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Response of Sesame (*Sesamum indicum* L.) to Potassium and Sulfur Application at Kafta Humera District, Western Tigray, Northern Ethiopia

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Authors' contributions

This work was carried out in collaboration among all authors. Author TS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors LW and AA managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Potassium and sulfur are among the most important nutrients limiting sesame production. EthioSIS soil testing map indicate that nutrients such as K and S are deficient in the study site. Study was carried out to investigate response of sesame to K and S application at Humera Agricultural Research Center, Kafta Humera district, Tigray, Ethiopia in 2016 main cropping season. Treatments consisted four levels of potassium (0, 20, 40 and 60 kg K_2O ha^{-1} as KCl) and four levels of sulfur (0, 20, 40 and 60 kg ha^{-1} as $CaSO_4.2H_2O$). The experiment was laid out as Randomized Complete Block Design (RCBD) in factorial arrangement with three replications using Setit-1 sesame variety. Soil sample was taken, result of soil analysis revealed that the soil was clayey textural class, neutral in soil reaction (pH = 7.35), low organic matter content (0.73%), very low total N (0.03 %) and very low available P (0.74 mg kg^{-1}), high soil cation exchange capacity (CEC) (40 cmol(+) kg^{-1}), medium exchangeable K (0.26 cmol(+) kg^{-1}) and low extractable sulfur (4.78 mg kg^{-1}). Maximum sesame grain yields (1371.67 kg ha^{-1}) was obtained from plot treated with 20 kg K_2O ha^{-1}

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+ 40 kg S ha^{-1} which resulted 145.3% increase over the control plot`s yield. From plots fertilized with K and S levels at a rate of 20 kg K ha^{-1} and 40 kg S ha^{-1} was obtained higher yield of sesame. It is conclude, therefore, it will be good to promote K and S for further demonstration.

Keywords: Potassium; sulfur; sesame; grain yield.

1. INTRODUCTION

Ethiopia is one of the major sesame (*Sesame indicum* L.) producing countries in the world. Based on the total average production over 2002/12, Ethiopia is the 5th in the list of sesame producing countries [1]. The total area of land allocated for sesame production during 2014/15 cropping season was 3.35%, which is about 420,490.98 hectares out of the total arable land of the country that was covered by grain crops [2].

All factors constraining the increased production of other crops also affect sesame production. The low productivity of sesame in Ethiopia is attributed to a number of factors. The most important that reduced sesame production in Ethiopia are limited production inputs such as fertilizers, wider adapting cultivars, non-synchronous maturity, poor stand establishment, profuse branching and low harvest index [3]. Beside these productions limiting factors, soil fertility depletion is the major constraint to crop production in Ethiopia in general [4] and Humera district in particular. Therefore, improving and sustaining sesame production and productivity will be helpful for Ethiopia to ensure food security and play its role in the transformation agenda.

Crop productivity could be increased by improving soil fertility and productivity. To increase food production, integrated use of suitable fertilizer types and cropping system are of key for sustainable crop production as proper combination of fertilizers and cropping system can increase crop yield by 50% [5].

Potassium involves in many plant physiological processes, such as water plant relations, photosynthesis, assimilate transport and enzyme activation [6]. Potassium deficiency can lead to a reduction in both crop growth and yields [6].

Sulfur (S) is essential for synthesis of the amino acids like *cystine, cysteine* and *methionine*, a component of vitamin A and activates certain enzyme systems in plants [7]. Under S deficient conditions, the efficiency of applied NPK fertilizers may be seriously affected and crop yield levels may not be sustainable [8].

Potassium and sulfur are becoming limiting nutrient for crop yield in many regions of the world. K and S fertilizer is among of the main inputs for oil crop production systems. The increase of agricultural food production worldwide over the past four decades has been associated with a 7-fold increase in the use fertilizers [9]. Thus, application of Potassium and sulfur is possibly will vital for the enhancement of soil fertility and crop productivity.

The results of national soil fertility mapping initiative has also indicated that nutrients such as K, S, Zn and B are found to be deficient in Ethiopian soils and specifically in the study area [10]. Therefore, appropriate K and S fertilizer rate of application may improve sesame production and productivity. With the general objective to investigate effects of potassium and sulfur on sesame yields yield components and with specific objectives to assess response of sesame to different levels of K and S application at Kafta Humera district

2. MATERIALS AND METHODS

The experiment was conducted during 2016 cropping season in Kafta Humera Wereda (Fig. 1), Northern Ethiopia. It is located at about 600 km west of Mekelle the capital of the Tigray region, at 1512218.50 m to 1597861.12 m Northing and 213444.75 m to343131.93 m Easting, with an elevation range of 527 to 1891 m a.s.l and 6756 km^2 area coverage. It is bounded by Eritrea in the North, Laelay Adyabo and Welkayt Weredas in the East, Tsegede wereda in the South, and Sudan in the West. Vertisol is the dominant soil type of this area [11].

The mean annual rainfall of the area is about 577.6 mm that usually starts at about the end of June and ends in early September with maximum temperature ranges from 42ºC to 33ºC while the minimum temperature from 22.2ºC to 17.5ºC.

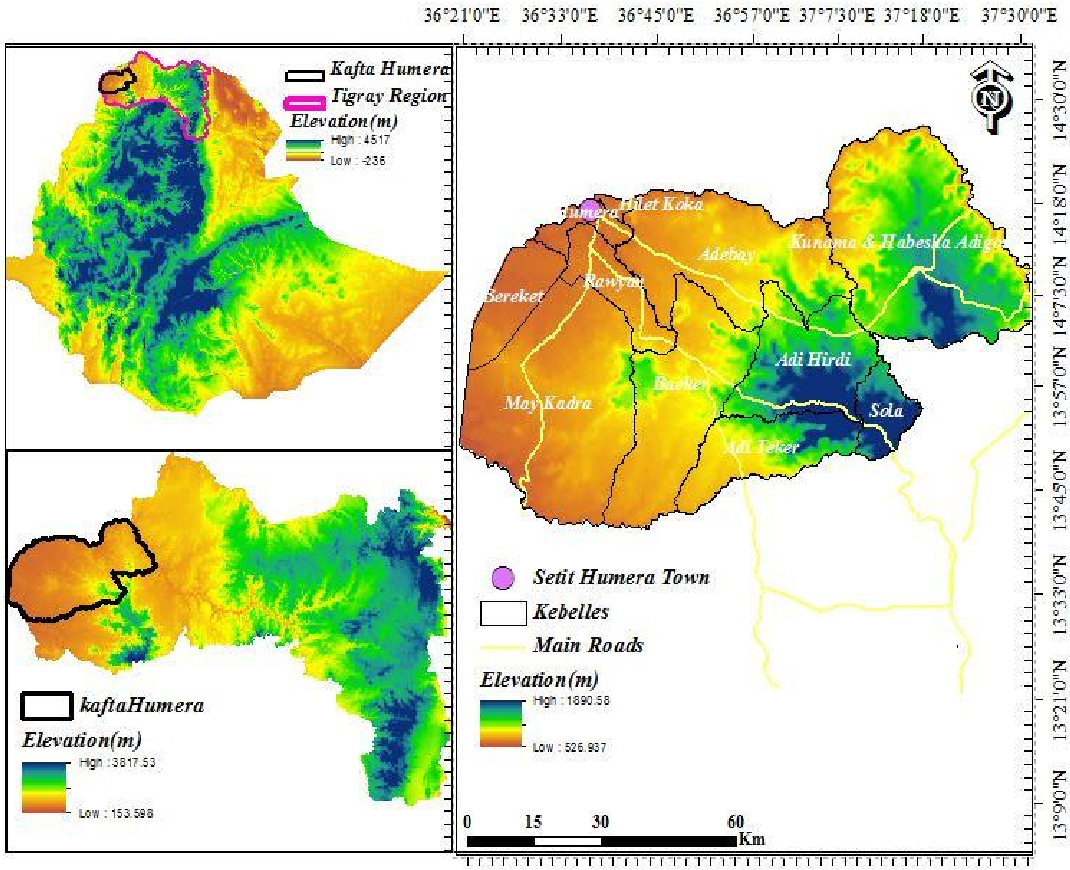

Fig. 1. Map of the study area

2.1 Soil Sampling and Analysis

This was conducted at high pH Vertisol. Before planting, 48 soil samples were collected from the experimental site. A one composite soil sample was taken by inserting the auger up to a depth of 20 cm. All the subsample of a single composite sample were collected in a bucket and thoroughly mixed. Finally, about 1 kg of soil was taken using quartering method from the bulk composite soil sample to a polyethylene bag with the necessary label on it and this soil sample was air-dried, milled and sieved to pass through 2 mm diameter mesh sieve and laboratory analysis were made for texture, pH, EC, organic matter, total N, available P, available S exchangeable K and CEC following their respective standard procedures at Mekelle soil research center.

2.2 Experimental Design and Procedures

Potassium (K) and Sulfur (S) were used as treatments for this experiment. Four levels K_2O (0, 20, 40 and 60 kg ha^{-1} designated as K_0, K_1, K_2 and K_3) were arranged with four levels of S (0, 20, 40, and 60 kg ha^{-1} S and designated as S_0, S_1, S_2 and S_3,) The experiment was laid out as a Randomized Complete Block Design (RCBD) in a factorial arrangement with three replications. The gross and net harvestable plot sizes were 5 m × 2.8 m and 5 m × 2 m, respectively. The total number experimental plots were 48. The spacing between blocks, plots, raw and between plant were 1.5, 1, 0.4 m and 0.1 m, respectively.

Potassium (K) and sulfur (S) were applied in the form of murate of potash (KCl) and calcium sulfate ($CaSO_4.2H_2O$), respectively. The full dose or recommended rates of NP fertilizers were applied as basal to all plots based on the blanket recommendation of 23 kg N and 46 kg P_2O_5 ha^{-1}. Besides, 0.3 kg ha^{-1} of Borax ($Na_2B_4O_7.5H_2O$) and 1.72 kg ha^{-1} of Zinc Sulfate ($ZnSO_4.7H_2O$) adjusted to the amount of S required were applied as basal application for all treatments based on the ATA deficient nutrients report for the area by [10].

2.3 Agronomic Data Collection

Branch number, Plant height, Length of pod bearing zone, Number of Capsule per plant, Number of seed per Capsule, and Grain Yield were collected. Plant height was determined by measuring the length of the plants from the ground level to the top just before physiological maturity. At physiological maturity, the plants were harvested from a net plot size of 10 m^2 and; air dried in an open dry environment and Grain yield was determined by weighing using sensitive balance. Grain yield per plot was determined after carefully separating the grain from the straw.

2.4 Data Analysis

Analysis of variance was subjected to the statistical software program SAS, 2004, version 9.0 to carry out for yield and yield parameters of the crop was determined its response to the applied fertilizers. For statistically significant different parameters, the means were separated using the least significant difference (LSD). For profitability of sesame production using different fertilizer sources, marginal rate of return (MRR) was calculated as the change in net revenue (NR) divided by the change in total variable cost (TVC) of the successive net revenue and total variable cost levels [12].

3. RESULTS AND DISCUSSION

3.1 Initial Soil Physiochemical Characteristics of Experimental Site

Analytical results of soil at the experimental site indicated (Table 1) that the soil textural class was clayey with a particle size distribution of 52% clay, 30% silt and 18% sand. Berhanu [13] reported that Vertisol in Ethiopia generally contain more than 40% clay in their surface horizons and are characterized by high clay content with swelling and shrinking characteristics [14]. The textural properties of the soil favor sesame production as reported by Carlsson et al. [15] who said that sesame will perform best on well-drained clayey soils. It has been grown satisfactorily on clayey soils, but soil crusting during seedling establishment can be a problem in establishing sesame when clay content is higher and under moisture deficit. The yield of agricultural crops is dependent on proportion of soil particle size distribution and how well the soil has been managed. Since soil of the site has higher clay content than other particles, surface compaction might be expected due to the use of heavy machineries for sesame production. Therefore, management should be toward protecting the soil from compaction through application of organic matter.

Soil reaction: The soil reaction (pH) of the experimental site was 7.35 (Table 1) which is neutral in reaction as per the rating established by Tekalign [16]. According to FAO [17] the pH in the experimental site is within the preferable range for most productive soils (5.5 to 7.5). Thus, the pH of the experimental site soil was within the range for productive soils and does have soil productivity constraints associated with soil reaction.

Electrical conductivity: Measure of the EC in the experimental site was 0.18 mmhos/cm (Table 1). According to Marx and Hart [18], soil of the experimental site is categorized under low soluble salts content and has no salinity problem.

Soil organic matter: According to Tekalign [16], rating of soil organic matter, the organic matter content of the soil of the experimental site was low (Table 1). From the soil textural class perspective, clayey soils are expected to have higher SOM content, due to slow decomposition of organic matter. Azlan et al. [19] reported that soil texture influences the rate of soil organic matter (SOM) decomposition and can maintain organic matter in soil for several times. Despite, having higher clay content relative to other particles, organic matter content of the soil was low. This low organic matter content of the soil could be attributed to the management of organic matter sources such as crop residues collection after harvesting, little or non-application of compost or manure and mono cropping. Therefore, to increase the organic matter content of soil of the experimental site, incorporation of crop residues, manure or compost is vitally important.

Total nitrogen content: Total nitrogen content was 0.03% Table 1. According to [16], this value was rated as very low total N content of soil. This provides evidence that N is a limiting nutrient for crop production at the experimental site. Low nitrogen content of the soil could also be attributed to low soil organic matter content as discussed above. Thus, in addition to organic matter amendment, application of nitrogen fertilizers is necessary for increasing crop yields in these types of soils on which sesame is also grown.

Available phosphorous: Available phosphorous (Olsen P) content of soil of the experimental site was 0.74 mg kg^{-1} (Table 1), which is very low as per the rating established by [15]. According to Tisdale et al. [20] P availability rating in acid, neutral as well as in calcareous soils, available P content of the soil was in the low range. In most cases, pH of 6–7.5 is optimum for adequate P availability in soils. The pH value of soil of the experimental site was 7.35 which are in the range of optimum P availability to plant. This suggests that low available P content of the soil is not due to the soil reaction. Therefore, low available P content of the soil was probably s due to continuous sesame production without replenishment of P taken up by plant. It is therefore, evident that P application would be necessary in those soils in order to increase and sustain sesame production.

Cation exchange capacity (CEC): The (CEC) of the soil was 40 cmol (+)/kg (Table 1), which is high according to Hazelton and Murphy [21] rating of soil cation exchange capacity. It appears that high CEC level of the soil of the experimental site might be due to higher clay content of the soil relative to other particles. Clayey soils are reported to have higher CEC than sandy soils mainly due to presence of negative charges resulting from isormorphous substitution [22]. These negative charges are responsible for the retention of cation which can be exchanged by other cation through exchange processes.

Exchangeable K: Exchangeable K content of soil of the experimental site was 0.26 cmol (+)/kg (Table 1). According to FAO [17], the soil of the study area had medium exchangeable K. It is so difficult to build soil K levels especially in soils with a high percentage of clay. Clay provides hiding places for K to bind and become unavailable for plant uptake [23]. Thus, this implies that application of K either in of organic or inorganic form in to the soil may significantly increase both yield or yield components of sesame.

Extractable sulfur: The value for extractable sulfur was 4.78 mg/kg (Table 1). Based on the rating suggested by [21], sulfur content of soil of the experimental site was in the low range. The low in sulfur value of the experimental soil may be because of low in OM and soil management practices (intensity of cultivation). As reported [24] who indicated that the lower the organic matter contents of the soil the more likely S deficiency to be occurred. Similar to N and P, sulfur is also the limiting nutrient for optimum crop production on soil of the experimental site.

Sulfur is the integral part of biological molecules like cyteine and methionine which cause variation in oil and protein content and synthesis of chlorophyll, protein as well as amino acids in plants physiology. Higher availability of sulfur in the root zone of crops was reported to cause enhancement for sulfur storage, which could involve in oil and protein formation [7]. This implies that sulfur is important for increasing crop productivity and to improve quality of the yields. Analytical result indicated lower sulfur content of soil of the experimental site, which suggests sulfur is deficient. Thus, application of sulfur is necessary to increase soil productivity and improve crop quality.

3.2 Sesame Response to Potassium and Sulfur

3.2.1 Number of branches per plant

The main effects of K and S and their interaction significantly ($P \leq 0.01$) influenced the number of branches per plant. Increasing application rates of K and S significantly enhanced the number of branches per plant over the control (Table 2). The highest number of branches per plant (3.57) was produced in response to the combined application of 20 kg K_2O ha^{-1} and 40 kg S ha^{-1} while the lowest (1.11) value was obtained from the control plot. The increase in terms of percent was 221.62%. The increase in the number of branches per plant could be attributed to the synergetic effect of K and S on the overall growth of the plant. Potassium increases root growth,

Table 1. Initial Surface (0-20 cm) physical and chemical property of the experimental field

Texture (%)			pH	OM	TN	Av. P-Olsen	CEC	Av.K	Av.S
Clay	Silt	Sand	(1:2.5H_2O)	(%)	(%)	(mg kg^{-1})	($cmol^C$ kg^{-1})	(cmol(+)kg^{-1})	(mg kg^{-1})
52	30	18	7.35	0.73	0.03	0.74	40	0.26	4.78

Note: OM= Organic Matter; CEC= Cation Exchange Capacity; TN= Total Nitrogen and Av. P= Available Phosphorus, avK=available potassium and avS=available Sulfur

Table 2. Interaction effect of potassium and sulfur on number of branches per plant

Number of branches per plant				
		S kg ha^{-1}		
K kg ha^{-1}	**S_0**	**S_{20}**	**S_{40}**	**S_{60}**
K_0	1.11^f	2.34^d	2.40^b	1.69^e
K_{20}	1.63^e	2.39^{dc}	3.57a	3.10^b
K_{40}	2.40^{dc}	2.60^c	2.21dc	3.17b
K_{60}	1.50^e	2.40^e	2.37^{dc}	3.20^b
		K×S		
LSD(0.05)		0.24		
CV (%)		6.00		

Means followed by the same letters are not significantly different (P≤0.05) according to Tukey Test; K = Potassium; S = Sulfur; CV = Coefficient of variation; LSD = Least significant difference

Table 3. Interaction effect of potassium and sulfur on plant height

Plant height (cm)				
		S kg ha^{-1}		
K kg ha^{-1}	**S_0**	**S_{20}**	**S_{40}**	**S_{60}**
K_0	120.80^f	142.33^e	151.73^d	141.87^e
K_{20}	161.53^{bc}	138.87^e	169.13^a	169.07^a
K_{40}	162.67^{bc}	143.33^e	157.07^c	160.53^{bc}
K_{60}	144.40^e	157.40^c	142.40^e	155.13^c
		K×S		
LSD(0.05)		6.51		
CV (%)		2.59		

Means followed by the same letters are not significantly different (P≤0.05) according to Tukey Test; K = Potassium; S = Sulfur; CV = Coefficient of variation; LSD = Least significant difference

improves drought and disease resistant, aid the process photosynthesis and food formation [25]. On top of this, sulfur plays a crucial role for synthesis of chlorophyll, protein as well as amino acids such as methionine and cysteine in plants physiology [7], which result in enhanced branches production by plant. Similar to results of this study [26], Rajiv and Prakash [27] reported that application of K and S nutrients increased the number of branches produced per sesame plant. The improvement in vegetative growth might be due to the role of K in sugar translocation in plant and its involvement in cell enlargement. Bhosale et al. [28] Also reported more number of branches per plant. They suggested that the balanced nutrients furnished might have enhanced cell division and plant growth.

3.2.2 Plant height

The main effects of K and S and their interaction were significant ($P < 0.01$) on plant height. The maximum plant height (169.13 cm) was obtained 20 kg K_2O ha^{-1} + 40 kg S ha^{-1} whereas; the minimum plant height (120.0 cm) was recorded from the control plot (Table 3). The increase in terms of percent was 40%. The reason for maximum height of the plant on plots treated with the combination of the two nutrients could be attributed to the rapid carbohydrates synthesis due to the pronounced role in photosynthesis and cell elongation, which thereby increases number and size of growing cells, and ultimately increase plant height. The results of this study agree with that of [28] who reported the maximum height of sesame was recorded in response to the application of different rates of potassium combined with sulfur.

In general, the enhanced height of sesame plants in response to the combined application of the two nutrients might be attributed to the synergistic effects of the nutrients, which were supplied to the soil. Possibly, the application of the two nutrients might have enhanced cell division and growth, which subsequently resulted in increased plant height.

3.2.3 Length of Capsule/ Pod

The interaction effect of K × S was significant ($P<0.01$) on length of capsule (Table 4). However, the main effects of K and S on this trait were not significant. The longest (2.65 mm) capsule was produced in response to the combined application of 20 kg K_2O and 40 kg S ha^{-1}. On the other hand, the shortest (2.02 mm) capsule was recorded for plant grown on the control plots. The increase in terms of percent over the control was 31.18%. However, this treatment was at par with 20 kg K_2O ha^{-1} 20 kg S ha^{-1}.

Potassium and sulfur had pronounced effect on sesame capsule length. These results are in line with the finding of [27] who claimed that capsule length of sesame plant increased significantly with potassium and sulfur application. In this case, it appeared that potassium and sulfur apparently played more synergistic role in enhancing capsule length. Sulfur is important for the synthesis of amino acids such as *cystine, cysteine* and *methionine*, a component of vitamin A and activates variance enzyme systems in plants [7]. On top of this, K is an essential nutrient for photosynthesis, in carbohydrate transport, in water regulation, and in protein synthesis activities that favored plant growth [29].

3.2.4 Number of capsule per plant

The analysis of variance showed that the main effects of K and S and their interaction were significant ($P<0.01$) on the number of capsule produced per plant. The enhanced number of capsule per plant in response to the combined application of the two nutrients could be attributed to the synergistic effects of the nutrients. The maximum number of capsules per plant (57.53) was obtained from combined application of 20 kg K_2O ha^{-1} applied with 40 kg S ha^{-1}, whereas the lowest value (22.27) was obtained from the control plots (Table 5). The extent of increase in number of capsule per plant in terms of percent was 158.32%. This shows the synergistic effect of the nutrients throughout the growing period resulting in enhancing capsule number per plant. Several authors [26,27] reported marked increases in capsule number per sesame plant as a result of applying K in combination with S.

3.2.5 Number of seeds per capsule

The analysis of variance showed that the main effects of K and S and their interaction were significant ($P < 0.01$) on the number of capsule produced per plant. Increasing the rates of potassium and sulfur over the control significantly increased number of seeds produced per capsule. Thus, significantly the highest number of seeds produced per capsule (58.67) was obtained from plots that received the two

Table 4. Interaction effect of potassium and sulfur on capsule length

Capsule length (mm)				
		S kg ha^{-1}		
K kg ha^{-1}	**S_0**	**S_{20}**	**S_{40}**	**S_{60}**
K_0	2.02^{ed}	2.04^{ed}	2.38^{bc}	2.19^{dc}
K_{20}	2.38^{bc}	2.64^{a}	2.65^{a}	2.56^{ba}
K_{40}	2.46^{ba}	2.50^{ba}	2.47^{ba}	2.41^{bac}
K_{60}	2.32^{bc}	2.43^{bac}	2.41^{bac}	2.38^{bc}
		K×S		
LSD(0.05)		0.25		
CV (%)		6.39		

Means followed by the same letters are not significantly different (P≤0.05) according to Tukey Test; K = Potassium; S = Sulfur; CV = Coefficient of variation; LSD = Least significant difference

Table 5. Interaction effect of potassium and sulfur on number of capsule per plant

Number of capsule per plant				
		S kg ha^{-1}		
K kg ha^{-1}	**S_0**	**S_{20}**	**S_{40}**	**S_{60}**
K_0	22.27^{i}	35.47^{ef}	39.73^{d}	27.60^{h}
K_{20}	35.40^{egf}	40.40^{d}	57.53^{a}	44.27^{c}
K_{40}	45.97^{c}	34.07^{fg}	53.00^{eb}	53.47^{b}
K_{60}	45.00^{c}	32.40^{g}	37.87^{ed}	51.27^{b}
		K×S		
LSD(0.05)		3.03		
CV (%)		4.39		

Means followed by the same letters are not significantly different (P≤0.05) according to Tukey Test; K = Potassium; S = Sulfur; CV = Coefficient of variation; LSD = Least significant difference

Table 6. Interaction effect of potassium and sulfur on number of seeds per capsule

Number of seeds per capsule				
		S kg ha^{-1}		
K kg ha^{-1}	S_0	S_{20}	S_{40}	S_{60}
K_0	37.40^{j}	45.60^{ih}	50.67^{feg}	49.67^{fg}
K_{20}	51.87^{fde}	54.27^{bdec}	58.67^{a}	52.47^{fdec}
K_{40}	55.13^{bdac}	49.40^{fhg}	56.33^{bac}	57.13^{ba}
K_{60}	50.20^{fg}	55.00^{bdac}	47.33^{ihg}	44.53^{i}
		K×S		
LSD(0.05)		3.92		
CV (%)		4.62		

Means followed by the same letters are not significantly different (P≤0.05) according to Tukey Test; K = Potassium; S = Sulfur; CV = Coefficient of variation; LSD = Least significant difference

Table 7. Interaction effect of potassium and sulfur on thousand seed weight

Thousand seed weight (gm)				
		S kg ha^{-1}		
K kg ha^{-1}	S_0	S_{20}	S_{40}	S_{60}
K_0	0.62^{d}	1.27^{c}	1.33^{c}	1.20^{c}
K_{20}	1.65^{a}	1.75^{a}	1.76^{a}	1.54^{a}
K_{40}	1.70^{a}	1.30^{c}	1.35^{c}	1.72^{a}
K_{60}	1.54^{a}	1.22^{c}	1.69^{a}	1.66^{a}
		K×S		
LSD(0.05)		0.27		
CV (%)		11.05		

Means followed by the same letters are not significantly different (P≤0.05) according to Tukey Test; K = Potassium; S = Sulfur; CV = Coefficient of variation; LSD = Least significant difference

nutrients in combination, at 20 kg K_2O ha^{-1} + 40 kg S ha^{-1} (Table 6). The magnitude increase due the nutrients over the control was 56.87%. The reason for higher seed number per capsule from the plots treated with potassium plus sulfur might be due to the fulfillment of potassium and sulfur requirements of sesame at this rates. These results are in agreement with the findings of [30] who reported that highest sesame seed numbers were counted for the plots treated with combinations of potassium and sulfur nutrients than did for sole applications. In line with this, the maximum seeds number per capsule was also observed for the application of 30 kg K ha^{-1} and 20 kg S ha^{-1} [27]. Similarly, the highest number of seeds per capsule of sesame was reported as a result of combined application of K with S [31].

3.2.6 Thousand seeds weight

Analysis of variance showed that the main effects of K and S significantly ($P< 0.01$) influenced thousand seed weight of sesame. Similarly the interaction effects of K × S on thousand seed weight was significant ($P< 0.05$).

The maximum thousand seed weight was attained at 20 kg K_2O ha^{-1} + 40 kg S ha^{-1}. On the other hand, the minimum thousand seed weight was measured for the control plots. This treatment was at par with 20 kg K and no sulfur application. But the mean thousand seed weights obtained from plots fertilized with 20 kg K_2O and 40 kg S ha^{-1} exceeded the mean seed weight obtained from the control plot by 183.87% (Table 7).

The increment in thousand seed weight in response to increased rates of the two nutrients may be attributed to the supply of optimum potassium and sulfur applied that led to high mean thousand seed weight through facilitating leaf growth and photosynthetic activities, thereby increasing partitioning of assimilate to the storage organ. Similar, result was also reported by [26] showing significant effect of 40 kg K_2O ha^{-1} and 40 kg S ha^{-} application on thousand grain weight of sesame seed.

3.2.7 Grain/seed yield

The analysis of variance showed that the main effects of K and S and their interaction were significant ($P < 0.01$) on the grain/seed yield. The mean grain yield as a result of the two nutrients interaction is presented in Table 8. Increasing the rate of potassium and sulfur significantly increased grain yield compared to the yield obtained from the control plot. The highest grain yield was obtained at 20 kg K_2O ha^{-1} and 40 kg S ha^{-1} of the two nutrients whereas the minimum was recorded for the control plot. Thus, sesame plants grown at 20 kg K_2O ha^{-1} + 40 kg S ha^{-1} produced about twice as much yield additional increment of 145.3% as the grain yield was produced with this treatment compared to the control plot. These results show that there is high potential to increase sesame grain yield through increased application of potassium and sulfur fertilizers. This higher grain yield obtained from the combined application of potassium and sulfur nutrients is attributable to the continuous supply of nutrients throughout the developmental stages of the crop. Results reported by [26] showed higher grain yield (706 kg ha^{-1}) due to the combined application of potassium and sulfur fertilizers. Application of these nutrients may enhance supply of other nutrients to the crops synchronized with all growth stages in accordance with the demand of the plant [32]. This finding is also supported by the results of [30] who revealed that the combined application of potassium and sulfur nutrients ensured higher returns in crop yields.

The overall increase in grain yield in response to increasing the rates of the two nutrients to the different levels could be attributed to the synergistic effects of K and S nutrients in promoting and enhancing photo assimilation and eventually partitioning of photosynthetic products to the grains. Singh et al. [33] Also attributed increase in grain yield of 710 kg ha^{-1} as a result of K and S application to the role played by the two nutrients in promoting and enhancing in photosytitic assimilations.

3.2.8 Straw yield

The analysis of variance showed that the main effects of K and S and their interaction were significant (P<0.01) on the straw yield. Under the levels of the two nutrients, the straw yield of sesame was found higher under combined rate of potassium and sulfur when compared to control. The highest straw yield was obtained at 20 kg K_2O ha^{-1} + 40 kg S ha^{-1} while the minimum straw yields was produced under control the plot following several combined rates of the two

Table 8. Interaction effect of potassium and sulfur on grain yield

Grain yield (kg ha^{-1})				
	S kg ha^{-1}			
K kg ha^{-1}	**S_0**	**S_{20}**	**S_{40}**	**S_{60}**
K_0	559.13^{f}	797.18^{e}	962.30^{c}	951.15^{c}
K_{20}	884.96^{de}	982.02^{c}	1371.67^{a}	1184.13^{b}
K_{40}	1117.94^{b}	1006.99^{c}	976.87^{c}	964.29^{c}
K_{60}	927.06^{dc}	979.73^{c}	828.37^{e}	961.55^{c}
		K×S		
LSD(0.05)		93.11		
CV (%)		5.79		

Means followed by the same letters are not significantly different (P≤0.05) according to Tukey Test; K = Potassium; S = Sulfur; CV = Coefficient of variation; LSD = Least significant difference

Table 9. Interaction effect of potassium and sulfur on straw yield

Straw yield (kg ha^{-1})				
	S kg ha^{-1}			
K kg ha^{-1}	**S_0**	**S_{20}**	**S_{40}**	**S_{60}**
K_0	2726.20^{h}	3206.30^{g}	4238.10^{dc}	3218.30^{g}
K_{20}	3678.60^{f}	4107.10^{dfcg}	6226.20^{a}	4496.00^{c}
K_{40}	4142.90^{dce}	4138.90^{dce}	5361.10^{b}	3785.70^{fe}
K_{60}	3793.70^{dfe}	4400.80^{c}	4087.30^{dfce}	4424.60^{c}
		K×S		
LSD(0.05)		446.26		
CV (%)		6.50		

Means followed by the same letters are not significantly different (P≤0.05) according to Tukey Test; K = Potassium; S = Sulfur; CV = Coefficient of variation; LSD = Least significant difference

Table 10. Correlation coefficients between mean agronomic traits of sesame grown with application of potassium and sulfur

	Nbpp	Ph	Lc	Ncpp	Nspc	Tswgt	Byld	Gyld
Nbpp	1.00							
Ph	0.659**	1.00						
Lc	0.173NS	0.371NS	1.00					
Ncpp	0.633**	0.711**	0.212NS	1.00				
Nspc	0.495*	0.753**	0.508*	0.622**	1.00			
Tswgt	0.596**	0.643**	0.300NS	0.729**	0.627**	1.00		
Byld	0.673**	0.673**	0.205NS	0.647**	0.671**	0.501*	1.00	
Gyld	0.726**	0.806**	0.297NS	0.644**	0.777**	0.627**	0.802**	1.00

*Nbpp = Number branch per plant; Ph = plant height; Lc = length of capsule, Ncpp = Number of capsule per plant; Nspc = Number seeds per capsule; Tswgt = thousand seed weight, Gyld = Grain yield; Syld = Straw yield. NS, * and **= non-significant, significantly different at 5%, and 1%, respectively*

nutrients. The highest straw yield (6226.20 kg ha^{-1}) was obtained in response to the application of 20 kg K_2O ha^{-1} and 40 kg S ha^{-1} that resulted in 128.38% increase over that of the control (Table 9). The increase in straw yield might have resulted from improved root growth, increased uptake of nutrients favoring better growth, and delayed ageing of leaves of the crop. The result is also in agreement with that of [28] who found that combined application of potassium and sulfur increased straw yield of sesame by up to 132%, revealing the benefit realized by exploiting interactions.

3.3 Correlations between Selected Agronomic Traits

There existed significant positive associations of grain yield with number of branches produced per plant (r= 0.726**), plant height (r= 0.806**), number of capsule per plant (r= 0.644**), number of seeds per capsule (r= 0.777*), thousand seed weight (r= 0.627**) and straw yield (r= 0.802**). In addition, number of branches per plant had significant correlation with plant height (r= 0.659**), number of capsule per plant (r= 0.633**), number of seeds per capsule (r= 0.495*), thousand seed weight (r= 0.596**) and straw yield (r= 0.673**). Similarly, there was a significant positive correlation among plant height with number of capsule per plant (r= 0.711**), number of seeds per capsule (r= 0.753**), thousand seed weight (r= 0.643**) and straw yield (r= 0.673**). Furthermore, number of capsule per plant had significant correlation with number of seeds per capsule (r= 0.622**), thousand seed weight (r= 0.729**) and straw yield (r= 0.647**). Similarly, number of seeds per capsule had significant correlation with length of capsule (r= 0.508) thousand seed weight (r= 0.627**) and straw yield (r= 0.671**) (Table 10). This suggests that any increase in such traits will lead to seed yield improvement [34]. The authors reported positive and significant correlation between number of branches per plant, plant height, and seed number per capsule, 1000 seed weight and straw yield with seed yield which is in concordance with the present result. Similar result was also reported by [35] who revealed that grain yield had a significant and positive association with these parameters. However, length of capsule had non-significant correlation with number of branches produced per plant (r= 0.173^{ns}), plant height (r= 0.371^{ns}), number of capsule per plant (r= 0.212^{ns}), thousand seed weight (r= 0.300^{ns}), straw yield (r= 0.205^{ns}) and straw yield (r= 0.297^{ns}). This is in agreement with [34] were also reported no significant correlations of grain yield and length of capsule.

3.4 Partial Budget Analysis

The result of MRR of the K and S levels is presented in Table 11. The highest net revenue was obtained from plots fertilized with K and S levels at a rate of 20 kg K ha^{-1} and 40 kg S ha^{-1} (48730.12). The highest marginal rate of return was also obtained from plots treated with 20 kg K ha^{-1} and 40 kg S ha^{-1} (30347.60%), K as potassium chloride 20 kg K ha^{-1} and S as calcium sulphate respectively. As indicated in the Table 11 the rates assigned as D were found dominated treatments, negative MRR. The negative marginal rate of return values obtained was rejected. According to the manual for economic analysis of [12] the recommendation is not necessarily based on the treatment with the highest marginal rate of return compared to that of neither next lowest cost, the treatment with the highest net benefit, and nor the treatment with the highest yield. The identification of a recommendation is based on a change from one

Table 11. Partial budget analysis for sesame

Levels K and S kg ha^{-1}	Fertilizer cost (Birr)	Application cost (Birr)	Total Variable cost (Birr)	Grain Yield Adjusted (10%) kg ha^{-1}	Total revenue [Grain yield*40]	Net revenue [TR-TVC]	MRR (ratio)	MRR (%)
$K_0\|\|S_0$	0	0	0	503.22	20128.68	20128.68		
$K_0\|\|S_1$	100	70	170	717.46	28698.48	28528.48	49.41	4941.06
$K_1\|\|S_0$	240	70	310	796.46	31858.56	31548.56	21.57	2157.20
$K_0\|\|S_2$	200	140	340	866.07	34642.80	34302.80	91.81	9180.80
$K_1\|\|S_1$	340	140	480	883.82	35352.72	34872.72	4.07	407.09
$K_0\|\|S_3$	300	210	510	856.04	34241.40	33731.40	D	D
$K_2\|\|S_0$	480	140	620	1006.15	40245.84	39625.84	33.95	3395.09
$K_1\|\|S_2$	440	210	650	1234.50	49380.12	48730.12	303.48	30347.60
$K_2\|\|S_1$	580	210	790	906.29	36251.64	35461.64	D	
$K_1\|\|S_3$	540	280	820	1065.72	42628.68	41808.68	D	
$K_3\|\|S_0$	720	210	930	834.35	33374.16	32444.16	D	
$K_2\|\|S_2$	680	280	960	879.18	35167.32	34207.32	D	
$K_3\|\|S_1$	820	280	1100	881.76	35270.28	34170.28	D	
$K_2\|\|S_3$	780	350	1130	867.86	34714.44	33584.44	D	
$K_3\|\|S_2$	920	350	1270	745.53	29821.32	28551.32	D	
$K_3\|\|S_3$	1020	420	1440	865.40	34615.80	33175.80	D	

TR=Total revenue, TVC=Total variable cost MRR= Marginal rate of return and D = Dominated treatment

treatment to another if the marginal rate of return of that change is greater than the minimum rate of return (100%). According to the marginal rate of return the rate of 20 kg K ha^{-1} with 40 kg S ha^{-1}, respectively was found economically profitable compared to other treatments.

4. CONCLUSION AND RECOMMENDATION

The results of the investigation indicated that the application of potassium and sulfur has influence on yield and yield components of sesame increased with application compared to control or no application K and S. From plots fertilized with K and S levels at a rate of 20 kg K ha^{-1} and 40 kg S ha^{-1} was obtained higher yield of sesame. The highest marginal rate of return was also obtained at this rate. It is conclude, therefore, it will be good to promote K and S for further demonstration.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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