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.) is one of the world's oldest oil seed crops. It is composed of 46-64 percent oil and 15-16 percent protein" [1]. "It is known by various names such as gingely, til, simsim, biniseed, and so on. Sesame is known as the Queen of Oilseeds due to its high concentration of poly unsaturated stable fatty acids, which provide resistance to rancidity. Sesame oil contains methionine, tryptophan, niacin, and minerals (Ca and P). Because of the high antioxidant activity of seeds, their oil has a longer shelf life and is known as 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 leads the world in terms of sesame area and production. Sesame is grown on an area of 18.50 lakh ha in India, with a production of 8.30 lakh tonnes and a productivity of 474 kg per ha. Maharashtra, Uttar Pradesh, Rajasthan, Orissa, Andhra Pradesh, Madhya Pradesh, Tamil Nadu, West Bengal, Gujarat, and Karnataka are the major growing states. It is grown on 0.45 lakh ha in Karnataka, with a production of 0.23 lakh tonnes and a productivity of 480 kg per ha" [4].

"Sesame's lower productivity is primarily due to poor management and cultivation in marginal and sub-marginal lands with low input, starved, rainfed conditions. Yield is the result of various physiological processes in plants, which can be altered by management practises in a given environment". [36]"Nutrient management is the most important factor in determining sesame yield among management practises". [35]

"Sulphur requirements are equivalent to phosphorus requirements, where it is required for plant growth and development" [5]. "Sulphur is required for the synthesis of sulphur-containing amino acids such as methionine (21%), cysteine (26%), and cystine (27%), which are essential protein constituents in sesame" [6]. "These amino acids contain approximately 90% of the plant sulphur. Sulphur is also required for the synthesis of metabolites such as coenzyme A, biotin, thiamin or vitamin B1, and glutathione, as well as the synthesis of chlorophyll, glucosides and glucosinolates, enzyme activation, and sulphydryl linkages, which provide pungency in oils. It also encourages root growth and seed formation in sesame.Sulphur is also important in plant metabolism, as it is required for the synthesis of essential oils and the formation of chlorophyll, which is required for cell development" [7]. "It also provides cold resistance and drought resistance to oilseed crops. It is found in a variety of organic compounds" [8]. "It also raises the percentage of seed oil" [9].

"Boron is one of the essential micronutrients required for normal crop growth" [10,11]. "Its deficiency is the most common worldwide, causing significant losses in crop production both quantitatively and qualitatively. It is associated with the pollen producing capacity of the anther, viability of pollen tubes, pollen tube germination, and pollen tube growth" [12]. "Boron supply reduction degrades oil quality" [13,14]. The occurrence of secondary and micronutrient deficiency in India is primarily due to the cultivation of high yielding crops, varieties that remove greater amounts of nutrients, leaching and erosion losses, intensive agriculture, reduced recycling of plant residues, and a gap between secondary and micronutrient removal and addition.

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.

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

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.

$$\text{Buptake } (\text{gha}^{-1}) = \frac{\text{B content in seed (\%)xseedyield (kg/ha)}}{100} + \frac{\text{B content in stalk (\%) xstalkyield(kg/ha)}}{100}$$

"The experimental data on various growth and yield parameters of the sesame plant were subjected to Fishers method of -Analysis of Variance (ANOVA) as outlined by [20]. Wherever the F-test was found to be significant for comparing treatment means, an appropriate critical difference (CD) was calculated. Otherwise, the abbreviation NS was placed next to the CD values. All data was analysed, and the findings were presented and discussed at a probability level of 5% for the field experiment and 1% for the laboratory experiment". [35]

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.

"Sulphur at 40 kg per ha improved the plant vigour by increased availability of nutrients, resulting in better assimilation and increased dry matter, associated with higher leaf area per plant and in turn higher leaf area index, because of increased chlorophyll formation" [21]. "Leaf area index is often used as indicator of plant growth for evaluating assimilation, transpiration rate and is a major factor in determining the solar radiation interception and canopy photosynthesis. Amount of dry matter production influenced the leaf area by effective translocation of photosynthates by sulphur nutrition. The leaf area index was increased due to increase in the total dry matter production per plant, in turn increased the leaf area duration by increasing the major factor determining the photosynthesis by sulphur application" [22]. "Enhanced sugars and carbohydrates transport resulted increased absolute growth rate, net assimilation rate and crop growth rate due to increased dry matter production within a short time by 40 kg sulphur per ha nutrition" [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

"The data on seed yield of sesame as influenced by different levels of sulphur andboronarepresented intable 5. The application of 40 kg sulphur per ha recorded significantly higher seed yield(424.67 kg ha^{-1}) and which was on par with 30 kg per ha sulphur application (423.90 $kgha^{-1}$). Significantly lowest seed yield (290.53 kg ha^{-1}) was recorded with no sulphurapplication". [35]

"Significantly higher seed yield (393.25 kg ha^{-1}) recorded with application of 5 kgborax per ha. It was on par with 2.5 kg per ha borax (381.29 kg ha^{-1}). Significantly lowestseedyield (347.12 kgha^{-1}) was recordedwith noboraxapplication. Among interaction, application of 30 kg sulphur with 5 kg borax per ha recordedsignificantly higher seed yield (470 kg ha^{-1}). And it was on par with application of 40 kgsulphur with 5 kg borax per ha, 40 kg sulphur with 2.5 kg borax per ha and 30 kg sulphurwith2.5 kgboraxper ha (461.56, 455.13 and 445.67 kgha^{-1}, respectively).Significantly lowestseedyieldof273.33kgperhawasrecordedwithnosulphurandboraxapplication". [35]

Stalkyield

The data on stalk yield of sesame as influenced by different levels of sulphur andboronarepresented intable5. "Application of 40 kg sulphur per ha recordedsignificantly higher stalkyield(2578.89 kg ha^{-1}) and it found on par with 30 kg per ha sulphur (2473.33 kg ha^{-1}).Significantlyloweststalkyield(1985.56kgha^{-1})wasrecordedwithnosulphurapplication. Significantly higher stalkyield (2507.50 kg ha^{-1}) recorded with application of 5kg borax per ha. It was on par with 2.5 kg per ha borax (2355 kg ha^{-1}). Significantlyloweststalkyield (1981.92kgha^{-1}) wasrecordedwith no boraxapplication. Among interaction, treatment receiving 30 kg sulphur with 5 kg borax per harecorded significantly higher stalk yield (3126.67 kg ha^{-1}). It was on par with applicationof 40 kg sulphur with 5 kg borax per ha, 40 kg sulphurwith 2.5 kg borax per ha and 30kg sulphur with 2.5 kg borax per ha (2826.67, 2733.33 and 2626.67 kg ha^{-1}, respectively).Significantly lowest stalk yield (2006.67 kg ha^{-1}) was recorded with no sulphur and boraxapplication". [35]

Protein content

The data on protein content (%) of sesame seed as influenced by application of different levels of sulphur and boron is presented in the table 5. Application of 30 kg sulphur per ha recorded significantly higher protein content of 10.46 per cent, which found on par with 40 kg sulphur per ha (10.44 %). Significantly lowest (9.69 %) was recorded with no sulphur application. Significantly higher protein content (10.33 %) recorded with 5 kg per ha borax application and it found on par (10.19 %) with 2.5 kg per ha borax application. Significantly lowest protein (10.03 %) reported with no borax application. Among interactions, Application of 40 kg sulphur with 5 kg borax per ha reported significantly higher protein (10.72 %), and it was on par with application of 40 kg sulphur with 2.5 kg borax per ha, 30 kg sulphur with 5 kg borax per ha and 30 kg sulphur with 0 kg borax per ha (10.66, 10.45 and 10.53 %, respectively). Significantly lowest (9.56 %) recorded with no sulphur and borax application.

This might be due to the fact that at 40 kg per ha sulphur with borax 5 kg per ha application involved in several structural regulation of secondary metabolites and catalytic functions in the sense of proteins, tripeptide glutathione (redox buffer) and certain proteins such as thioredoxin, glutaredoxin and protein disulphide isomerase. This attributing to regulation activity, involved in light reaction (CO_2 fixation) of photosynthesis, which will increase the assimilation of nitrogen and sulphur responsible for sulphur containing amino acids, viz., methionine and cysteine. This result was in close association with the findings of [23 and 24]. In plant system boron enhances enzymatic activities for protein synthesis [24 and 25].

Effectofdifferentlevelsofsulphurandborononttotalnutrientuptakeofsesame

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". [36]Thesefindings arein line with[29, 30 and 31].

Potassium

Data pertaining to uptake of potassium in sesame (kg ha^{-1}) are presented in thetable6. Totaluptakeofpotassiuminsesamewasfoundtobesignificantlyhigherwiththeapplicationof40kgsulphurperha(36.78kgha^{-1})andwhichfoundonparwith applicationof30kgsulphurperha(36.21kgha^{-1}).Treatmentappliedwithnosulphurshowedsignificantlyfewer uptakes (25.95 kgha^{-1}). Significantly higher total potassium uptake found with the application of 5 kgborax per ha (35.60 kg ha^{-1}) and which found on par with application of 2.5 kg borax perha (32.90 kg ha^{-1}). Significantly less (27.49 kg ha^{-1}) total potassium accumulation insesamefound with application ofno borax.

"Application of 30 kg sulphur with 5 kg borax per ha recorded significantly highertotal potassium uptake atharvest (45.23 kg ha^{-1}) and it found on par withapplication 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 (40.47, 39.09 and 38.14 kg ha^{-1}). Significantly lowestuptake(25.36 kgha^{-1})foundwithno sulphurand boraxapplication". [35]"The increased potassium uptake might be due to sufficient quantity of potassiumpresent in soil and also supplied through MOP fertilizer. In addition, being responsive formore storage in plant even when not required. The higher photosynthetic activity in leafexertedbypotassiumwithnitrogenandsulphurnutritionindirectlyledtoefficientutilization of nutrient applied to the soil". [36] Similar findings were reported by [3 and 10].

Sulphur

"Datapertaining touptake ofsulphurinsesame (kgha^{-1})arepresentedinthetable6. Significantly higher total sulphur uptake found with theapplication of 40 kgsulphur per ha (10.42 kg ha^{-1}) and which was on par with application of 30 kg sulphur perha (9.89 kg ha^{-1}). Treatment with no sulphur showed significantly less total sulphuraccumulation insesame(5.96 kgha^{-1}). Totaluptakeofsulphurinsesamewasfoundtobesignificantly higherwiththeapplicationof5kgboraxperha(9.55kgha^{-1})andwhichfoundonparwith applicationof2.5kg boraxperha(8.54kgha^{-1}).Significantlyless(6.91kg ha^{-1})reportedwithno boraxapplication. Application of 30 kg sulphur with 5 kg borax per ha recorded significantly highertotal sulphur uptake at harvest (13 kg ha^{-1}) and it found on par with application of 40 kgsulphur with 5 kg borax per ha, 40 kg sulphur with 2.5 kg borax per ha and 30 kg sulphurwith 2.5 kg borax per ha (11.49, 11.16 and 11.12 kg ha^{-1}). Significantly lowest uptake(5.84 kgha^{-1})foundwith no sulphur and boraxapplication. The increased uptake of sulphur might be due to application of sulphur, suppliedthrough elemental sulphur" [32]. "In addition, the higher photosynthetic activity in leaf exertedby sulphur nutrition, indirectly led to efficient utilization of nutrients applied to the soil"[10 and 33]. "Since sulphur is structural part of proteinsinvolved in various biological functions, it increased the root proliferation and rhizosperearea that helped for more uptake of"[34]. Increasedsulphur uptake synergistically also increases the uptake of boron. Similar findings werereportedby[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	18015	56891	38876	3.2
S_3B_2	18165	57695	39530	3.2