Growth, yield components, and yield response of food barley (*Hordeum vulgare* L.) to the application of sulfur nutrient under balanced fertilization at North Central Highland of Ethiopia

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Abstract

Deficiency of sulfur (S) is increasingly being reported in the soils of Ethiopia. While some studies have shown significant response of barley to S application, information on the response of barley to S application is conspicuously lacking. 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 growth, 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 study results revealed that growth and yield components of barley were not affected by various levels of S. In the case of barley 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. Application of 20 kg S ha⁻¹ produced the highest marginal rate of return (MMR) (3493.2%). The present result revealed that barley yield has been improved by the application of S fertilizer. Therefore, the application of 20 kg S ha⁻¹ is initiate to be the further most economically feasible treatment for food barley production in the Basona woreba district.

Keywords Balanced fertilization · Sulfur · Food barley

Abbreviations

ANOVA	Analysis of variance
CSA	Central Statistical Authority
CIMMYT	International Maize and Wheat Improvement Center
GY	Grain yield
RCB	Randomized complete block

S	Sulfur
STY	Straw yield

Introduction

Barley (*Hordeum vulgare* L.) is an ancient cereal crop and is considered the fourth-largest grown cereal crop in the world with a share of 7% of the global cereal production. 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. 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. 2020a, b). The crop is considered as a poor man’s crop and better adaptable to problematic soils and marginal lands (Verma et al. 2011).

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The world average productivity of barley in 2018/19 is 2.89 t ha⁻¹ (Dukhnytskyi 2019). Barley in Ethiopia occupies about 811,782.08 hectares of land annually with an estimated production of 48,380,740.91 quintals (CSA 2019). The average yield of barley in the country is lower (2.18 t ha⁻¹), compared to the world average (2.89 t ha⁻¹) and its potential yield of 6 t ha⁻¹. Know a day, 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. It is due to several constraints like 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 micronutrients. 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 (Menna et al. 2016; Assefa et al. 2017).

In addition to N and P nutrients, sulfur (S) deficiency is also widely distributed in Ethiopian soils. For example, Menna (2016), Assefa et al. (2020a; b), and Assefa 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 (11–13 mg kg⁻¹ SO₄⁻²-S) for optimum production of the crop. In another research study, reported that, the effect of S on cereal crop grown in in the semi-arid region of Ethiopia and found that grain yield and S uptake was significantly increased due to S application (Kiros Hagos and Singh 2009).

In the study district has no information on the response of barley to the application of S, the present experiment was conducted to study the effect of S application on growth, yield, and yield components of barley grown at Goshebad and Gudoberet locations in Basona werena District.

Materials and methods

Description of the study areas

The experiment was conducted for three consecutive (2014–2016) cropping seasons /years on two locations at Goshebad and Gudoberet about 147 and 172 km northwest,

and East from the capital City of Ethiopia, respectively. Geographically, the field experiment lies between 09°, 43', 58.4" to 09°, 44', 45.8" N and 039°, 25', 39.1" to 039°, 27', 29.4" E and an altitude of 2796 to 2990 m.a.s.l at Goshebad and 09°, 46', 21.2" to N 09°, 47', 06.5" and 039°, 39', 37.3" to 039°, 40', 08.5" E and 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 that the experiment conducted in Goshebad and Gudoberet location, respectively. Major crops are grown in both locations; wheat, Barley, lentil, faba bean, and chickpea, field pea, and grass pea in decreasing orders of area cultivated under these crops.

Soil sampling and analyses

Pre-planting soil samples were collected from each location for the analyses of selected physicochemical properties. Composite soil samples were taken from each site from a depth of 0–20 cm using augur randomly from 15 spots by walking in a zigzag pattern. After thoroughly mixing the composite samples, 1 kg of sub-sample was taken and brought to Debre Birhan agricultural research Centre soil laboratory where it 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. 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's 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) accompanied by 69P₂O₅, 80K₂O, 92 N, and micronutrients (2Zn, 0.5Cu, and 0.5B kg ha⁻¹) and was laid out in randomized complete block design (RCBD) with three replications. Gypsum (CaSO₄*2H₂O), Borax, Zinc Sulfate, Copper Sulfate, and Triple superphosphate (TSP) were used as S, B, Zn, Cu, and P sources, respectively. The test crop, barley variety, HB-1307 was planted in a unit plot size of 3.6×3.4 m 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 in both sides of rows just before planting as per the treatment. The Urea-N was split in which one half of N was applied at planting and the remaining one half was applied

1 month after planting and after weeding. Micronutrients (Zn, B, and Cu) in the form of ZnSO_4 , Borax, and gypsum, respectively were applied foliar mode two times at the tillers developments stage of the crops. All agronomic management of the trails was done as per the specific recommendation for the crop.

Data analysis

The collected data were subjected to statistical analysis of variance (ANOVA) and carried out using SAS software program using 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 average prices of relevant inputs required to do the partial budget analyses were collected from different sources. Accordingly, the prices of gypsum fertilizer during the planting of this experiment were collected from Debre Berhan town. Accordingly, the price of gypsum was 1.2 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 using the 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 the 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. $\text{AJY} = \text{AY} - (\text{AY} \times 0.1)$.

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. $\text{GFB} = \text{AJY} \times \text{field/farm gate price of a crop}$.

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. $\text{NB} = \text{GFB} - \text{TC}$.

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.

$$\text{MRR} (\%) = \frac{\text{Change in NB}}{\text{Change in TVC}} \times 100$$

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

Soil physical and chemical properties

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

Effect of S on growth and yield components of barley

Growth and yield components of food barley didn't respond significantly to S, the interaction of sulfur (S) by location (L), S by year (L) ($\text{S} \times \text{L}$ and $\text{S} \times \text{Y}$), and interaction of S by L and Y ($\text{S} \times \text{L} \times \text{Y}$) (Table 2). Data in Tables 3, 4 showed that the interaction effects of $\text{S} \times \text{L}$ on growth and yield components of barley.

Effects of S on the overall mean of growth, yield components, and yield of barley

Sulfur by location (S*L), Sulfur by year (S*Y), and sulfur by location and year interaction (S*L*Y) had no significant effect on any of the measured parameters of barley (Table 2). While the overall mean of grain and straw yield of barley were significantly affected by the effects of S application (Table 2). Data in Table 5 showed the effects of S on overall

mean growth, yield components, 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, those treatments increased straw yield by 16.7 and 20.2% over the control, respectively.

Table 1 Soil physico and 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

Table 2 Mean squares for sources of variation

Parameters		Mean squares for sources of variation with respective degrees of freedom in parenthesis						
	S (5)	Y (2)	L (1)	Rep in L (2)	S*Y (10)	S*L (5)	S*Y*L (20)	Error (70)
PH	52 ^{ns}	2345 ^{**}	440 ^{**}	17.0	30 ^{ns}	30 ^{ns}	26 ^{ns}	33
SPL	0.423 ^{ns}	22.6 ^{**}	0.65 [*]	0.327	0.055 ^{ns}	0.198 ^{ns}	0.073 ^{ns}	0.162
NT	1.15 ^{ns}	127.4 ^{**}	0.05 ^{ns}	0.88	0.58 ^{ns}	2.26 ^{ns}	0.78 ^{ns}	0.53
FT	1.12 ^{ns}	100.8 ^{**}	2.50 ^{ns}	1.31	0.58 ^{ns}	1.16 ^{ns}	0.57 ^{ns}	0.51
GY	1384576 [*]	7561429 ^{**}	1080306 ^{**}	5471663	283524 ^{ns}	289705 ^{ns}	309493 ^{ns}	445292
STY	3563515 ^{**}	2892512 [*]	50043026 ^{**}	12088192	197988 ^{ns}	1155467 ^{ns}	340368 ^{ns}	681751

PH plant height (cm), SPL spike length (cm), NT number of total tillers, FT fertile tillers, GY grain yield, STY straw yield, S Sulfur, Y year, L location

Table 3 Interaction effects of S with location and year on plant height and spike length of barley

Year	Location	Plant height (cm)						Spike Length (cm)					
		S-rate kg ha ⁻¹						S-rate kg ha ⁻¹					
		0	10	20	30	40	50	0	10	20	30	40	50
1	Goshebado	90.0	92.4	94.4	95.0	99.7	98.2	6.3	6.0	6.5	6.2	6.1	6.1
	Gudoberet	67.5	71.5	71.4	64.2	64.1	68.2	4.8	4.2	4.5	4.7	4.4	5.1
2	Goshebado	87.3	94.5	93.6	89.5	93.7	91.2	5.7	5.9	6.1	6.0	6.0	6.1
	Gudoberet	86.1	89.1	90.2	88.3	89.1	93.9	7.1	6.9	7.4	7.0	7.1	7.4
3	Goshebado	85.1	86.9	94.8	88.1	87.0	89.4	6.9	6.8	7.3	6.8	6.9	7.1
	Gudoberet	108.3	104.2	107.2	106.2	103.0	106.5	7.2	6.7	6.8	6.8	6.8	7.1
LSD (<0.05)		Ns						ns					

Therefore, the present finding revealed that barley yield has been improved by the application of S fertilizer. Data regarding interaction effects of S with location, interaction effects of S with years, and interaction effects of S with locations on grain and straw yield of barley are presented in Table 6.

Effect of years and locations on mean growth, yield components, and yield of barley

Years have significantly affected the growth, yield components, and yield of barley (Table 2). Data regarding the main effect of year on growth, yield components, and yield of barley showed in Table 7. 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,

Table 4 Interaction effects of S with location and year on total and fertile tillers of barley

Year	Location	Total tillers plant ⁻¹						Fertile tillers plant ⁻¹					
		S-rate kg ha ⁻¹						S-rate kg ha ⁻¹					
		0	10	20	30	40	50	0	10	20	30	40	50
1	Goshebado	4.7	4.7	4.7	4.5	4.7	5.4	4.5	4.4	4.3	4.4	4.4	5.0
	Gudoberet	3.8	4.0	4.2	3.8	3.9	3.7	3.3	3.7	3.9	3.5	3.6	3.4
2	Goshebado	6.8	6.5	6.5	7.0	6.6	6.9	6.3	6.1	6.0	6.4	6.2	6.4
	Gudoberet	6.3	8.7	6.3	6.7	8.3	7.0	6.1	8.2	6.6	6.6	8.1	6.8
3	Goshebado	7.7	7.3	8.0	8.1	7.9	8.3	6.6	6.4	6.6	6.8	6.7	6.9
	Gudoberet	7.6	9.1	7.2	8.9	8.4	7.2	7.1	8.4	6.8	8.7	8.0	6.7
LSD (<0.05)		ns						ns					

Table 5 Effect of S on overall mean of growth, yield components, and yield of barley

S-rate (kg ha ⁻¹)	Plant height (cm)	Spike length (cm)	Total tillers plant ⁻¹	Fertile tillers plant ⁻¹	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)
0	87.4	6.3	6.1	5.7	4028.0c	5452.7c
10	89.9	6.0	6.7	6.2	4620.1ab	6543.2ab
20	91.9	6.5	6.4	6.1	4840.8a	6833.1a
30	88.6	6.2	6.5	6.1	4577.0ab	6290.9b
40	89.4	6.2	6.6	6.2	4665.4a	6278.3ab
50	91.3	6.5	6.4	5.9	4658.3a	6121.5b
CV (%)	13.58	6.38	11.36	11.98	14.62	13.17
LSD (<0.05)	ns	ns	ns	ns	604.3	523.7

Table 6 Interaction effects of S with locations on grain and straw yield of barley

Year	Location	Grain Yield (kg ha ⁻¹)						Straw yield (kg ha ⁻¹)					
		S-rate kg ha ⁻¹						S-rate kg ha ⁻¹					
		0	10	20	30	40	50	0	10	20	30	40	50
1	Goshebado	3819.9	4557.6	4606.8	4444.7	4824.6	5274.2	4573.9	4918.9	5280.0	5260.9	5348.4	5509.0
	Gudoberet	3276.6	3705.9	3927.7	3700.5	4032.2	3389.7	6101.1	7156.8	7755.5	6716.0	7658.1	6339.0
2	Goshebado	3967.5	4473.0	4834.6	4219.6	3819.9	4395.8	5888.5	6164.2	6550.2	6251.0	5850.0	6087.6
	Gudoberet	4055.8	5208.3	4862.1	4813.2	4819.2	4745.7	5656.0	7938.1	7699.8	6752.5	7325.4	6869.0
3	Goshebado	3130.4	3522.1	4640.2	4019.6	3899.0	3696.1	4603.4	5147.1	6065.2	5816.2	5721.1	5275.0
	Gudoberet	5918.0	5887.8	6173.2	6264.1	6597.2	6448.2	5893.2	7468.6	7047.6	6949.2	7100.8	6649.6
LSD (<0.05)		ns						ns					

respectively. This might be due to better rainfall distribution and temperature suitability in year 3.

Partial budget analyses

The results of partial budget analysis data of S fertilizers are summarized in Table 8. 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.

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. 2019a, b). Currently, deficiency of sulfur S is increasingly being reported in soils of Ethiopia. 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 et al. 2015a, b). However, the current finding showed that increasing S rates beyond 20 kg ha⁻¹ showed a decreasing trend in grain and straw yield of barley. Similarly, Islam (2006) reported that application of S at the higher rate (40 kg S ha⁻¹) showed a reduction in yields.

Conclusion and recommendation

It has been observed that application of S fertilizer has significantly increased grain and straw yield of food barley grown in the study district, compared to control treatment. Maximum grain and straw yield of barley was obtained with treatment involving application of 20 kg S ha⁻¹. When considering the partial budget analysis result revealed that, 10 kg S ha⁻¹ produced the highest MMR (7274.1%) followed

Table 7 Main effect of year and location on growth, yield components, and yield of barley

Year	Plant height (cm)	Spike length (cm)	Total Tillers plant ⁻¹	Fertile Tillers plant ⁻¹	Grain Yield (kg ha ⁻¹)	Straw Yield (kg ha ⁻¹)
1	81.3c	5.4b	4.33c	4.0c	4130.0c	6051.5b
2	90.5b	6.6a	6.97b	6.7b	4517.9b	6173.2b
3	97.5a	6.9a	7.9a	7.2a	5059.0a	6586.0a
LSD (<0.05)	5.9	1.01	0.95	0.41	316.58	325.5
Location						
Goshebedo	91.8a	6.4a	6.44	5.9	4243.67b	5580.85b
Godoberet	87.7b	6.1b	6.39	6.0	4879.2a	6948.67a
LSD (<0.05)	3.4	0.25	ns	ns	608.23	1189.32

1 = 2014, 2 = 2015, 3 = 2016

Table 8 Partial budget analysis of barley to the study areas

S-rate (kg ha ⁻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

by 20 kg S ha⁻¹. Therefore, based on the net benefit it is suggested that 20 kg S ha⁻¹ is found to be an economically feasible treatment for food barley production in the study district of Basona woreda.

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Data availability The datasets used during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no competing interests.

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