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RESEARCH ARTICLE

RESPONSE OF MAIZE (*ZEA MAYS L.*) TO DIFFERENT LEVELS OF NITROGEN AND SULFUR FERTILIZERS IN CHILGA DISTRICT, AMHARA NATIONAL REGIONAL STATE, ETHIOPIA

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ABSTRACT

Grain yield of cereals such as maize in the highlands of northern Ethiopia is low mainly due to the low content of essential nutrients. Fertilizer application has commonly done by blanket recommendation of fertilizer rates without soil test and tissue analysis for a specific site. Use of fertilizers in Ethiopia is dominantly based on nitrogen (N) and phosphorus (P). The attention given to other essential nutrients such as sulfur (S) is practically none. The objective of this study was to evaluate the yield response of maize to different rates of N and S and recommend N and S fertilizers to maize production on Vertisols of Chilga District. The experiment was conducted during the 2008 growing season. The experimental design was laid out as two-factor experiment of three levels of S and four levels of N in Randomized Complete Block Design (RCBD) with three replications. The S rates were (0, 15 and 30 kg S ha^{-1}) and four rates of N (0, 30, 60 and 90 kg N ha^{-1}) and the test crop was hybrid maize of BH-540. The experimental site is low in its soil fertility status: slightly acidic (pH 6.5); clay in texture (23.3 % sand, 21.9 % silt and 54.8 % clay); high in CEC 65.3 cmol+/kg; soil organic carbon content of 1.4%; total N 0.09%; and available S 1.5 ppm. Nitrogen concentration of maize leaves was increased with increasing N rates. The results of the experiment showed that the maximum grain yield for the main effect N fertilizer was recorded in plots treated with 90 kg N ha^{-1} while for S fertilizer in plots treated with 15 kg S ha^{-1}. For fertilizers N and S interactions, the maximum grain yield and dry biomass were recorded on plots treated with the combination of 90 kg N with 15 kg S ha^{-1} rates which were significantly higher ($p \leq 0.05$) than the control by 391.7 and 479.9%, respectively. This work showed that the yield response and nitrogen use efficiency (NUE) of maize crop were improved with N and S fertilizer applications that benefit the maize-producing farmers in soils deficient in these nutrients.

INTRODUCTION

Background of the Study

Erosion is the main land degradation problem in the high lands and in Ethiopia, about 50% of land degradation in the form of water erosion comes from croplands (Kruger *et al.*, 1996). The average annual soil loss from these arable lands has estimated to be 42 ton per hectare (t ha^{-1}) and sometimes reaching 280 t ha^{-1} from steep plateaus of the highlands, with the average annual production decline of croplands by 0.2% (Hurni, 1993). Low soil fertility is one of the bottlenecks to sustainable agricultural production and productivity in Ethiopia (Wakene *et al.*, 2007).

Chemical fertilizers play a major role in supplementing soil's ability to provide both macro and micro nutrients for crops (Nyle, 2002).The use of mineral fertilizers (e.g. N, P and potassium (K)) has been proven to improve yields in short terms in Ethiopia (Jozef, 1998). A study of the maize production trends in East Africa (Ethiopia, Kenya, and Tanzania) showed that maize yields increased substantially (from 1 t ha^{-1} in the early 1960s to 1.5 t ha^{-1} in the mid 1980s) which could be attributed partly to the increase in the use of inorganic fertilizers (Hugo *et al.*, 2002). However, even if fertilizers are available, farmers are unable to apply them at recommended rates and appreciable time (Peter, 2002). In spite of efforts made by the government of Ethiopia to develop the agricultural sector, agricultural productivity growth remain low and the majority of farmers practice low-input. Inorganic fertilizers in Ethiopia are used by only approximately 30% households and cover 37% of the cultivated area (http://www.aec.msu.edu/agecon,).

Nitrogen is an indispensable nutrient for plant growth and its yield (Kiros, 2007). Nitrogen is a vital plant nutrient and a major yield determining factor required for maize production by which its availability in sufficient quantity throughout the growing season is essential for optimum maize growth (Kogbe and Adediran, 2003). Without N fertilizers, an estimated one-third of our current agricultural production would be lost

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(http://pmep.cce.cornell.edu/facts-slides-self/facts/nit-el-grw89.htm).

The rate of fertilizers used in the last 20 years in Ethiopia has increased notably from 2.6 kg ha^{-1} in 1986 to 26.9 kg ha^{-1} of arable land in 2005. However, little or no attention is given to nutrients other than NPK such as S where their impact on crop performance is untouched and inorganic fertilizers that are used in Ethiopia seldom contain S (Kiros, 2007). The response of crop growth and yield to the addition of S, especially with N has reported from most agricultural areas of the world. The increased report on S deficiency is related to the decrease in emission of oxides of S from industries, increased use of high analysis fertilizers with little S, seldom addition of manures, increased N fertilization with high N-efficiency cultivars (Schereer, 2001). However, S is needed in plants for the synthesis of the amino acids, cysteine and methionnine, various enzymes and coenzymes, and it is an integral component of membranes, lipids and chlorophyll proteins (Schereer, 2001).

Sulfur is reported to affect the NUE of crops, limiting better yield as N assimilation in plants is linked to S-metabolism, where the shortage in S supply for crops decreases their NUE (Shug *et al*., 1993). Consequently, the poor NUE caused by the insufficient S needed to convert the N losses from cultivated soils (Ceccotti, 1996). Sulfur is required for plant growth in quantities equal to and sometimes exceeding those of P, which account about 9 - 15% of N uptake. The sufficiency or deficiency levels of S in Ethiopian soils are little known (Kiros, 2007). Thus, the lower yield and NUE of the cereals growing in Ethiopia might be partly caused by untimely use of N and/or lack of other essential nutrients like S.

Maize (*Zea mays L.*) is an important grain crop of the world. Maize seems most probable originated in Mexico or Central America (Onwueme and Sinha, 1991). Maize was introduced to Ethiopia, probably by the Portuguese, in the late 16th century or early 17th century. Maize is one of the major cereals grown in Ethiopia and is the main staple food in many parts of the country. Maize production has slightly increased over the past decade. Fertilizer has been a major component of improved maize production technologies being promoted by the extension package (Fufa and Hassen, 2006). In the country, it is one of the leading food grains selected to assume a national commodity crop to support the food self-sufficiency program (Kebede *et al*., 1992).

Although the consumption of inorganic fertilizers has increased from time to time, the right application rate, source and type have not been taken place by the farmers of the study area. There is no appropriate recommendation of fertilizers based on different types of soils, crops and climatic conditions. Therefore, this study was designed to investigate the rate of N to be recommended and the importance of S fertilizer for maize yield in the Vertisols of Chilga District.

Rational of the Study

In Ethiopia, adoption and intensity of fertilizer application, especially on maize grown by small holders remained very low, despite government's efforts to promote its use (Fufa and Hassen, 2006). At present, fertilizer recommendations supplied to farmers are general rather than related to site-specific and crop-nutrient requirements. These factors resulted in unbalanced and inefficient fertilizer use that results in poor economic returns to the farmers and inefficient use of costly imported inorganic fertilizer materials (Tasnee and Yost, 2003).

In Ethiopia, by 1970's, the Ministry of Agriculture recommended 100 kg ha^{-1} DAP and 50 kg ha^{-1} of urea for all crops and all areas (http://www.aec.msu.edu/agecon/fs2/inputs/documents/stepanek-Dissertation-Body-pdf). Nationwide, the average level of commercial fertilizers (DAP and urea) used by users in 1995/96 was 72 kg ha^{-1} for all crops and all areas (Julia, 2001). In Amhara National Regional State (ANRS), in areas of sufficient rain fall, the recommended rate of fertilizers for maize in all soil types is 100 kg DAP and 100 kg urea ha^{-1} (ANRS Agriculture Bureau, 2000) which is in blanket application.

From all plant nutrients, N fertilizer rates deserve highest attention because too high rates may result in nitrate leaching, volatilization of N_2O (green house) and affect the farmers' profit, and too low rates will also depress the profit (Megel *et al.*, 2006). Despite the important roles of S in agriculture, research pertaining to its status in soils and crop response studies related to this element are almost non-existent in Ethiopia (Itana, 2005). Sulfur is one of the macronutrients needed for plant growth and an essential constituent of proteins. It is as important in plant growth as P and magnesium (Mg), but its role is often underestimated (FAO, 2000). Deficiency of S is becoming increasingly common in Africa on land continuously cropped with N fertilization for food production (Ray and Spider, 2000).

Fertilizer use in Ethiopia is dominantly based on NPK, where the effect of other essential nutrients such as S on yield and quality of crops is nonexistence. In the study area, soil fertility is low and nutrients have depleted. To increase the yield of maize, many farmers use N and P fertilizers in the form of blanket application of Urea and DAP. Since there is no proper recommendation of fertilizer levels approved by research, the yield of maize has not increased. The average yield of maize in Ethiopia is about 1.7 tones/ha (Hugo *et al.*, 2002). Maize becomes the main staple food in the wereda in general and study site in particular. Thus, the main purpose of this study is to investigate the different rates of combined N and S fertilization on yield and yield components, and the importance of S for maize production in Vertisols of Chilga wereda and recommend the right levels of N and S fertilizers.

Objective of the study

General objective

- To study the response of maize to different levels of N and S fertilizers in Chilga District.

Specific objectives

- To assess the effects of N and S fertilizers on the yield and yield components of maize.
- To evaluate N and S concentrations on the leave tissues for different N and S levels, and investigate their correlations to their respective yields.
- To recommend the appropriate combined levels of N and S fertilizers.

Hypothesis

To test the above stated objectives, it was generally hypothesized that different rates of combined N and S fertilization had significant effects on yield, yield components and nutrient concentrations of maize (BH-540) under the humid conditions of northwestern Ethiopia.

MATERIALS AND METHODS

Description of the Study Area

Location

The experiment was conducted on farmer field around Aykel town about 45 km away from Gondar town and 755 km from Addis Ababa, capital of Ethiopia in Chilga District-ANRS in a special village called Sihuana (Awedarda Peasant Association) during the 2008 cropping season. The location of the experimental site is 12^0 32 ' 40 " N Latitudes and 37^0 06 ' 59 " E Longitudes. The altitude of the site is 1925 meter above sea level (m.a.s.l).

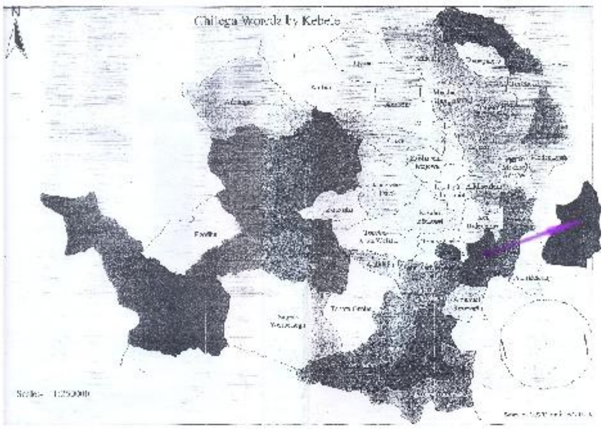

Figure 1 Location map of the study area

Area and topography

Chilga District has an area of 276,885 ha. It has a rugged terrain with much of ups and downs. The altitude of the District ranges between 900 - 2267 m.a s.l. The proportion of land feature of the District is 30% plain, 20% mountainous and 50% rugged that triggers soil erosion (Agriculture and Rural Development office of Chilga District, 2007).

Climate

The District is characterized by 67% Kolla and 33% as Weinadega. The minimum, maximum and mean annual rainfall of the District is 995, 1175 and 1085 mm, respectively with unimodal distribution of summer season. The minimum, maximum and mean temperature of the District is 11, 32 and 21.5^{o}C, respectively (Chilga District Agriculture and Rural Development Office, 2007). The experimental site is situated in the sub-humid agro-climatic zone.

Soil

The soil types of the District are not well studied. However, in terms of color, about 15% of the soils are red, 45% brown and 40% black (Chilga District Agriculture and Rural Development Office, 2007). The soil types of the trial site are Vertisols with clay texture having about 54.8% clay content. The site had been under cultivation for a century and applied with inorganic fertilizers of DAP and urea for more than twenty years. The soil analysis results showed that they are low in plant nutrients.

Natural Vegetation

The natural vegetation cover of the District is about 23%. The vegetation types are mainly of wood lands and bush lands which are concentrated in the Kolla areas. The Weinadega areas are almost devoid of natural vegetation except artificially recently planted eucalyptus trees (Chilga District Agriculture and Rural Development Office, 2007). The experimental site is devoid of vegetation which is used only for cultivation.

Farming systems

The farming system of the experimental site is characterized by mixed farming or crop-livestock production where about 92% of the population is engaged in agriculture. Land covered by crops in the District for 2004 to 2007 was about 43171.75 ha (Chilga District Finance and Economic Development Office, 2008). Crops grown in the study site are *teff*, sorghum, legumes, maize and oilseeds. Frequently, agricultural fields are plowed more than three times before sowing crops. Crop production in the study site is rain-fed system. There is no the practice of fallowing due to shortage of land or high population pressure.

Experimental methods and data collection

Soil sampling

The site was selected based on the criteria of: land with the application of S free fertilizers for the last 15 or more years, land not applied with manure (compost) and not cropped with leguminous crops for the last five or more years. The soil of the experimental site is Vertisols with 54.8% clay contents and CEC of 65.3 Cmolc kg^{-1}. Soil samples (0 – 30 cm) were collected from the trial field before sowing maize to assess the plant nutrient status of the soil. The soil samples were collected with augur in the boarders and central areas of each of the three replications (blocks) on January 1st 2008. There were totally six soil samples for the soil depths of 0 - 15 and 15 0- 30 cm in three blocks and composite. Composite soil samples of 1 kg which were mixed thoroughly were collected from 0 - 15 and 15 - 30 cm depths in each of the blocks within 13 spots (sub-samples) before the planting of maize.

Soil samples were put in an individual polyethylene bags, leveled and transported to Gondar Soil Laboratory Center to determine the soil physicochemical properties of texture, pH, total N, available P, available K, exchangeable cations of calcium (Ca), Mg, K, sodium (Na), CEC, electrical conductivity (EC), and organic carbon (OC). Available S was analyzed in the soil laboratory of Kulumsa Soil Laboratory Center. Soil samples were air dried, crushed and passed through a 2 mm sieve for the analysis of all parameters except OC and total N which were passed through 0.5 mm sieve.

Soil samples were analyzed for texture using Hydrometer method according to (Day, 1965, pH in suspension of a 1: 1.2 soil to water ratio (as indicated in Sahlemedin and Taye, 2000), total N using micro-Kjedahl method (Jackson, 1958), available P using Olsen method (Olsen, *et al*,1954), available K by Morgan method (Morgan, 1941), exchangeable Ca, Mg, K and Na using Ammonium Acetate method (Okalebo *et al*., 1993), CEC by Ammonium Acetate method (Okalebo *et al*., 1993), EC using EC Meter (as indicated by Sahlemedin and Taye, 2000), OC using Walkley and Black method (Walkley and Black, 1934) and available S by Turbidimetric method (Kowalenko, 1985).

Besides, a profile (pit) was opened to 2 m depths for the description of the soil's morphological, physical and chemical characteristics. The opened pit had four layers: 0 - 30, 30 – 60, 60 - 100 and 100 – 200 cm based on the observed changes in color with depth and analysis of soil physicochemical properties. Vertisols with a moist chrome of 1.5 or less within the upper 30 cm is grouped as pellic Vertisols and > 1.5 chromic Vertisols. Based on this source, the soil classification of the experimental site was Pellic Vertisols with chrome of 1. (http://www.fao.org/Wairdocs/ILRI/x5456E/x5456e04.htm).

Plant sampling for tissue analysis

The above ground parts of maize were cut at ground level from tasseling to silking stages. Four maize stands were taken in each plot selected randomly. The stalks and leaves were air dried for 35 to 42 days. Steams were oven dried for 48 hours at 65^0C for constant weight. Leaves were ground and passed in 1 mm sieve for laboratory test. Plant leaf samples were analyzed for N concentrations of maize using the standard procedure of micro-Kjedahl method that was carried out at Mekelle Soil Laboratory Center while for S concentrations by Turbidimetric methods which was carried out at Mekelle University Soil Laboratory Center.

The total N and S concentrations of maize leaf was analyzed. The plant nutrient analysis can be interpreted based on nutrient sufficiency (threshold) levels as a guide. For maize, the nutrient sufficiency levels are N (2.76 to 3.50%), P (0.25 to 0.40%), K (1.71 to 2.50%), Ca (0.21 to 1.0%), Mg (0.16 to 0.60%), and S (0.16 to 0.50%), manganese (Mn) (20 to 150 ppm) and iron (Fe) (21 to 250 ppm) from the plant part (maize ear leaf sampled at initial silking stage) (Ray *et al*., 1990). Soil testing for S is not as reliable for predicting S availability throughout the growing season as for other nutrients. Plant tissue analysis can be helpful in building an experience base. When the N to S ratio is greater than 15:1 in plant tissue, low S levels are indicated (Joyce, 1999).

Experimental design, layout and treatments

The experiment was a three by four (3*4) factorial combinations laid out in RCBD with three replications. The space between blocks was 1m and between plots was 50 cm with a 1.5 m space border. The plot size was 3 m by 4 m (12 m^2) with net area of 3.36 m^2. The total area used for this project including the border area was 17 m by 44.5 m (756.5 m^2).

The treatments were four N fertilizer rates (0, 30, 60 and 90 kg N ha^{-1}) and three S fertilizer rates (0, 15 and 30 kg S ha^{-1}). Triple super phosphate (TSP) fertilizer was applied to all plots as a basal with the rate of 20.4 kg P ha^{-1} (46 kg P_20_5 ha^{-1}). Full doses of P as TSP as well as S (ammonium sulfate and potassium sulfate) were applied at the time of maize sowing/planting.

Concentration of N in $(NH_4)_2$ SO_4 was balanced with urea. Nitrogen as urea was applied in two splits: half at sowing and half at knee height stage of maize. The fertilizers were applied banding on rows about 3 cm away from the seed and 5 cm depth. For plots treated with N fertilizer without S, only urea was applied while for S fertilizer without N, potassium sulfate was applied.

The crop cultivar sowed was hybrid maize variety of Bako hybrid (BH-540). The land was plowed four times before planting. Sowing was done on 9 June 2008. The maize seeds were planted on rows. The space between rows was 80 cm and the space between the standing plants (seeds) was 30 cm. Inter row spacing of maize seeds generally vary from 70 – 100 cm and seed should be sown at a space of 20 – 30 cm along the row (Onwueme and Sinha, 1991).There were 4 rows in one plot and 8 seeds in a row.

Two seeds were planted in one hole in 5cm depth and thinning was done after 24 days of sowing. There were 32 seeds planted in one plot with the plant population of 26,667 plants per ha. All the agronomic practices were kept normal and uniform for all the treatments. Furrow or ridge was made between rows and plots to avoid the water logging effects of Vertisols. Hoeing was done three times. Harvesting was done 6 months after planting maize.

Nitrogen use efficiency as agronomic use efficiency (AE) was also calculated. Nitrogen use efficiency in crop plants is the ratio of output (yield) to the applied input (fertilizers) for a process or complex system or ability of crop to convert inputs into outputs, and has significant positive association with grain yield in crops (Fageria, 2009). This means that improving NUE in crops can improve grain yield. The agronomic use efficiency of N nutrient was calculated using procedures described by Mengel and Kirkby (1996) as:

$$AE = \frac{G_N - G_0}{N}$$

Where, G_N stands for grain yield of the plot fertilized at 'N' fertilizer rate; G_o for grain yield of unfertilized plot and 'N' is rate of applied fertilizer nutrient.

Data Analyses

All data collected were analyzed statistically using two-way of analysis of variance (ANOVA) procedures using JMP-5. The means were compared by the least significant difference (LSD) at ($P \leq 0.05$). Where the parameters were found significantly different at the given level of significance, mean comparison for the treatment was computed using each pair LS Means Tuky's HSD method. Correlations and regressions were also used to analyze the yield and yield components of maize.

RESULTS AND DISCUSSION

Soil physical and chemical analysis

The experimental site is clay in texture (with 54.8% clay, 23.3% sand and 21.9% silt contents). The pH is slightly acidic (6.5) which is in agreement with the report of Desta (2003) that reported the pH of Vertisols is often slightly acidic to neutral.

Soil at the site is non saline (0.04 dSm^{-1}); very low in total N (0.09%); very low in available P (1.5 ppm) that is consistent with the findings of Tesfu (2006) who reported that soils with EC of 0 – 2 dSm^{-1} is very low; total N of 0 – 0.1% is very low. Olsen (1982) reported that soils with S content of < 5 ppm are deficient, 5 – 10 ppm is medium and > 10 ppm contains enough S.

The site is very low in available S (1.5 ppm) for crop production and according to Tisdale *et al*. (2002), concentrations of 3 to 5 ppm or more $SO4^{2-}$ in the soil solution is adequate for the growth of many plant species. The experimental site has very high CEC (65.3 $cmol_+$/kg) which coincides with the study of Landon (1991) as cited by Negash (2008) who reported that soils with CEC values of > 40cmol+/kg is very high in CEC.

The site has medium OC (1.4%) that matched with the report by Vande, 2005 as cited by Tesfu (2006), who reported that OC of 1.2 – 3% is medium. The organic matter of the site is medium (2.3%). Vande 2005 as cited by Tesfu (2006) reported that exchangeable bases of Ca^{2+} > 20 cmol+/kg is very high, Mg^{2+} > 8 cmol+/kg is very high, and K^+ 0.6 –1.2 cmol+/kg is high. Based on this report, the soil of the experimental site has exchangeable bases of very high Ca^{2+} (42.9 $cmol_+$/kg), very high Mg^{2+} (14.4 $cmol_+$/kg), high K^+ (1.1 $cmol_+$/kg) and medium Na^+ (0.4 $cmol_+$/kg where the percent base saturation of the soil is about 90%.

Although there were no significant differences in pH (P > 0.05), EC, available P, available S, exchangeable Ca^{2+}, Mg^{2+}, K^+ and particle size of sand between soil depths of 0-15 and 15-30cm (Table 9), there were a slight reduction from the surface (0 - 15cm) to the lower depth (15 - 30cm) which might be due to the reduction in OM contents and clay lesivage down the profile. However, pH, exchangeable Mg^{2+} and clay texture showed a slight increase from the surface to down the profile. Significant differences ($P \leq 0.05$) were observed in CEC, OC, TN and exchangeable Na between the soil depths of 0 – 15 and 15 – 30 cm. The results of the statistical analysis of soil physical and chemical properties of the base line data before treatment application in the soil depths of 1-15 and 15-30 cm are presented in Table 1.

Table 1 Analysis of the chemical properties of soil before treatment application (0-15 and 15-30 cm)soil depth

Parameter	Soil depth (cm)		R^2	P Value
	0 – 15	15 - 30		
pH	6.50a	6.52a	0.02	0.8005
EC	0.04a	0.03a	0.52	0.1012
Total N	0.12a	0.07b	0.8	0.0161
Available P	2.15a	0.94a	0.64	0.0560
Available S	1.53a	1.46a	0.93	0.4226
Available K	116.60a	144.86a	0.81	0.3368
CEC	72.97a	57.72b	0.97	0.0344
Organic Carbon	1.72a	1.09b	0.98	0.017
Organic Matter	2.74a	1.88a	0.81	0.1492
Exchangeable Ca	43.94a	41.88a	0.64	0.055
Exchangeable Mg	13.04a	15.79a	0.53	0.0993
Exchangeable K	1.15a	1.08a	0.07	0.6079
Exchangeable Na	0.38b	0.43a	0.74	0.0285
Sand	24.00a	22.66a	0.04	0.7096
Silt	21.89a	21.89a	0	1.0
Clay	54.1a	55.44a	0.05	0.6702

Levels in a row connected by the same letter are not significantly different at P < 0.05
R^2 = Coefficient of determinism

Analysis of Grain Yield and Yield Components of Maize

Both grain yield and biomass were significantly ($P \leq 0.001$) increased with the application of N fertilizer as shown in Table 2. Grain yield and total dry biomass increased with the increase of N rates. Grain yield increased in plots treated with 30, 60 and 90 kg N ha^{-1} by 71.4, 148.2 and 175.4% respectively compared to the control. The highest grain yield and biomass were recorded at N3 (90 kg N/ha) application indicating that the maximum level of N fertilizer for maize yield in the experimental site was 90 kg N ha^{-1}. Similar results were reported in the work of Desta (2003) that high response to N is understandable because total N in most Vertisols of Ethiopia is low and the application of 90 kg N ha^{-1} for most crops may be justified under such conditions, since the maximum yield for grain crops was found at this fertilizer level.

Grain yield and biomass were significantly increased ($P \leq 0.05$ and 0.01) respectively with the application of S fertilizer (Table 2). The maximum grain yield and biomass were observed at 15 kg S ha^{-1} (S1) application which indicated that the maximum level for maize yield was 15 kg S ha^{-1}. Similar results were reported by Mac *et al*., (1996) who notified that it is within the range of 10 – 20 kg S ha^{-1} where the maximum response of cereals to S is commonly obtained. Similar S rates were reported for *teff* and wheat by Habtegebrial and Singh (2008).

Combined N and S fertilizer applications highly significantly ($P \leq 0.01$) increased the grain yield and grain number per cob, and significantly ($P \leq 0.05$) improved the biomass of maize. The highest increases of such parameters were observed in plots treated with the combination of 90 kg N and 15 kg S ha^{-1} (N3S1). Grain yield, dry biomass and grain number per cob were increased in plots treated with 90 kg N and 15 kg S ha^{-1}

by 391.7, 479.9 and 842%, respectively compared to the control as shown in Table 2.

Thus, the maximum levels of N and S fertilizer interactions for the grain yield of maize in the experimental site was the combination of 90 kg N and 15 kg S ha^{-1}. The yield in these combinations (5.36 t ha^{-1}) is higher than the average yield of the world (3.6 t ha^{-1}) (Onwueme and Sinha, 1991). Almost similar results were reported by Ray and Spider (2000) in the upland areas of highly weathered soils of Lilongwe and Mzuzu areas of Malawi who elucidated that application of 80 kg N and 20 kg S ha^{-1} did give significant responses to maize. Row number per cob was also significantly (P ≤ 0.05) different when N was fertilized with S. The highest Row number per cob was also observed in plots treated with 90 kg N and 15 kg S ha^{-1} which was increased by 126.9% compared to the control.

Nitrogen Use Efficiency (NUE) is defined in this work as the amount of grain yield (kg) obtained with the application of 1 kg N ha^{-1}. The application of N with S increased the NUE significantly (P ≤ 0.05) with grain yield increase of 17.7% in maize yield compared to the control plots (N1S0, N2S0 and N3S0) as shown in Table 2.

Table 2 Effects of nitrogen and sulfur fertilizers interaction on the number of rows in a cob, grain number per cob, dry biomass production (t ha^{-1}), grain yield (t ha^{-1}) and nitrogen use efficiency of maize

Treatments	Number of rows per cob	Grain number per cob	Biomass	Grain yield	Harvest index	NUE
N0S0	6.33b	46.00e	2.14e	1.09f	0.51ab	--
N0S1	10.66a	139.66be	4.7e	1.88ef	0.4abc	--
N0S2	11.66a	175.66cd	4.55e	2.08de	0.52a	--
N1S0	12.00a	249.00bc	7.83d	3.14c	0.43abc	104.63a
N1S1	12.33a	201.33cd	7.51d	2.72cd	0.4abc	90.57ab
N1S2	13.00a	201.33cd	7.33d	2.79cd	0.45abc	75.5bc
N2S0	14.00a	366.00a	8.09cd	4.16b	0.36c	69.43cd
N2S1	13.66a	349.33a	9.84abcd	4.35b	0.38bc	75.5bc
N2S2	14.33a	331.33abc	9.43bcd	3.99b	0.44abc	66.63cd
N3S0	13.33a	429.00a	10.97ab	4.71ab	0.43abc	52.4d
N3S1	14.33a	433.33a	12.41a	5.36a	0.43abc	59.6cd
N3S2	13.00a	397.66a	10.65ab	4.79ab	0.45abc	53.17cd
R^2	0.76	0.95	0.94	0.97	0.58	0.9
P Value (N rate)	<0.0001	<0.0001	<0.0001	<0.0001	0.0118	-
P Value (S rate)	0.0302	0.7999	0.0036	0.0496	0.0102	-
P Value (N and S interactions)	0.0329	0.0016	0.0449	0.0021	0.2626	0.0442

Levels in a column connected by the same letter are not significantly different at P < 0.05,
Note: N0 = 0 kg N ha^{-1}; N1 = 30 kg N ha^{-1}; N2 = 60 kg N ha^{-1}; N3 = 90 kg N ha^{-1}; SO = 0 kg S ha^{-1}; S1 = 15 kg S ha^{-1}; S2 = 30 kg S ha^{-1}; NUE = Nitrogen use efficiency

Very high Significant (P ≤ 0.001) differences were also observed in the parameters of plant height, cob number per plot, cob weight and length of maize among the main effects of N rates as shown in Table 3. Such parameters increased with the increase of N fertilizers rates.

Plots treated with 30, 60, and 90 kg N ha^{-1} showed an increase in plant height by 47.6, 62.85 and 71.43%, respectively relative to the control groups while maize plants treated with 30, 60 and 90 kg N ha^{-1} increased in cob weight by 87.5, 190.2, and 254.9%, respectively relative to the control. Similar results were reported by Yadav *et al*. (2003) as cited by Negash (2008) who stated that plant height increased as N rate increased. The increase of grain number per cob for the plots treated with 30, 60 and 90kg N ha^{-1} was 80.34, 192.44 and 240.97%, respectively compared to the control.

Very highly significant (P ≤ 0.001) differences were also observed in the parameters of plant height, cob weight and cob length of maize among the main effects of S rates as shown in Table 3. There was an increase in plant height in plots treated with 15 and 30 kg S ha^{-1} by 7.63 and 10.41%, respectively relative to the control groups. The increase in cob length in plots treated with 15 and 30 kg S ha^{-1} was 9.28 and 11.97%, respectively relative to the control.

Combined N and S fertilization improved very highly significantly (P ≤ 0.001) in plant height, cob length, cob weight and cob number per plot of maize as shown in Table 3. The maximum cob length, weight and number per plot were observed in plots treated with the combination of 90 kg N with 15 kg S ha^{-1} that increased by 177.7, 1400 and 128.3%, respectively relative to the control. This indicated that N3S1 is the maximum level of N and S interactions for maize production in the experimental site (Vertisols). While, the tallest maize crop was grown on the combined treatments of 90kg N and 30 kg S ha^{-1} which showed an increase of 148.65% relative to the control.

Table 3 Effects of nitrogen and sulfur fertilizers interaction on plant height (meter), cob number per plot, cob length (meter) and cob weight (kg).

Treatment	Parameters			
	Plant height	Cob number per plot	Cob length	Cob weight
N0S0	0.74f	28.33b	0.103f	0.02f
N0S1	1.15e	32.66ab	0.216e	0.099c
N0S2	1.25e	33.33ab	0.236de	0.109e
N1S0	1.660bcd	34.33ab	0.263bcd	0.173d
N1S1	1.51d	34.00ab	0.25cde	0.136de
N1S2	1.54cd	33.66	0.25cde	0.158d
N2S0	1.65abcd	35.00a	0.273bc	0.25bc
N2S1	1.75abc	35.00a	0.283abc	0.129c
N2S2	1.74abc	35.00a	0.28abc	0.235bc
N3S0	1.78ab	38.00a	0.31a	0.275ab
N3S1	1.79ab	36.66a	0.286a	0.3a
N3S2	1.84a	35.33a	0.286ab	0.29a
R^2	0.96	0.63	0.97	0.98
P Value (N rate)	<0.0001	0.0003	<0.0001	<0.0001
P Value (S rate)	0.0002	0.7431	<0.0001	0.0036
P Value (N and S interactions)	<0.0001	0.0143	<0.0001	<0.0001

Levels in a column connected by the same letter are not significantly different at P < 0.05,
Note: N0 = 0 kg N ha^{-1}; N1 = 30 kg N ha^{-1}; N2 = 60 kg N ha^{-1}; N3 = 90 kg N ha^{-1}; SO = 0 kg S ha^{-1}; S1 = 15 kg S ha^{-1}; S2 = 30 kg S ha^{-1}

There were significant differences (P ≤ 0.05) in the dates of germination, tasseling, silking and maturity of maize among the main effects of N rates (Table 4). Plots treated with 90 kg N ha^{-1} delayed in germination and maturity by 2 days relative to the control groups. However, late tasseling and silking were observed in the control (N0). Plots treated with 30 kg N ha^{-1} matured earlier while plots treated with 90 kg N ha^{-1} matured late. This might indicate that as the rate of N increases the maturity of maize crop slows down. Brady (2002) reported that when too much N is applied, excess vegetative growth occurs and crop maturity delayed. However, significant (P > 0.05) differences were not observed among the main effects of S rates in the days of germination, tasseling and silking as shown in Table 4. Combined N and S fertilization improved significantly ($P \leq 0.05$) the germination, tasseling, silking and maturity days of maize as shown in Table 4. Maize crops treated with 90 kg N with 15 kg S ha^{-1} were germinated lately by 3 days compared to the control (N0S0). Plots treated with fertilizer rates of 60 kg N and 15 kg S ha^{-1} (N2S1) were tasseled and silken earlier by 5 and 12 days, respectively relative to the control groups. However, Plots treated with the combination of 90 kg N with 15 kg S ha^{-1} matured lately by 3 days relative to the control. Davies *et al.* (1993) stated that when N is excessive, plants are very dark green, leafy and slow to mature.

Table 4 Effect of nitrogen and sulfur fertilizers interaction on the germination, tasseling, silking and maturity days of maize

Treatment	Parameters (Days)			
	Germination	Tasseling	Silking	Maturity
N0S0	9.33b	102.00a	109.66a	163.33abc
N0S1	10.00ab	96.66b	100.33b	162.00bcd
N0S2	9.66ab	96.66b	100.33ab	166.33a
N1S0	10.00ab	95.33b	98.66b	159.00d
N1S1	10.33ab	96.00b	99.66b	164.00abc
N1S2	10.00ab	95.66b	99.00b	162.33abcd
N2S0	9.66ab	95.66b	97.33b	161.00cd
N2S1	10.00ab	95.00b	97.66b	163.33abc
N2S2	10.00ab	96.00b	100.33b	165.00abc
N3S0	10.66ab	96.66b	99.33b	166.00ab
N3S1	12.00a	97.33b	100.66ab	166.33ab
N3S2	10.66ab	96.33b	99.00b	164.33abc
R^2	0.46	0.75	0.79	0.77
P Value (N rate)	0.0087	0.0001	<0.0001	0.0002
P Value (S rate)	0.1676	0.5821	0.8342	0.0036
P Value (N and S interactions)	0.0434	0.0014	<0.0001	0.001

Levels in a column connected by the same letter are not significantly different at P <. 0.05, Note: N0 = 0 kg N ha^{-1}; N1 = 30 kg N ha^{-1}; N2 = 60 kg N ha^{-1}; N3 = 90 kg N ha^{-1}; SO = 0 kg S ha^{-1}; S1 = 15 kg S ha^{-1}; S2 = 30 kg S ha^{-1}

Grain yield was very highly significantly ($P \leq 0.001$) and very strongly (r = 0.97) correlated with total dry biomass for the combined N and S fertilizer applications. Grain yield was also very highly significantly ($P \leq 0.001$) correlated with grain number per cob (r = 0.99), cob weight (r = 0.91), cob length (r = 0.85) and plant height, respectively as shown in Table 5.

Table 5 Pair wise correlations between grain yield and yield components of maize for nitrogen and sulfur fertilizers Interactions

Variable	by Variable	Correlation	Count	Probability
Dry biomass (t ha^{-1})	Grain yield (t ha^{-1})	0.9733	12	0.0000
Cob weight (kg)	Grain yield (t ha^{-1}))	0.9112	12	0.0000
Cob weight (kg)	Biomass (t ha^{-1})	0.8884	12	0.0001
Grain number per cob	Grain yield (t ha^{-1})	0.9900	12	0.0000
Grain number per cob	Biomass (t ha^{-1})	0.9515	12	0.0000
Grain number per cob	Cob weight (kg)	0.9239	12	0.0000
Cob length (meter)	Grain yield (t ha^{-1})	0.8511	12	0.0004
Cob length (meter)	Biomass (t ha^{-1})	0.8818	12	0.0001
Cob length (meter)	Cob weight (kg)	0.8186	12	0.0011
Cob length (meter)	Grain number per cob	0.8754	12	0.0002
Plant height (meter)	Grain yield (t ha^{-1})	0.9159	12	0.0000
Plant height (meter)	Biomass (t ha^{-1})	0.9444	12	0.0000
Plant height (meter)	Cob weight (kg)	0.8571	12	0.0004
Plant height (meter)	Grain number per cob	0.9104	12	0.0000
Plant height (meter	Cob length (meter)	0.9562	12	0.0000

Analysis of Nitrogen and Sulfur Concentrations by Maize Crop

The nitrogen concentration of leaves of maize crop was increased significantly (P < 0.0001) with the increasing rate of N application as shown in Table 6. The increase of N concentration of leaves in plots treated with 30, 60 and 90 kg N ha^{-1} was 14.9, 62.2 and 79.8%, respectively relative to the control. Nitrogen fertilization rates did not show significant (P > 0.05) difference in S concentrations of the leaves of maize as shown in Table 6.

Sulfur concentration in leaves was observed to increase very highly significantly ($P \leq 0.001$) with the amount S rates as shown in Table 6. The increase of S contents of maize leaves in plots treated with S1 and S2 was 50 and 68.8% compared to the control plots (S0). Nitrogen concentrations of leaves did not show significant (P > 0.05) difference with the increase of S fertilizer rates but decreased with increasing rate of S application (Table 6).

Combined N and S fertilization significantly ($P \leq 0.05$) improved the N concentrations of maize leaves. The highest N concentration was observed in plots treated with the combination of 90 kg N with 15 kg S/ha which was increased by 106.3% compared to the control group as shown in Table 6. Combined N and S fertilization also significantly ($P \leq 0.05$) improved the S contents of maize leaves. The highest S concentration of leaves was observed in plots treated with the combination of 60 kg N/ha with 30 kg S ha^{-1} which was increased by 88.2% compared to the control (N0S0).

Very highly significant ($P \leq 0.001$) difference was also observed in the N: S ratio of maize leaves among the main effects of N fertilizer rates as shown in Table 6. The N: S ratio of leaves had an increasing trend with N rates. Similar result was reported by Kiros (2007) who stated that the N: S ratio had significantly increased with increasing N rates while decreased with S rates both in leaves and grains.

Table 6 Nitrogen and sulfur concentration of maize leaves as influenced by nitrogen and sulfur fertilizers interactions.

Treatments (kg ha^{-1})	Nitrogen content (%)	Sulfur content (%)	N:S ratio
N0S0	1.76c	0.17b	10.57c
NOS1	1.85c	0.27ab	7.0c
N0S2	2.04c	0.25ab	8.4c
N1S0	2.46abc	0.16b	15.5abc
N1S1	1.89c	0.26ab	6.93c
N1S2	2.13bc	0.24ab	9.1c
N2S0	3.29ab	0.16b	21.2a
N2S1	2.88abc	0.22ab	11.66c
N2S2	2.97abc	0.32a	9.5c
N3S0	3.58a	0.16b	23.4a
N3S1	3.63a	0.18b	20.6a
N3S2	2.93abc	0.28ab	10.9c
R^2	0.78	0.68	0.83
P Value (N rate)	<0.0001	0.306	0.0002
P Value (S rate)	0.6919	<0.0001	<0.0001
P Value (N and S interactions)	0.0313	0.0436	0.0141

Levels in a column connected by the same letter are not significantly different at P <. 0.05, Note: N0 = 0 kg N ha^{-1}; N1 = 30 kg N ha^{-1}; N2 = 60 kg N ha^{-1}; N3 = 90 kg N ha^{-1}; SO = 0 kg S ha^{-1}; S1 = 15 kg S ha^{-1}; S2 = 30 kg S ha^{-1}

The highest N: S ratio of leaves was found to be obtained in plots treated with the combination of 90 kg N with 15 kg S ha^{-1} which was increased by 94.9% relative to the control.

DISCUSSION

The total N level of the soil of the experimental site was very low. This might be due to the low content of plant residues or OM of the soil. Organic matter holds more than 95% of the soil N, often half or more of the total soil P and as much as 80% of the soil S (Raymond and Ray, 1997). The available S content of the soil of the experimental site was also very low which might be due to low OM content of the soil and the leaching effect. Since S is readily leached, surface layers of soil are often low in S contents (Edward, 1992). Sulfate is held more strongly than nitrate but it is fairly easily leached (Archer, 1988).

This experimental work also revealed the positive effects of N and S fertilizers on the yield and yield components of maize. Grain yield, above ground total dry biomass, grain number per cob, and plant height as well as cob weight of maize was positively affected by N and S fertilizers. Such parameters increased with the increase of N fertilizers rates.

Nitrogen fertilization increased both grain yield and total dry matter (Kiros, 2007). Nitrogen is essential for photosynthesis and is the major ingredient of proteins, enzymes, amino acids, amids and nuclic acids (Yayock *et al*., 1988). An adequate supply of N is associated with high photosynthetic activity and vigorous vegetative growth of crops (Samuel *et al*., 1993).

Sulfur fertilization increased maize yield by 17.7% in the experimental site. Similar studies were reported by Ray and Spider (2000) who noted that as a few experiments in the early literature reported significant responses by maize to S, generally in the range of 12 to 20% increase in yield in Kenya, Zimbabwe and Nigeria.

The present work on maize crop demonstrated the positive effects of fertilizing N with S on grain yield and biomass. Response of crop growth on yield and yield components on addition of S with N has been reported for different crops including maize (Stabursvik and Heide, 1974; Inal *et al*., 2003; Zhao *et al*., 1999). This is because of the fact that an insufficient S supply can affect the yield and quality of the crop, caused by the S requirement for protein and enzyme synthesis (Zhao *et al*., 1999). Furthermore, S is reported to enhance the photosynthetic assimilation of N in crops Anderson (1990) which in turn increased the dry matter and grain yields. Peoples *et al*. (1980) elucidated that about 90% of the plant's dry weight is considered to be derived from products formed during photosynthesis. Sulfur is essential for the synthesis of some amino acids and proteins, important for the development and increase of plant oils, required for N fixation by legumes and a constituent of some vitamins (Paul and Roger, 1981).

Grain yield was found to correlate significantly ($P \leq 0.05$) with the number of grains per cob, dry biomass, cob weight, etc of maize crop in the experimental site. Several works have shown from green house and field studies that the effect of S deficiency is primarily on the number of grains per spike of wheat affecting the yield per head (Zhao *et al*., 1999 as cited by Kiros, 2007) either by reducing the initiation of spikelet and/or floret, or increasing the mortality of florets.

Nitrogen use efficiency of the maize crop was enhanced with S fertilization. This might be due to the fact that both N and S are involved in the protein biosynthesis, the vital process in determining yield, where the requirement of one depends on the supply of the other (Kiros, 2007). Shung *et al*. (1993) also reported similar increases in fertilizer NUE with S for wheat and oil seed rape.

The present work on maize crop demonstrated that N and S fertilizations increased the N and S concentrations in the leaves. Similar increases in N and S concentration in plant shoots with combined N and S fertilization were reported for different crops (Schnug *et al*., 1993; Abdin and Ahmed, 2000; Inal *et al*., 2003). The significant positive interaction between S and N could be due to a metabolic coupling between S and N assimilation in the synthesis of proteins. According to Anderson (1990), N assimilation is linked to S metabolism, so that as S metabolism slows down, N assimilation is also down regulated. The meeting point between N and S metabolism is considered to be the synthesis of cysteine (Zhao *et al*., 1999).

The N: S ratio, which is a reliable indicator of S deficiency, increased with the increase of N and reduction of S rates. Joyce (1999) reported that the ratio of N: S in plant tissue is commonly used as a measure of S nutritional status of plants and when the N to S ratio is greater than 15:1 in plant tissue, low S levels are indicated. Based on this assumption, the soil of the experimental site is deficient in S content.

CONCLUSIONS AND RECOMMENDATIONS

In this experimental study, maize crop was found to respond significantly to the combined application of N and S fertilizers in terms of the increase in grain yield and total dry biomass. Nitrogen concentration of maize leaves increased with the increase of N rates. Nitrogen use efficiency of maize was increased when N was fertilized with S. The main effect N fertilizer significantly increased maize yield. The maximum grain yield (4.95 t ha^{-1}) and biomass (11.34 t ha^{-1}) were recorded in plots treated with 90 kg N ha^{-1}. There were also significant responses observed to the application of S in grain yield and dry biomass production of maize. The maximum grain yield (3.58 t ha^{-1}) and biomass (8.62 t ha^{-1}) for the main effect S was observed in plots treated with 15 kg S ha^{-1}. Combined application of N and S fertilizers had shown significant effect on maize yield and yield components where the maximum grain yield of 5.36 t $ha^{-1}$was recorded in plots treated with 90 kg N and 15 kg S ha^{-1}. Thus, fertilization of maize crop with N and S could substantially increase grain yield. From this study point of view

- Farmers should use 90 kg N ha^{-1} fertilizer on Vertisols to increase the yield of maize.

- Sulfur at the rate of 15 kg ha^{-1} is best recommended with the application of N fertilizer at the rate of 90 kg N ha^{-1} for the maximum yield of maize on Vertisols.
- Since this study was made only for one rainy season, similar studies should be done on different successive rainy seasons to fully evaluate the essence of S fertilizer, rate of N fertilizer and their interaction levels for maize yield on Vertisols.

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