Nutrient uptake and quality of sesame (*Sesamum indicum* L.) as influenced by sulphur and boron

Abstract

At the Agronomy Field Unit, ZARS, UAS, GKVK, Bengaluru, a field experiment was carried out in kharif 2017 to examine the impact of sulphur and boron on sesame yield and quality (*Sesamum indicum* L.).Twelve treatments were reproduced three times in the experiment, which was set up using a factorial RCBD design.The application of the recommended dose of fertilisers (RDF) with 30 kg sulphur and 5 kg borax per ha resulted in significantly higher seed yield (470.00 kg ha^{-1}) and stalk yield (3126 kg ha^{-1}) than the application of the recommended dose of fertilisers with 40 and 5, 40 and 2.5, 30 and 5 kg sulphur and borax per ha (461.56 and 2826.67, 455.13 and 2733.33, 445.67 and 2626.67 kg per ha, respectively). Increased nutrient uptake of nitrogen (40.23 kg ha^{-1}) phosphorus (15.01 kg ha^{-1}) potassium (45.23 kg ha^{-1}) sulphur (13 kg ha^{-1}) and boron (162.4 ppm)was primarily responsible for increased seed and stalk yield.The application of the recommended dose of fertilisers with 40 kg sulphur and 5 kg borax per ha resulted in higher seed protein (10.72%). This matched RDF + 40 kg sulphur + 2.5 kg borax (10.66%). RDF+30 kg sulphur + 5 kg borax per ha produced the highest C: B ratio (3.5).

Keywords: Sulphur, Boron, Sesame, Nutrient uptake

INTRODUCTION

"Sesame (Sesamum indicum L.) stands as one of the earliest cultivated oilseed crops globally. With an oil content ranging from 46-64% and a protein content of 15-16%, it goes by various names like gingely, til, simsim, biniseed, and more"[1]. Recognized as the Queen of Oilseeds, sesame owes this title to its abundance of polyunsaturated stable fatty acids, imparting resistance to rancidity. Sesame oil boasts essential components such as methionine, tryptophan, niacin, and minerals like calcium and phosphorus. The seeds' potent antioxidant activity contributes to the oil's prolonged shelf life, earning it the moniker "seeds of immortality" [2].

Oil seed cake is the residue left over after oil extraction and is used as cattle feed. Sesame cakes are used as organic manure as well as a good feed concentrate for livestock. Because of the higher methionine content in sesame seeds, it is highly valued as poultry feed [3].

“India holds the global forefront in both sesame cultivation area and production. In India, sesame is cultivated across 18.50 lakh hectares, yielding a production of 8.30 lakh tonnes and a productivity rate of 474 kg per hectare. The primary sesame-producing states include Maharashtra, Uttar Pradesh, Rajasthan, Orissa, Andhra Pradesh, Madhya Pradesh, Tamil Nadu, West Bengal, Gujarat, and Karnataka. Specifically, in Karnataka, sesame is cultivated on 0.45 lakh hectares, resulting in a production of 0.23 lakh tonnes and a productivity rate of 480 kg per hectare” [4].

The relatively lower productivity of sesame can be attributed mainly to inadequate management practices and cultivation in marginal and sub-marginal lands with limited inputs, particularly under rainfed conditions. Yield is an outcome of diverse physiological processes in plants, and these can be influenced by the implementation of various management practices within a specific environment. Notably, nutrient management emerges as the pivotal factor in determining sesame yield among these practices.

“Sulphur plays a crucial role in plant growth and development, with its requirements being comparable to those of phosphorus” [5]. “In sesame, sulphur is essential for the synthesis of sulphur-containing amino acids like methionine (21%), cysteine (26%), and cystine (27%), which constitute vital protein components, accounting for approximately 90% of the plant's sulphur content” [6]. “Moreover, sulphur is necessary for the synthesis of metabolites such as coenzyme A, biotin, thiamin (vitamin B1), and glutathione. It also contributes to the synthesis of chlorophyll, glucosides, and glucosinolates, as well as enzyme activation and sulphydryl linkages, imparting pungency to oils. Additionally, sulphur promotes root growth and seed formation in sesame. In plant metabolism, sulphur is crucial for the synthesis of essential oils and chlorophyll, which is vital for cell development” [7]. “Furthermore, sulphur enhances cold and drought resistance in oilseed crops and is present in various organic compounds” [8]. “Its presence also positively influences the percentage of seed oil” [9].

Boron stands out as an essential micronutrient crucial for normal crop growth [10,11]. “Its deficiency is a widespread issue globally, leading to substantial losses in both quantitative and qualitative aspects of crop production. Boron plays a crucial role in the pollen-producing capacity of the anther, the viability of pollen tubes, as well as pollen tube germination and growth" [12]. A reduction in boron supply has been linked to a decline in oil quality [13,14]. In India, the occurrence of secondary and micronutrient deficiencies is largely attributed to the cultivation of high-yielding crops and varieties that extract higher amounts of nutrients, as well as factors such as leaching and erosion losses, intensive agricultural practices, reduced recycling of plant residues, and a disparity between the removal and addition of secondary and micronutrients.

MATERIAL AND METHODS

The field experiment was carried out at the Zonal Agricultural Research Station, Gandhi Krishi Vignana Kendra, University of Agricultural Sciences, Bengaluru, in Plot No. 2 of E block. The farm is located at 13^{o} 05' N latitude and 77^{o} 34' E longitude, at an elevation of 924 m above mean sea level, in Karnataka's Eastern Dry Zone (ACZ-V). The experimental site's soil was sandy red clay loam in nature. Before sowing, composite soil samples to a depth of 0-30 cm were collected from the experimental site and analysed for physicochemical properties. The experiment used a factorial randomised block design with three replications and twelve treatments. The first factor was sulphur levels (4): S_0-0 kg ha^{-1}, S_1-20 kg ha^{-1}, S_2-30 kg ha^{-1}, S_3-40 kg ha^{-1} and second factor as borax levels (3): B_0-0 kg ha^{-1}, B_1-2.5 kg ha^{-1}, B_2-5.0 kg ha^{-1}. GT-1 is a white seeded sesame variety released by UAS, GKVK, Bengaluru during 2012 and the duration is 85-90 days. This variety is short stature and grows to a height of 1-1.5 m with more of branches and arranged oppositely instead of alternate branching in other varieties. Plant bears more number of pods per plant and more number of locules per pod, under good management practices with favourable climate yields 750- 800 kg per ha.The observations on crop growth and other parameters were taken at different growth stages. The various growth indices were calculated using following methods.

Absolutegrowth rate

Itexpressedthedryweightincreaseperunittimeandiscalculatedbyusingthefollowingformulaand expressed asgper day **[15]**.

$$AGR = W_2 - W_1 / t_2 - t_1$$

Where,W_2andW_1arethe total dryweightplant^{-1}at time$t_2$and t_1, respectively.

Cropgrowthrate

Crop growth rate is defined as the amount of dry matter produced per unit ground area per unit time [15]. It was calculated using the formula below and expressed in grammes per square metre per day.

$$CGR = W_2 - W_1 / t_2 - t_1 x P$$

W_2	=Drymatterproductionper plant (g)at t_2
W_1	=Drymatterproductionper plant (g)at t_1
$t_1$and t_2	=timeintervals
P	=land area(cm^2)

Netassimilationrate

Net assimilation rate is the rate of dry weight increases per unit leaf areaper unit time. It was calculated by following formula [16] and expressed in gdm^2per day.

$$NAR = W_2 - W_1 / t_2 - t_1 x Log_e L_2 - Log_e L_1 / L_2 - L_1$$

Where,

L_2andW_2=Leafarea(dm^2)andtotaldryweightoftheplant(g),respectivelyattimet_2

L_1andW_1=Leafarea(dm^2)andtotaldryweightoftheplant(g),respectivelyat time t_1 $t_1$and t_2=timeintervals

Leafareaduration

The integration of the leaf area index over a growth period is known as leaf area duration [15]. LAD was calculated using the formula of [17] and expressed in days for various growth periods.

$$LAD = \frac{L_1 + L_2}{2} x (t_2 - t_1)$$

Where,

L_1	= LAIat timet_1
L_2	= LAIat timet_2
t_2-t_1	=Timeintervalbetweencropgrowthperiodindays

The plant sample was collected and analysed for the nutrient content and nutrient uptake.

Nitrogenuptake

Nitrogen content was calculated in percentage using a modified Micro-method Kjeldhal's as described in [18]. Nitrogen uptake (kg ha^{-1}) by crop was calculated separately for each treatment using the formula below.

$$\text{Nitrogenuptake}(\text{kgha}^{-1}) = \frac{\text{Nitrogenconcentration}(\%)}{100} \text{ xDrymatter}(\text{kgha}^{-1})$$

Phosphorusuptake

Phosphoruscontentinthedigestedplantsamplewasestimatedby Vanadomolybdate phosphoric yellow colour method in nitric acid medium and the colourintensity was measured at 660 nm wave length as outlined by [18]. It iscalculatedusingthefollowingformula.

$$\text{Phosphorus uptake}(\text{kgha}^{-1}) = \frac{\text{Phosphorusconcentration}(\%)}{100} \text{ xDrymatter}(\text{kgha}^{-1})$$

Potassiumuptake

The amount of potassium in the plant samples digest was calculated by atomizing the diluted acid extract in a flame photometer, as described in [18]. It is calculated using the formula below.

$$\text{Potassium uptake (kg ha-1)} = \frac{\text{Potassium concentration (\%)}}{100} \times \text{Dry matter (kg ha-1)}$$

Sulphuruptake

Sulphurinplantpartswasestimatedbyturbidometricmethodusingspectrophotometer at 420 nm [19]. Uptake was calculated by using thefollowingformulaandexpressed in kgper ha.

$$\text{S uptake}(\text{kgha}^{-1}) = \frac{\text{S content in seed (\%) xseed yield (kg/ha)}}{100} + \frac{\text{S content in stalk (\%)xstalkyield (kg/ha)}}{100}$$

Boronuptake

Boronwasestimated byusingspectrophotometer.

$$\text{B uptake (g ha}^{-1}) = \frac{\text{B content in seed (\%)} \times \text{seed yield (kg/ha)}}{100} + \frac{\text{B content in stalk (\%)} \times \text{stalk yield (kg/ha)}}{100}$$

The data obtained from experiments on different growth and yield parameters of the sesame plant underwent analysis using Fisher's method of Analysis of Variance (ANOVA), following the procedure outlined by [20]. In cases where the F-test yielded significance in comparing treatment means, the corresponding critical difference (CD) was calculated. Otherwise, the abbreviation "NS" (not significant) was indicated alongside the CD values. All data underwent thorough analysis, and the results were presented and discussed at a significance level of 5% for the field experiment and 1% for the laboratory experiment.

RESULTS AND DISCUSSION

Leafareaduration

The data on leaf area duration (LAD) of sesame as influenced by different levelsofsulphurand boron are presented intable1.Applicationof40kgsulphurperhareportedsignificantlyhigherleafareaduration of 63.97 daysat 30- 60 DAS and 103.47 days at 60 DAS- at harvest. Thisfound on par with leaf area duration of 63.67 days and 102.27 days at 30 - 60 DAS and at60 DAS - at harvest, respectively with application of 30 kg sulphur per ha. Significantlylowest leaf area duration of 49.43 days and 68.71 days at 30 - 60 DAS and at 60 DAS - atharvest,respectivelywereobservedwith no sulphurapplication.Significantly higher leaf area duration of 60.52 days at 30 - 60 DAS and 93.34days at 60 DAS - at harvest reported for application of 5 kg borax per ha. It found on parwith leaf area duration of 58.57 days and 89.68 days at 30 - 60 DAS and at 60 DAS - atharvest,respectivelywithapplicationof2.5kgboraxperha.Significantlylowest(54.44 daysand82.79days)at30-60DASandat60DAS-atharvest,respectivelywereobservedwith no boraxapplication.

At 30 - 60 DAS, interactions did not vary significantly. At 60 DAS – at harvest,applicationof30kgsulphurwith5kgboraxperharecordedsignificantlyhigherLADof 110.12 days, it found on par with 40 kg sulphur with 5 kg borax per ha and 30 kg sulphurwith2.5kg boraxper ha(107.26daysand106.59days,respectively).SignificantlylowestLAD (61.67days)observedwith nosulphur andboraxapplication.

Absolutegrowthrate

The data on absolute growth rate (AGR) of sesame as influenced by differentlevelsof sulphurand boron arepresented intable 2. At 30 - 60 DAS, application of 40 kg sulphur per ha reported significantly higherAbsolutegrowthrateof0.45gperdayanditfoundonparwith30kgsulphurperha(0.44 g day^{-1}). Significantly lowest (0.27g day^{-1}) observed with no sulphur application.At60 DAS –at harvest differenttreatments did notdiffer significantly. Application of 5 kg borax per ha reported significantly higher Absolute growthrate of 0.40 g per day at 30 - 60 DAS. It found on par with 2.5 kg borax per ha (0.39 gday^{-1}). Significantlylowest(0.32gday^{-1}) observedwithnoboraxapplication.At60DAS – atharvestdifferenttreatmentsdidnotdiffersignificantly. Interactions did not vary significantly at 30 - 60 DAS. At 60 DAS – at harvest,applicationof30kgsulphurwith5kgboraxperharecordedsignificantlyhigherAGRof 0.28 g per day, and it found on par with 40 kg sulphur with 5 kg borax per ha (0.25 g day^{-1}).Significantlylowest (0.20 gday^{-1}) observed with no sulphurand boraxapplication.

Cropgrowthrate

The data on crop growth rate (CGR) of sesame as influenced by different levels ofsulphurand boron arepresented intable3. At 30 - 60 DAS, application of 40 kg sulphur per ha reported significantly higher crop growth rate of 9.99 g per m^2 per day and it found on par with 30 kg sulphur per ha (9.71 g m^{-2} day^{-1}). Significantly lowest (5.98 g m^{-2} day^{-1}) observed with no sulphur application. Different treatments did not differ significantly for CGR at 60 DAS – at harvest.Application of 5 kg borax per ha reported significantly higher crop growth rate of 9 g per m^2 per day at 30 - 60 DAS, it found on par with 2.5 kg borax per ha (8.57 g m^{-2} day^{-1}). Significantly lowest crop growth rate of 7.10 g per m^2 per day observed with no borax application. At 60 DAS – at harvest different treatments did not differ significantly.At 30 - 60 DAS, interactions did not vary significantly. At 60 DAS – at harvest, application of 40 kg sulphur with 0 kg borax per ha recorded significantly higher CGR of 6.14 g per m^2 per day followed by 20 kg sulphur with 5 kg borax per ha (5.56 g m^{-2} day^{-1}). Significantly lowest CGR (3.73 g m^{-2} day^{-1}) observed with no sulphur and borax application.

Net assimilation rate

The data on net assimilation rate (NAR) of sesame as influenced by different levels of sulphur and boron are presented in table 4. Application of 40 kg sulphur per ha reported significantly higher net assimilation rate (6.52 g^{-1} dm^{-2} leaf $area^{-1}$ day^{-1} at 30 - 60 DAS and 3.48 g^{-1} dm^{-2} leaf $area^{-1}$ day^{-1} at 60 DAS - at harvest). This found on par with 30 kg sulphur per ha (6.25 g^{-1} dm^{-2} leaf $area^{-1}$ day^{-1} at 30 - 60 DAS and 2.85 g^{-1} dm^{-2} leaf $area^{-1}$ day^{-1} at 60 DAS - at harvest). Significantly lowest (4.98 g^{-1} dm^{-2} leaf $area^{-1}$ day^{-1} at 30 - 60 DAS and 2.11 g^{-1} dm^{-2} leaf $area^{-1}$ day^{-1} at 60 DAS - at harvest) were observed with no sulphur application. The different treatments did not differ significantly due to application of different levels of borax at different growth stages of sesame for net assimilation rate. Interactions did not found significant for net assimilation rate at different growth stages of sesame.

The application of 40 kg of sulphur per hectare had a positive impact on plant vigor by enhancing nutrient availability. This, in turn, led to improved assimilation and increased dry matter, contributing to higher leaf area per plant. Consequently, there was an elevation in the leaf area index due to augmented chlorophyll formation [21]. The leaf area index serves as an indicator of plant growth, reflecting assimilation and transpiration rates, and is a significant factor in determining solar radiation interception and canopy photosynthesis. The increase in dry matter production, influenced by effective translocation of photosynthates through sulphur nutrition, played a role in augmenting the leaf area. This rise in leaf area index was attributed to an increase in total dry matter production per plant, subsequently extending the leaf area duration. This extension became a major factor influencing photosynthesis through sulphur application [22]. The heightened transport of sugars and carbohydrates resulting from sulphur application at 40 kg per hectare led to an increased absolute growth rate, net assimilation rate, and crop growth rate. This effect was attributed to the accelerated dry matter production within a short time frame due to the nutritional boost from sulphur [2].

5 kg per ha borax application recorded higher leaf area index significantly. This might be due to increased dry matter production and leaf area through increased metabolic activities. Increased LAI led to increased leaf area duration by effective translocation of photosynthates [11, 14]. Boron nutrition increased dry matter per plant and induced the cell division. This became responsible for enhanced absolute growth rate and crop growth rate. These findings are in accordance with findings of in soybean [7].

Sulphur and boron nutrients being synergistic in action, both help for cell division, expansion and elongation of cells. This resulted more growth parameters which in turn recorded higher growth indices. These results are in accordance with findings of [2].

Seedyield

Table 5 presents the seed yield data for sesame influenced by varying levels of sulphur and boron. Notably, the application of 40 kg sulphur per hectare resulted in a significantly higher seed yield at 424.67 kg/ha, on par with the yield from 30 kg/ha sulphur application (423.90 kg/ha). The lowest seed yield of 290.53 kg/ha was observed in the absence of sulphur application. Similarly, the application of 5 kg borax per hectare led to a significantly higher seed yield of 393.25 kg/ha, comparable to the yield from 2.5 kg/ha borax application (381.29 kg/ha). The lowest seed yield of 347.12 kg/ha was recorded when no borax was applied. In terms of interaction effects, the combined application of 30 kg sulphur with 5 kg borax per hectare resulted in a significantly higher seed yield of 470 kg/ha. This was on par with the yields from the combinations of 40 kg sulphur with 5 kg borax per hectare, 40 kg sulphur with 2.5 kg borax per hectare, and 30 kg sulphur with 2.5 kg borax per hectare, which recorded yields of 461.56 kg/ha, 455.13 kg/ha, and 445.67 kg/ha, respectively. The lowest seed yield of 273.33 kg/ha was recorded when neither sulphur nor borax was applied.

Stalkyield

Table 5 outlines the data on stalk yield of sesame under the influence of different levels of sulphur and boron. Notably, the application of 40 kg sulphur per hectare resulted in a significantly higher stalk yield of 2578.89 kg/ha, on par with the yield from 30 kg/ha sulphur application (2473.33 kg/ha). The lowest stalk yield of 1985.56 kg/ha was recorded in the absence of sulphur application. Similarly, the application of 5 kg borax per hectare led to a significantly higher stalk yield of 2507.50 kg/ha, comparable to the yield from 2.5 kg/ha borax application (2355 kg/ha). The lowest stalk yield of 1981.92 kg/ha was observed when no borax was applied. In terms of interaction effects, the treatment receiving 30 kg sulphur with 5 kg borax per hectare recorded a significantly higher stalk yield of 3126.67 kg/ha. This was on par with the yields from the combinations of 40 kg sulphur with 5 kg borax per hectare, 40 kg sulphur with 2.5 kg borax per hectare, and 30 kg sulphur with 2.5 kg borax per hectare, which recorded yields of 2826.67 kg/ha, 2733.33 kg/ha, and 2626.67 kg/ha, respectively. The lowest stalk yield of 2006.67 kg/ha was recorded when neither sulphur nor borax was applied.

Protein content

Table 5 provides data on the protein content (%) of sesame seeds influenced by varying levels of sulphur and boron. Notably, the application of 30 kg sulphur per hectare resulted in a significantly higher protein content of 10.46%, on par with the protein content from 40 kg sulphur per hectare (10.44%). The lowest protein content of 9.69% was recorded in the absence of sulphur application. Similarly, a significantly higher protein content of 10.33% was observed with the application of 5 kg borax per hectare, on par with the protein content from 2.5 kg borax per hectare (10.19%). The lowest protein content of 10.03% was reported when no borax was applied. Regarding interaction effects, the application of 40 kg sulphur with 5 kg borax per hectare resulted in significantly higher protein content (10.72%). This was on par with the protein content from the combinations of 40 kg sulphur with 2.5 kg borax per hectare, 30 kg sulphur with 5 kg borax per hectare, and 30 kg sulphur with 0 kg borax per hectare, which recorded protein contents of 10.66%, 10.45%, and 10.53%, respectively. The lowest protein content of 9.56% was recorded when neither sulphur nor borax was applied. The observed results may be attributed to the joint action of 40 kg sulphur and 5 kg borax per hectare, playing a role in structural regulation of secondary metabolites and catalytic functions, particularly in proteins. This involvement is seen in proteins such as tripeptide glutathione (redox buffer) and certain proteins like thioredoxin, glutaredoxin, and protein disulphide isomerase. These regulatory activities are associated with the light reaction (CO_2 fixation) of photosynthesis, leading to increased assimilation of nitrogen and sulphur, which is responsible for sulphur-containing amino acids, namely methionine and cysteine. These findings align closely with the results of [23 and 24]. Additionally, in plant systems, boron is known to enhance enzymatic activities for protein synthesis [24 and 25].

Effectofdifferentlevelsofsulphurandborononotalnutrientuptakeofsesame

Dataontheuptakeofmajornutrients(nitrogen,phosphorus,potassium),secondarynutrient(sulphur)andmicronutrient(boron)atharvestasinfluencedbyapplicationof different levels ofsulphurand boraxarepresented below.

Nitrogen

Data pertaining to uptake of nitrogen in sesame(kg ha^{-1}) are presentedin thetable6. Totaluptakeofnitrogeninsesamewasfound tobesignificantly higherwiththe application of 40 kg sulphur per ha (33.86 kg ha^{-1}) and which found on par withapplication of 30 kg sulphur per ha (32.73 kg ha^{-1}). Treatment applied with no sulphurshowedsignificantlylesstotalnitrogenaccumulation insesame (23.57 kgha^{-1}). Significantly higher total nitrogen uptake found with the application of 5 kg boraxper ha (32.30 kg ha^{-1}) and which found on par with application of 2.5 kg borax per ha(30.12 kgha^{-1}). Significantlyless (25.26 kgha^{-1}) observedwith no boraxapplication. Application of 30 kg sulphur with 5 kg borax per ha recorded significantly highertotal nitrogen uptake at harvest (40.23 kg ha^{-1}) and it found on par with application of 40kg sulphur with 5 kg borax per ha, 40 kg sulphur with 2.5 kg borax per ha and 30 kgsulphur with 2.5 kg boraxper ha (37.24, 36 and 34.59 kg ha^{-1}). Significantly lowestuptakeof23.19 kgper haobserved withno sulphur and boraxapplication.

This was mainly due to higher growth and yield parameters that recorded byapplication of recommended dose of nitrogen, phosphorous and potassium with sufficientquantity of sulphur and borax. This quantity element (nitrogen) since has synergisticaction with both sulphur and boron, resulted increased uptake. These findings are similarwithfindings of [10, 26, 27 and 28].

Phosphorous

Data pertaining to uptake of phosphorous in sesame (kg ha^{-1}) are presented in thetable6.Significantly higher total phosphorous uptake found with the application of 40 kgsulphur per ha (12.13 kg ha^{-1}) and which was on par with application of 30 kg sulphur perha (11.76 kg ha^{-1}). Treatment applied with no sulphur showed significantly less totalphosphorous accumulation in sesame (7.40 kgha^{-1}). Total uptake of phosphorous in sesame was found to be significantly higher withthe applicationof 5kgboraxper ha (11.25kg ha^{-1}) andwhichfoundonpar withapplication of 2.5 kg boraxper ha (10.28 kg ha^{-1}). Significantly less(8.38 kg ha^{-1})observedwith no boraxapplication. Application of 30 kg sulphur with 5 kg borax per ha recorded significantly highertotal phosphorous uptake at harvest (15.01 kg ha^{-1}) and it found on par with application of40 kg sulphur with 5 kg borax per ha, 40 kg sulphur with 2.5 kg borax per ha and 30 kgsulphur with 2.5 kg borax per ha (13.21, 12.71 and 12.52 kg ha^{-1}). Significantly lowestuptake(7.05kgha^{-1})found with no sulphur and boraxapplication. This increased phosphorous uptake is mainly due to enhanced uptake of nitrogenby higher root proliferation, anchorage to deep penetration which in turn increases theuptake from rhizosphere. Also the sulphur and boron are in synergistic for uptake withphosphorous.Thesefindings arein line with[29, 30 and 31].

Potassium

Table 6 presents data on the uptake of potassium in sesame (kg/ha), influenced by different levels of sulphur and boron. Notably, the total uptake of potassium in sesame was significantly higher with the application of 40 kg sulphur per hectare (36.78 kg/ha), on par with the uptake from 30 kg sulphur per hectare (36.21 kg/ha). The treatment with no sulphur application showed significantly lower uptake (25.95 kg/ha).Similarly, significantly higher total potassium uptake was found with the application of 5 kg borax per hectare (35.60 kg/ha), on par with the uptake from 2.5 kg borax per hectare (32.90 kg/ha). Significantly less total potassium accumulation in sesame (27.49 kg/ha) was observed with no borax application.Regarding interaction effects, the treatment with 30 kg sulphur and 5 kg borax per hectare recorded significantly higher total potassium uptake at harvest (45.23 kg/ha). This was on par with the total potassium uptake from the combinations of 40 kg sulphur with 5 kg borax per hectare, 40 kg sulphur with 2.5 kg borax per hectare, and 30 kg sulphur with 2.5 kg borax per hectare, which recorded uptakes of 40.47 kg/ha, 39.09 kg/ha, and 38.14 kg/ha, respectively.

The lowest uptake (25.36 kg/ha) was found with no sulphur and borax application.The observed increase in potassium uptake could be attributed to the sufficient quantity of potassium present in the soil and supplied through MOP fertilizer. Additionally, potassium, even when not required, tends to be responsive for more storage in the plant. The higher photosynthetic activity in the leaf, influenced by potassium with nitrogen and sulphur nutrition, indirectly led to the efficient utilization of nutrients applied to the soil. Similar findings were reported by [3 and 10].

Sulphur

Table 6 provides data on the uptake of sulphur in sesame (kg/ha), influenced by different levels of sulphur and boron. Notably, significantly higher total sulphur uptake was found with the application of 40 kg sulphur per hectare (10.42 kg/ha), on par with the uptake from 30 kg sulphur per hectare (9.89 kg/ha). The treatment with no sulphur application showed significantly lower total sulphur accumulation in sesame (5.96 kg/ha).Similarly, the total uptake of sulphur in sesame was significantly higher with the application of 5 kg borax per hectare (9.55 kg/ha), on par with the uptake from 2.5 kg borax per hectare (8.54 kg/ha). Significantly less (6.91 kg/ha) sulphur uptake was reported with no borax application.Regarding interaction effects, the treatment with 30 kg sulphur and 5 kg borax per hectare recorded significantly higher total sulphur uptake at harvest (13 kg/ha). This was on par with the total sulphur uptake from the combinations of 40 kg sulphur with 5 kg borax per hectare, 40 kg sulphur with 2.5 kg borax per hectare, and 30 kg sulphur with 2.5 kg borax per hectare, which recorded uptakes of 11.49 kg/ha, 11.16 kg/ha, and 11.12 kg/ha, respectively.

The lowest uptake (5.84 kg/ha) was found with no sulphur and borax application. The observed increase in sulphur uptake could be attributed to the application of sulphur, supplied through elemental sulphur [32]. Additionally, the higher photosynthetic activity in the leaf, influenced by sulphur nutrition, indirectly led to the efficient utilization of nutrients applied to the soil [10 and 33]. Since sulphur is a structural part of proteins involved in various biological functions, it increased root proliferation and rhizosphere area, aiding in more nutrient uptake [34]. The increased sulphur uptake also synergistically increased the uptake of boron. Similar findings were reported by [35].

Boron

Datapertainingtouptakeofboroninsesame(gha^{-1})arepresentedinthetable6. Totaluptakeofboroninsesamewasfoundtobesignificantlyhigherwiththe application of 40 kg sulphur per ha (125.3 g ha^{-1}) and which found on par withapplicationof30kgsulphurperha(123gha^{-1}).Treatmentnosulphurshowedsignificantlyless total boron accumulation in sesame (79.9gha^{-1}). Significantly higher total boron uptake found with the application of 5 kg boraxper ha (120.6 g ha^{-1}) followed by application of 2.5 kg borax per ha recorded (107.7 g ha^{-1}).Significantlyless(87.5gha^{-1})totalboronaccumulationinsesamefoundwithnoboraxapplication. Application of 30 kg sulphur with 5 kg borax per ha recorded significantly highertotal boron uptake at harvest (162.4 g ha^{-1}) and it found on par with application of 40 kgsulphur and 5 kg borax per ha (139.9 g ha^{-1}). Significantly lowest uptake (78.7 g ha^{-1})foundwith no sulphur and boraxapplication.

This is mainly due to sulphur application where it reduced soil pH and increasedrootgrowth,soabilityofrootstoabsorbandtranslocateboronenhanced.ReducedsoilpH increased the micronutrient availability [33 and 36]. Sufficient quantity ofborax application also enhanced the uptake due to its sufficiency in soil and higherphotosynthetic activity in leaf exerted by sulphur nutrition, indirectly led to efficientutilization of boron nutrient applied to the soil [11 and 14]. Increased rhizosphere area by sulphur alsohelpsformoreuptakeofboron.Thesefindingsareinagreementwithfindingsof[24].

Economics

The data on economics as influenced by application of different levels of sulphur and boron in sesame (kg ha^{-1}) are presented in the table 7. Higher gross returns, net returns and C: B ratio were recorded in treatment with application of 30 kg sulphur with 5 kg borax per ha (Rs 58750, 41918 and 3.5, respectively). Lower gross returns, net returns and C: B ratio (Rs 34166, 21633 and 2.7, respectively) were obtained with 40 kg sulphur with 0 kg borax per ha application. This could be attributed to higher seed yield of sesame recorded in this treatment. Maximum net return and C: B ratio was realized by application of 30 kg sulphur per ha, although it was on par with 40 kg sulphur per ha [6]. This is due to the increase in the uptake of nutrients which intern increased the seed yield which increased the net monetary returns and the benefit cost ratio. Similar results were reported by [30].

CONCLUSION AND FUTURE SCOPE

The application of sulphur and boron will not only improve the yield but also quality parameters. The foliar application of these two nutrients has immense importance in crop nutrition. Quality parameter like protein content of seed has recorded significantly high with application of 40 kg sulphur with 5 kg borax per ha. It was on par with 40 and 2.5, 30 and 5 And 30 and 0 kg sulphur and borax per ha and significantly lower protein content was recorded with no sulphur and borax application. Application of 30 kg sulphur and 5 kg borax per ha along with RDF recorded higher sesame seed yield (470 kg ha^{-1}), net return (41918 Rs ha^{-1}) and C: B ratio of 3.5. Effect of different sources of sulphur and boron along with efficient sulphur oxidizing strain on growth, yield and quality of sesame is required. Use of INM studies along with micronutrients is required.

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Table1:Leafareadurationofsesameasinfluencedbyapplicationofdifferentlevelsofsulphurand boron.

Treatments	30-60DAS(Days)	60DAS-Atharvest(Days)
FactorA : Sulphurlevels (S)		
S_0: 0 kgha^{-1}	49.43	68.71
S_1: 20 kgha^{-1}	54.31	79.98
S_2: 30 kgha^{-1}	63.67	102.27
S_3: 40 kgha^{-1}	63.97	103.47
S.Em±	1.18	1.12
CD(P=0.05)	3.45	3.29
FactorB:Boronlevels(B)		
B_0:0 kgha^{-1}	54.44	82.79
B_1:2.5 kgha^{-1}	58.57	89.68
B_2:5.0 kgha^{-1}	60.52	93.34
S.Em±	1.02	0.97
CD(P=0.05)	2.99	2.85
Interaction (AxB)		
S_0B_0	44.98	61.67
S_0B_1	50.28	69.21
S_0B_2	53.02	75.24
S_1B_0	51.87	79.12
S_1B_1	55.00	80.06
S_1B_2	56.07	80.75
S_2B_0	58.86	90.10
S_2B_1	64.98	106.59
S_2B_2	67.17	110.12
S_3B_0	62.06	100.28
S_3B_1	64.04	102.88
S_3B_2	65.81	107.26
S.Em±	2.04	1.94
CD(P=0.05)	NS	5.70

Table2:Absolutegrowthrateofsesameasinfluencedbyapplicationofdifferentlevelsofsulphura nd boron.

Treatments	**30-60DAS (g day^{-1})**	**60DASAtharvest(g day^{-1})**
FactorA : Sulphurlevels (S)		
S_0: 0 kgha^{-1}	0.27	0.21
S_1: 20 kgha^{-1}	0.32	0.20
S_2: 30 kgha^{-1}	0.44	0.20
S_3: 40 kgha^{-1}	0.45	0.22
S.Em±	0.02	0.01
CD(P=0.05)	0.05	NS
FactorB:Boronlevels(B)		
B_0:0 kgha^{-1}	0.32	0.22
B_1:2.5 kgha^{-1}	0.39	0.20
B_2:5.0 kgha^{-1}	0.40	0.21
S.Em±	0.02	0.01
CD(P=0.05)	0.05	NS
Interaction(AxB)		
S_0B_0	0.23	0.20
S_0B_1	0.26	0.20
S_0B_2	0.31	0.18
S_1B_0	0.31	0.17
S_1B_1	0.32	0.19
S_1B_2	0.34	0.20
S_2B_0	0.33	0.19
S_2B_1	0.48	0.20
S_2B_2	0.50	0.28
S_3B_0	0.40	0.21
S_3B_1	0.48	0.19
S_3B_2	0.47	0.25
S.Em±	0.03	0.02
CD(P=0.05)	NS	0.06

Table 3: Crop growth rate of sesame as influenced by application of differentlevelsofsulphurand boron.

Treatments	**30-60DAS (g m^{-2}day^{-1})**	**60 DAS -At harvest(g m^{-2}day^{-1})**
FactorA : Sulphurlevels (S)		
S_0: 0 kgha^{-1}	5.98	4.58

S_1: 20 $kgha^{-1}$	7.21	4.48
S_2: 30 $kgha^{-1}$	9.71	4.46
S_3: 40 $kgha^{-1}$	9.99	4.97
S.Em±	0.41	0.31
CD(P=0.05)	1.20	NS
FactorB:Boronlevels(B)		
B_0:0 $kgha^{-1}$	7.10	4.80
B_1:2.5 $kgha^{-1}$	8.57	4.47
B_2:5.0 $kgha^{-1}$	9.00	4.59
S.Em±	0.35	0.27
CD(P=0.05)	1.04	NS
Interaction(AxB)		
S_0B_0	5.21	3.73
S_0B_1	5.83	4.65
S_0B_2	6.91	3.95
S_1B_0	6.90	3.74
S_1B_1	7.06	4.15
S_1B_2	7.65	5.56
S_2B_0	7.41	4.20
S_2B_1	10.68	4.80
S_2B_2	11.05	4.37
S_3B_0	8.89	6.14
S_3B_1	10.71	4.30
S_3B_2	10.37	4.48
S.Em±	0.71	0.24
CD(P=0.05)	NS	0.57

Table 4: Net assimilation rateof sesame as influenced by application of differentlevelsofsulphurand boron.

Treatments	30-60DAS (g^{-1} dm^{-2} $leafarea^{-1}$ day^{-1})	60DAS-Atharvest (g^{-1} dm^{-2} $leafarea^{-1}$ day^{-1})
FactorA : Sulphur levels (S)		
S_0: 0 $kgha^{-1}$	4.98	2.11
S_1: 20 $kgha^{-1}$	5.49	2.32
S_2: 30 $kgha^{-1}$	6.25	2.85
S_3: 40 $kgha^{-1}$	6.52	3.48
S.Em±	0.36	0.23
CD(P=0.05)	1.05	0.67

FactorB:Boronlevels(B)		
B_0:0 kgha^{-1}	5.42	2.95
B_1:2.5 kgha^{-1}	5.92	2.56
B_2:5.0 kgha^{-1}	6.08	2.50
S.Em±	0.31	0.20
CD(P=0.05)	NS	NS
Interaction(AxB)		
S_0B_0	4.82	4.21
S_0B_1	4.73	3.51
S_0B_2	5.38	2.73
S_1B_0	5.51	2.35
S_1B_1	5.30	2.57
S_1B_2	5.65	3.37
S_2B_0	5.19	2.27
S_2B_1	6.77	2.16
S_2B_2	6.78	1.91
S_3B_0	6.17	2.96
S_3B_1	6.89	1.99
S_3B_2	6.51	2.01
S.Em±	0.62	0.40
CD(P=0.05)	NS	NS

Table5:Seedyield,StalkyieldandProtein contentofsesameasinfluencedbyapplicationofdifferentlevels ofsulphurandboron.

Treatments	Seed yield(kg ha^{-1})	Stalk yield(kg ha^{-1})	Protein content (%)
FactorA : Sulphurlevels (S)			
S_0: 0 kgha^{-1}	290	1985	9.69
S_1: 20 kgha^{-1}	356	2088	10.14
S_2: 30 kgha^{-1}	423	2473	10.46
S_3: 40 kgha^{-1}	424	2578	10.44
S.Em±	7	129	0.06
CD(P=0.05)	22	380	0.17
FactorB :Boron levels(B)			
B_0:0 kgha^{-1}	347	1981	10.03
B_1:2.5 kgha^{-1}	381	2355	10.19
B_2:5.0 kgha^{-1}	393	2507	10.33
S.Em±	6.51	112.46	0.05
CD(P=0.05)	19.08	329.83	0.15

Interaction(AxB)			
S_0B_0	273	2006	9.56
S_0B_1	302	2033	9.69
S_0B_2	296	1916	9.82
S_1B_0	335	2077	10.07
S_1B_1	381	2026	10.01
S_1B_2	383	2160	10.33
S_2B_0	350	1666	10.53
S_2B_1	445	2626	10.39
S_2B_2	470	3126	10.45
S_3B_0	416	2176	9.95
S_3B_1	455	2733	10.66
S_3B_2	461	2826	10.72
S.Em±	13.01	224.92	0.10
CD(P=0.05)	38.16	659.67	0.30

Table 6: Total plant uptake ofnutrients at harvestofsesameasinfluenced byapplicationofdifferentlevels ofsulphurandboron.

Treatments	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	S (kg ha^{-1})	B (ppm)
FactorA :Sulphurlevels (S)					
S_0: 0 kgha^{-1}	23.57	7.40	25.95	5.96	79.9
S_1: 20 kgha^{-1}	26.75	8.58	29.05	7.06	92.7
S_2: 30 kgha^{-1}	32.73	11.76	36.21	9.89	123.0
S_3: 40 kgha^{-1}	33.86	12.13	36.78	10.42	125.3
S.Em±	1.33	0.44	1.49	0.38	4.9
CD(P=0.05)	3.91	1.30	4.37	1.12	14.3
FactorB:Boronlevels(B)					
B_0:0 kgha^{-1}	25.26	8.38	27.49	6.91	87.5
B_1:2.5 kgha^{-1}	30.12	10.28	32.90	8.54	107.7
B_2:5.0 kgha^{-1}	32.30	11.25	35.60	9.55	120.6
S.Em±	1.15	0.38	1.29	0.33	4.2
CD(P=0.05)	3.39	1.13	3.78	0.97	12.4
Interaction (AxB)					
S_0B_0	23.19	7.05	25.36	5.84	78.7
S_0B_1	24.21	7.61	26.78	5.99	81.0
S_0B_2	23.32	7.55	25.72	6.04	80.0

S_1B_0	26.13	8.20	28.55	6.72	89.2
S_1B_1	25.70	8.30	27.60	6.80	89.1
S_1B_2	28.41	9.24	30.99	7.65	99.9
S_2B_0	23.37	7.78	25.26	6.22	84.0
S_2B_1	34.59	12.52	38.14	10.46	129.4
S_2B_2	40.23	15.01	45.23	13.00	162.4
S_3B_0	28.33	10.48	30.79	11.12	97.9
S_3B_1	36.00	12.71	39.09	11.16	131.2
S_3B_2	37.24	13.21	40.47	11.49	139.9
S.Em±	2.31	0.77	2.58	0.66	8.43
CD(P=0.05)	6.77	2.51	7.56	1.94	24.72

Table 7: Economics of sesame as influenced by application of different levels ofsulphurandboron.

Treatments	**Cost of cultivation(Rsha^{-1})**	**Grossreturn(Rsha^{-1})**	**Netreturns(Rsha^{-1})**	**C:Bratio**
S_0B_0	12533	34166	21633	2.7
S_0B_1	12683	37750	25067	3.0
S_0B_2	12833	37032	24199	2.9
S_1B_0	15199	41959	26760	2.8
S_1B_1	15349	47652	32303	3.1
S_1B_2	15499	47884	32385	3.1
S_2B_0	16532	43820	27288	2.7
S_2B_1	16682	55708	39026	3.3
S_2B_2	16832	58750	41918	3.5
S_3B_0	17865	52111	34246	2.9
S_3B_1	1801	56891	38876	3.2

	5			
S_3B_2	1816 5	57695	39530	3.2