Food Barley (*Hordeum vulgare* L.) Yield and Yield Components Response to the Application of Sulfur Nutrient under Balanced Fertilization at North Central Highland of Ethiopia

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Abstract

*The average yield of barley in Ethiopia is lower compared to the world and potential yield. It is mostly constrained by the depletion of soil fertility, caused by imbalanced fertilization, limited application of organic manure, intensive cropping. A field experiment was conducted at two locations for three consecutive years (2014-2016) to determine the effect of S on yield components, and yield of food barley. An experiment consisting of six levels S (0, 10, 20, 30, 40, and 50 kg ha^{-1}) laid out in RCB design with three replications. The results revealed that, yield components of barley were not affected by various levels of S. On the contrary, grain and straw yield was significantly affected by S levels compared to control treatment. Application of S at 20 kg ha^{-1} increased grain and straw yield of food barley by 16.8 and 20.2 % compared to control respectively. The partial budget analysis result revealed that, application of 20 kg S ha^{-1} produced the highest net benefit (*39174.5 ETB*), while, compared to the marginal rate of return (MMR), application of 10 kg S ha^{-1} produced the highest MRR(*4899.8 *%) value. The current finding complements additional evidence to research entitlements that S is becoming the limiting nutrients in Ethiopian soils and barley yields have been improved by the application of S nutrient. Therefore, based on biological data and net benefit, the application of 20 kg S ha^{-1} is found to be the further most economically feasible treatment for food barley production in the Basona woreba district.*

Keywords: *Balanced fertilization, Sulfur, Food barley*

Introduction

Barley (*Hordeum vulgare* L.) is an ancient cereal crop and is the fourth-largest grown cereal crop in the world with a share of 7% of the global cereal production (Pal *et al*., 2012). It is a cool-season crop that is adapted to high altitudes (Bayeh and Berhane, 2011). In Ethiopia, barley is one of the most important crops for food, feed, malt, and income generation for many smallholder farmers in the highlands. Furthermore, it is used as animal fodder, as a source of beverages, and as a constituent of various health foods. Traditionally, barley grains are used for making homegrown recipes and drinks such as Dabo, kolo, genfo, kinche, 'beso,' tela', 'borde', and other types of food (Bekele *et al*., 2020). The crop is

lands (Verma *et al*. 2011).

The world average productivity of barley in 2018/19 is 2.89 tha^{-1} (*Dukhnytskyi, 2019*). The average yield of barley in Ethiopia is lower (2.18 tha^{-1}), compared to the world average (2.89 t ha^{-1}) and its potential yield of 6 tha^{-1}. Barley in Ethiopia occupies about 811,782.08 hectares of land annually with an estimated production of 48,380,740.91 quintals (CSA, 2019). Currently, barley consumption in Ethiopia is increasing due to the growth of population and a gradual change of lifestyle, but its productions have not expanded as required, and productivity is still low. This is due to several constraints such as depletion of soil fertility, which is caused by intensive cropping, imbalanced fertilization, limited application of organic manures, and soil erosion (Birhan *et al*., 2016; Parashar *et al*., 2020).

Balanced fertilization is efficient fertilizer utilization for sustainable high yields which indicates a total plant nutrition system that is capable of taking care of all deficient nutrients which occur in an area, they may be of macro-or micro-nutrients (Ryan, 2008). It is also seen as a dynamic approach that responds to the need for higher productivity and the emergence of any new deficiencies or disorder (Lin, 1997). For fertilizer use to be efficient and environment-friendly, balanced use is a prerequisite. Therefore, adequate mineral fertilization is considered to be one of the most important requirements for better yield and quality of crop (Parashar *et al*., 2020). Soils in the highlands of Ethiopia usually have low levels of essential plant nutrients, like low availability of nitrogen, and others are limiting nutrients to crop production (Taye *et al*., 2002; Menna *et al.*, 2016; Assefa *et al*., 2017).

In addition to N and P nutrients, sulfur (S) deficiency is also distributed in Ethiopian soils. For example, Assefa (2016), Shawl *et al*. (2020), and Shawl et al. (2021) studied the response of the wheat crop to S application and reported that significantly responded to S fertilizer application. Soils in those studies had S content below the critical level (11-14 mg SO_4^{-2}-S kg^{-1} dry soil) for optimum production of the crop. Other study reported that, the effect of S on cereal crop grown in the semi-arid region of Ethiopia found that grain yield and S uptake was significantly increased due to S application (Kiros Hagos and Singh, 2009). Likewise**,** *a field experiment was conducted in barley, shown that the application of 30 kg S ha^{-1} significantly increased the plant height, dry matter production, and number of tillers of barley (Kumawat* et al. *1997).* The national soil inventory data also revealed that in addition to NP, sulfur nutrient deficiency (92%) is widespread in Ethiopian soils including the study area (Ethio-SIS, 2013).

Without adequate supply of S, crops cannot reach their full potential in terms of yield or protein content (Zhao *et al.*, 1999). Among the essential elements, S is very much beneficial for increasing crop production and involved in the synthesis of chlorophyll, amino acids and some plant hormones (Rahman*et al*., 2007). Continuous removal of S from soils through plant uptake without replenishment has led to widespread S deficiency and affected soil S budget all over the world, even including the industrialized ones, areas where industrial pollutions can contribute S for plants (Imran *et al*., 2014). Hence, it is necessary to generate more information on S effect on barley production in the study area. Therefore, the present study was designed to investigate the effect of S application on yield and yield components of food barley grown in Basona werena District, North Centeral highland of Ethiopia.

Materials and Methods

Description of the Study Areas: The experiment was conducted for three consecutive (2014-2016) cropping seasons /years on two locations at Goshebado (147 km) and

Gudoberet (172 km) to northwest, and East from the capital City, Addis Abeba, Ethiopia respectively. Geographically, the field experiment lies between 09^0 ^{0}

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Goshebado and 09^0 ^{0} ^{0} ^{0}

E with an altitude of 2914 to 3043 m.a.s.l at Gudoberet. The study locations and the district as a whole are characterized by having a uni-modal rainfall pattern and receives an average annual rainfall of 921.2 mm. *Nitisols and Cambisols* are the dominant soil type in Goshebado and Gudoberet experimental location respectively. Major crops grown in both locations are wheat, Barley, lentil, faba bean, chickpea, field pea, and grass pea in decreasing orders of area coverage.

Soil Sampling and Analyses: Before planting of barley crop, the composite soil samples were collected from each site from a depth of 0-20 cm using augur randomly from 15 spots by walking in a zigzag pattern. After carefully mixing the composite samples, 1 kg of sub-sample was taken and brought to Debre Berhan Agricultural Research Center soil laboratory. The submitted soil sample was air-dried and grounded to pass a 2 mm mesh sized sieve.

The processed samples were analyzed for texture following the Bouyoucous hydrometer method (Bouyoucous, 1962). The pH of the soil was measured using a pH-water method by making soil to water suspension of 1: 2.5 ratio and was measured using a pH meter (VanReeuwijk, 1992). The soil OC content was determined by the wet digestion method (Walkley and Black, 1934). Total nitrogen (TN) was determined by using the modified micro Kjeldahl method (Cottenie, 1980). Available P (ava. P) was analyzed by using Olsen colorimetric method as described by Olsen *et al*. (1954).

Treatments, Design, and Experimental Procedure: The experiment consisting of six levels of S (0, 10, 20, 30, 40, and 50 kg ha^{-1}) and laid out in randomized complete block design (RCBD) with three replications. The recommended dose of 69 P_20_5, 80 K_20, 92 N kg ha^{-1}, and micronutrients (2Zn, 0.5Cu, and 0.5B kg ha^{-1}) was applied in each plot to avoid the limiting nutrients. Gypsum (CaSO4*2H2O), Borax, Zinc Sulfate, Copper Sulfate, Murat of potash and Triple superphosphate (TSP) were used as S, B, Zn, Cu, K and P sources respectively. The test crop, barley variety, HB-1307 was planted in a unit plot size of 3.6 x 3.4m with row spacing of 20 cm apart at a rate of 137.7 kg ha^{-1}. The whole doses of gypsum (CaSO4*2H2O), KCl, and TSP fertilizers were applied as basal before planting as per the treatment. The Urea-N was splited; one half of N was applied at planting and the remaining one half was applied one month after planting. Micronutrients (Zn, B, and Cu) in the form of $ZnSO_4$, Borax, and $CuSO_4$ respectively were applied in foliar form two times at the tillers developments stage of the crops. All agronomic management of the experiments were done as per the specific recommendation for the crop.

Data Analysis: The collected data were subjected to statistical analysis of variance (ANOVA) using SAS software program *(*SAS version 9.3; SAS Institute Inc, 2011). After verifying normality and homogeneity of error variance across years and locations, a combined analysis for the 3 years and locations was done by using the procedure of SAS software version 9.3 *(*SAS Institute Inc, 2011*).* Mean comparisons were done by Least Significant Difference (LSD) according to the procedure of Gomez and Gomez (Gomez and Gomez, 1984*)* at a 5% level.

Partial Budget Analysis: Partial budget analysis was done to determine the economic feasibility of S fertilizer for food barley production around the study areas following procedures described in CIMMYT (1998). The mean grain and straw yield data of barley were employed in the analyses. Furthermore, the grain and straw yield obtained from each treatment were adjusted down by 10 % to narrow the possible yield gap that may happen due to differences in field management. The average prices of relevant inputs required to do the partial budget analyses were collected from different sources. The prices of gypsum fertilizer during the planting of this experiment was collected from Debre Berhan town. Accordingly, the price of gypsum was 2.4 Ethiopian Birr (ETB) kg^{-1}. The field prices of grain and straw yield at the district local market around the study area were used. Accordingly, prices of grain and straw yield of barley were 7 and 2.4 ETB kg^{-1} respectively. The economic analysis procedure recommended by CIMMYT (1988) was applied as follows:

Average yield (AY) (kg ha^{-1}): It is the average yield of each treatment converted to hectare.

Adjusted yield (AJY): The adjusted yield for treatment is the average yield adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. AJY = AY - (AY x 0.1).

Gross benefit (GB): The gross field benefit for each treatment was calculated by multiplying the field/farm gate price that farmers receive for the crop when they sale it as adjusted yield. GFB = AJY x field/farm gate price of a crop.

Total variable costs (TC): This is the sum of all the costs that vary for a particular treatment. *Net benefits (NB):* This was calculated by subtracting the total costs from the gross field benefit for each treatment. NB = GFB   TC

Dominance analysis (D): This was carried out by first listing the treatments in order of increasing costs that vary. Any treatment that has net benefits that are less or equal to those of treatment with lower costs that vary is dominated.

Marginal rate of return (MRR): This was computed by dividing the marginal net benefit (i.e., the change in net benefits) with the marginal cost (i.e., the change in costs) multiplied by hundred and expressed as a percentage.

$$MRR\ (\%0 = \frac{Change\ in\ NB}{Change\ in\ TVC} * 100$$

Where NB=Net benefit, TVC= total variable cost, MRR= Marginal rate of return. Thus, (MRR) of 100% implies a return of one Birr on every Birr of expenditure in the given variable input.

Results and discussion

Soil Physical and Chemical Properties: Prior-planting soil analyses of selected physicochemical properties of samples collected from experimental locations at Goshebado and Gudoberet are summarized in (Table 1). The soils of Goshebado and Gudoberet was belonging to clay and clay loam textural class respectively. Goshebado soil reaction (soil pH) ranged from slightly acidic to neutral whereas the soil of Gudoberet ranged from moderately acidic to neutral reaction (Murphy, 1968). Goshebado TN ranges from low to moderate and whereas OC is low categories (Tekalign, 1991). The OC and total nitrogen (TN) content of Gudoberet is in low categories. The available P content of Gudoberet is low to the medium range while at Goshebado is ranged from *medium* to *high* categories (Olsen *et al*., 1954).

Table 1: Soil Physico-chemical properties of the study sites across years

Parameters	**Locations**					
	Goshebado			**Gudoberet**		
	2014	**2015**	**2016**	**2014**	**2015**	**2016**
pH (1:2.5)	6.34	6.81	6.8	6.68	5.8	5.6
Av. P (ppm)	6.90	7.90	6.70	24.78	15.50	13.80
TN (%)	0.10	0.15	0.15	0.07	0.08	0.09
OC (%)	1.17	1.46	1.40	0.75	0.77	0.77
C: N	11.47	10.01	9.62	11.20	9.85	8.63
Sand (%)	22	22	22	36	26	25
Clay (%)	52	46	46	28	34	35
Silt (%)	26	32	32	36	40	40
Textural Class	Clay	Clay	Clay	clay loam	clay loam	clay loam

Effect of Sulfur on Yield Components of Barley:

respond significantly to S, the interaction of sulfur (S) by location (L), S by year (L) (S*L and S*Y), and interaction of S by L and Y (S*L*Y) (Table 2). While, the main effect of Year (Y) and location (L) highly significantly ($p<0.01$) affected the yield components of food barley (Table 2).

The analysis of variance showed that, the maximum mean plant height (97.5 cm), spike length (6.9 cm), total tillers (7.9) and fertile tillers (7.2) was obtained in year 3 (Table 3). While, the lowest value of the above mentioned parameters was obtained in the first year (year 1). While considering location effect on yield components of food barley, significantly higher values of these parameters were obtained at Goshebado than

Gudoberet. At Goshebado, plant height, and spike length were higher by 4.5 and 4.7 % respectively over that produced in Gudoberet irrespective of treatments.

Table 2: Effect of S on overall mean of yield components of barley

S-rate (kg ha^{-1})	Plant height (cm)	Spike length (cm)	Total tillers plant^{-1}	Fertile tillers plant^{-1}
0	87.4	6.3	6.1	5.7
10	89.9	6.0	6.7	6.2
20	91.9	6.5	6.4	6.1
30	88.6	6.2	6.5	6.1
40	89.4	6.2	6.6	6.2
50	91.3	6.5	6.4	5.9
LSD (p<0.05)				
S*	ns	ns	ns	ns
L	5.9	1.01	ns	ns
Y	3.4	0.25	ns	ns
S*L	ns	ns	ns	ns
S*Y	ns	ns	ns	ns
S*L*Y	ns	ns	ns	ns
CV (%)	13.58	6.38	11.36	11.98

*S=sulfur level, L=location, Y=year

Table 3: Main effect of year and location on yield components of barley

Year*	Plant height (cm)	Spike length (cm)	Total Tilers plant^{-1}	Fertile Tillers plant^{-1}
1	81.3c	5.4b	4.33c	4.0c
2	90.5b	6.6a	6.97b	6.7b
3	97.5a	6.9a	7.9a	7.2a
LSD (<0.05)	**5.9**	**1.01**	**0.95**	**0.41**
Location				
Goshebado	91.8a	6.4a	6.44	5.9
Godoberet	87.7b	6.1b	6.39	6.0
LSD (<0.05)	**3.4**	**0.25**	**ns**	**ns**

*1=2014, 2=2015, 3=2016

Effect of Sulfur on Grain and Straw Yield of Barley: Grain and straw yield of food barley respond significantly ($p<0.01$) to main effect of S nutrient , but no, respond significantly to the interaction of sulfur (S) by location (L), S by year, and interaction of S by L and Y (

Rx). While the overall mean of grain and straw yield of barley were significantly ($p<0.05$) affected by the main effect of years and locations.

Data in

Rx showed that the effects of S on grain and straw yield of barley. The increasing S rates up to 20 kg ha^{-1} showed an increasing trend and attained the maximum grain and straw yield of barley. However, the increase of S rates beyond 20 kg ha^{-1} showed a decreasing trend in grain and straw yield of barley. Application of S at 10 and 20 kg ha^{-1} significantly increased grain yield by 12.8 and 16.8% over the control respectively. Similarly, these treatments increased straw yield by 16.7 and 20.2% over the control respectively. Therefore, the present finding revealed that barley yield has been improved by the application of S fertilizer.

Data regarding to main effect of year and location on grain and straw yield of barley presented in Table . The higher values of grain and straw yield were obtained in year 3 than in year 1 and 2. In year 3, grain yield was higher by 8.6 and 18.4% and straw yield by 2.0 and 8.1 % over that produced in year 1 and 2 respectively. This might be due to better rainfall distribution and temperature suitability in year 3 than year 1 and 2.

Location has significantly affected grain and straw yield of food barley. Accordingly, significantly higher values of grain and straw yields were obtained in Goshebado than Gudoberet location. At Goshebado, grain and straw yields were higher by 13.0 and 19.7% over that produced in Gudoberet irrespective of treatments (Table 5). This could be possible be due to better microclimate condition of food barley used in Goshebado than Gudoberet.

Table 4: Effect of Sulfur on grain and straw yield of barley

S-rate (kg ha^{-1})	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
0	4028.0c	5452.7c
10	4620.1ab	6543.2ab
20	4840.8a	6833.1a
30	4577.0ab	6290.9b
40	4665.4a	6278.3ab
50	4658.3a	6121.5b
LSD (<0.05)		
S*	**513.4**	**523.7**
L	**	**
Y	**	**
S*L	ns	ns
S*Y	ns	ns
S*L*Y	ns	ns
CV (%)	14.62	13.17

*S=sulfur level, L=location, Y=year

Table 5: Main effect of year and location on grain and straw yield of food barley

Year*	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})
1	4130.0c	6051.5b
2	4517.9b	6173.2b
3	5059.0a	6586.0a
LSD (<0.05)	**316.58**	**325.5**
Location		
Goshebado	4243.67b	5580.85b
Godoberet	4879.2a	6948.67a
LSD (<0.05)	**608.23**	**1189.32**

*1=2014, 2=2015, 3=2016

Partial Budget Analyses: The results of partial budget analysis data of S fertilizers are summarized in Table 6. Accordingly, treatments produced higher net benefit (NB) relative to the control treatment, which indicates the feasibility of S fertilizer application for barley production in the study district. Therefore, the highest NB (39174.5 ETB) was produced by the application of S at 20 kg ha^{-1} followed by application of S at 10 kg ha^{-1} which produced

(37124.9 ETB). When it comes to the marginal rate of return (MRR), the highest value of MRR (7274.1%) was produced by application of S at a rate of 10 kg ha^{-1} followed by 20 kg S ha^{-1}.

Table 6: Partial budget analysis of barley to the study areas

S-rate ($kgha^{-1}$)*	Adj grain yield	Adj straw yield	TVC	GB	NB	MRR	MRR (%)
0	3625.2	4907.4	5217	37154.2	31138.2	-	-
10	4158.09	5878.9	5300	43215.9	37124.9	72.74	7274.1
20	4396.72	6059.8	5383	46320.5	39174.5	48.99	4899.8
30	4119.3	5661.8	5466	42423.4	36182.4	21.10	D
40	4198.8	5650.5	5550	42953.3	36637.3	17.40	D
50	4192.47	5509.4	5633	42569.7	36178.7	12.99	D

*S=Sulfur, Adj=Adjusted, TVC=Total variable cost, GB=Growth benefit, NB=Net benefit, MRR=Marginal rate of return

Discussions

Sulfur (S) is an essential plant nutrient needed for higher crop yields and improved nutritional value, in recent decades the occurrence of S deficiency has increased and fertilizer S may steadily increase, this may lead to inefficient crop utilization of S and result in negative footprints on the environment (Aula et al. 2019). Previous research result revealed that, sulfur deficiency is capable of reducing crop yield even without expressing visual symptoms on plants (Tandon, 1995; Sharma and Gupta, 2003).

Currently, deficiency of sulfur is increasingly being reported in soils of Ethiopia. For instance, Assefa (2017), Shawl etal., (2020) and Shawl etal., (2021) research report indicated, the sulfur content of the expeimental soils were below the critical level and application of sulfur using wheat as a test crop significantly improved grain and straw yield of the test crop. In the present study, the application of S is improved barley yield. The increasing rate of S up to 20 kg ha^{-1} showed an increasing trend and attained the maximum grain and straw yield of barley. It was also observed from a previous study that, sulfur fertilizer improved yield and yield components of barley (Togay et al. 2008). Another study result indicated that the application of S plays an important role in barley nutrition (Environ

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