.65
	400	28.84	118.67	228.68	376.18	681.55	1.81
20:10:10	0	20.60	16.48	212.20	249.28	164.31	0.66
	350	27.81	103.01	217.35	348.17	547.43	1.57
	375	28.43	109.19	223.53	361.15	643.78	1.78
	400	28.84	115.37	228.68	372.89	563.28	1.51

*Analyses based on one hectare production of maize under field conditions.

Discussion

Chlorophyll content of plants generally increased following the application of the fertilizer formulations. Hokmalipour and Darbandi (2011) also made a similar observation in maize. The increased chlorophyll content recorded in the study was attributed to the availability of nutrients particularly N in the soil following the application of the fertilizers. In general, application of fertilizers to soils is essential in maintaining balances in the soil nutrient (Buri *et al*., 2008). Addai and Alimiyao (2015) reported that northern Ghanaian soils have low nutrient properties and often require soil amendment to boost crop production. Results on soil physicochemical analysis conducted in the present study confirmed this finding as the soils used for the study were low in nutrients. Thus, the application of the mineral fertilizers to the soil might have enhanced chlorophyll formation and synthesis through increases in photosynthetic activity of the treated plants which promoted rapid leaf growth (Ekwere *et al.*, 2013). The study showed that leaf area also increased with increases in the rates of the applied fertilizers. This observation agrees with Maqbool *et al*.

(2016) who also observed a significant effect of fertilizer application on leaf area index of maize. The increased leaf area and stem girth following fertilization was probably due to improved leaf expansion and stomatal conductance which might have enhanced photosynthetic activities of the leaves resulting in efficient assimilate production of the source. The low values of chlorophyll content and vegetative parameters of the unfertilized plants were therefore attributable to poor soil fertility. Amendments of the soil with the formulations generally improved the nutrient holding status of the soil for improved growth and efficient crop performance especially in terms of grain production (Morteza and Shankar, 2013). The observed increased seed weight following the application of higher rates of NPK might have resulted from the high leaf area which enhanced light interception leading to high assimilate production (Tripathi *et al*., 2018). The compound fertilizers provided the essential primary nutrients for growth and development, and they were prerequisites for the production of meristematic and physiological activities such as leaves, roots, shoots as well as dry matter. This resulted in efficient absorption and translocation of water and nutrients, and utilization of solar energy for improved carbon dioxide fixation as well as efficient partitioning or translocation of assimilates from sources to sinks (Stone *et al*., 2001).

In general, the higher the rates of application of the formulations, the higher the grain yields of maize. Trends in total grain yield and yield components recorded in the study are in agreement with the findings of Onasanya *et al.* (2009) who reported that the application of higher N and P rates (above 120 kgN/ha and 40 kg P) enhanced the grain yield of maize. Similarly, the increase in number of seeds per cob and cob lengths were all as a result of increases in rates of the applied fertilizers and improved physiological processes in maize which led to higher growth and supply of photosynthates to sinks (Whitbread *et al*., 2004). Variation in yield parameters of plants receiving the different rates and /or fertilizer formulations may have been attributed to differences in their supply of the elemental N, P and K. Achieng *et al.* (2010) also observed high number of cobs, dry matter accumulation and total grain yield of maize following the application of NPK fertilizers.

Economic analysis was computed to determine the benefits that characterized the various treatment combinations in the study and results from this analysis showed that the untreated plots recorded losses whilst all treated plots recorded profits. The implication here is that, the applied fertilizer formulations provided optimum quantities and proportions of the essential plant nutrients needed by maize to increase grain yield and to maximize profit. Adegede and Dittoh (1985) reported that any time the benefit - cost ratio is less than 1, then the business enterprise runs at a loss. However, when the ratio is equal to 1 the business is breaking even and when the ratio is greater than 1 the business is making profit. Therefore plants fertilized with 375 or 400 kg/ha rate of the NPK from the various formulations generally maximized the most profit.

Conclusion

The application rate of 400 or 375 kg/ha of the NPK was effective for the optimum growth and yield of maize, and in most cases did not vary significantly from each other. Hence exceeding 375 kg/ha may not be economical, as evident from the benefit - cost ratio. The study therefore recommends that irrespective of NPK fertilizer formulation, application of 375 kg/ha is recommended in maize production for maximum yield and profit. Based on accessibility and affordability, however, NPK 15-15-15 is highly recommended among the various formulations but should be applied at 375 kg/ha for optimum yield. The study also revealed that the application of 350 kg/ha in the case of NPK 23-10-10 could result in increased yield of maize and profit in the study area.

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