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Sulphur and boron nutrition on growth, yield and economics of Niger [*Guizotia abyssinica* Cass.] under rainfed conditions of Northern Transition Tract of Karnataka

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Abstract
A field experiment was conducted during *kharif* 2016 at Main Agricultural Research Station, Dharwad. The experiment was laid out in split plot design with three replications. The main plots comprised of five sulphur levels and sub plots comprised of boron applications at three different stages. Application of 20 kg sulphur ha^{-1} with sulphur oxidizing biofertilizer recorded higher seed yield (628 kg ha^{-1}), oil content (39.77%) and oil yield (249.9 kg ha^{-1}) of niger. Niger seed yield (597 kg ha^{-1}), oil content (38.78%) and oil yield (232.01 kg ha^{-1}) was also increased by foliar spray of solubor at branching and flowering over no foliar spray. Application of sulphur @ 10 kg ha^{-1} with sulphur oxidizing biofertilizer along with foliar application of boron at branching recorded significantly higher seed yield (630 kg ha^{-1}), oil content (38.51%) and oil yield (243.24 kg ha^{-1}) over without sulphur and boron applications. Higher total sulphur and boron uptake was obtained with the application of sulphur 20 kg ha^{-1} with sulphur oxidizing biofertilizer along with foliar application of boron at branching and flowering (4.62 kg ha^{-1} and 16.65 g ha^{-1} respectively) as compared to control.

Keywords: Sulphur, Sulphur oxidizing biofertilizer, foliar application, boron, oil content, nutrient uptake

Introduction

Oilseeds are the important sources of energy and required daily in human′s diet in his food. India is one of the fourth largest producer, third largest consumer and the second largest importer of vegetable oils in the world. Seven major edible oilseeds groundnut, rapeseed and mustard, soybean, sunflower, safflower, sesame, niger and two non edible oilseeds castor and linseed are cultivated in India. The present consumption of oil is 19.2 kg per capita and the demand will increase to 24 kg per capita by 2025 vowing to improvement in the economy and purchasing power of the population. Bringing additional area under intercropping and relay cropping in rainfed areas is one of the best approaches to increase the area and production of oilseeds. Niger (*Guizotia abyssinica* Cass.) is one of the important minor oilseed crops of India which can be cultivated as either sole, inter or relay crop. In Kannada, niger is called as huchellu/gurellu. Niger seed contain 35-40% oil, 20% protein and 10% crude fiber. Niger cake contains 24-34% protein, 4-14% oil and 8-24% crude fiber. Niger is mainly used for extraction of oil, soap making, lighting, lubricating and as drying oil. The oil is used in foods and the oilcake is used as feed. It is also having medicinal value and can be used as green manure also.

In the world, niger is grown over an area of 1.74 m ha with a production and productivity of 0.56 million tonnes and 382 kg ha^{-1} respectively. India is considered to be the chief niger producing country in the world with an area of about 0.52 million ha; production and productivity of 0.16 million tonnes and 340 kg ha^{-1} respectively. In Karnataka, niger is cultivated over an area of about 23385 ha with a production and productivity of 8179 tonnes and 353 kg ha^{-1} respectively (Anon., 2011).

Sulphur is the fourth most essential nutrient element after N, P and K for crop production and is actively involved in plant growth, seed yield, oil and protein synthesis as well as improved quality of produce owing to its role in enzymatic and metabolic processes (Hussain *et al.*, 2011) [3]. India has 41% of sulphur deficient soils while, 28.45% in Karnataka and 45% of soils in Dharwad district are deficient in sulphur (Anon., 2015). The work on soil fertility atlas for Karnataka as reported by ICRISAT and Department of Agriculture, Government of Karnataka, indicated that available sulphur in the soil is mainly deficient (< 10 ppm) in Dharwad, Vijayapur, Chamarajnagar, Tumkur, Chitradurga and Gadag districts. Use of sulphur oxidizing bacteria enhances the rate of natural oxidation of sulphur and speed up the production of sulfates and makes them available to plants at their critical stages, consequently resulting in increased plant yield. Chemolithotrophic bacteria of the genus *Thiobacillus* are considered as the main oxidizers of elemental sulphur and reduced sulphur compounds in soil under favorable conditions. Sulphur oxidisizers enhance the natural oxidation and speed up the production of sulphates (Vidyalakshmi *et al.*, 2009) [11].

Foliar fertilization is gaining more importance in recent years due to the availability of soluble fertilizers and is of great significance in rainfed areas under changing climatic conditions. Among the micronutrients, boron plays an important role in pollination and fertilization processes. Application of boron through foliar enhances the physiological process of plants resulting in higher crop yields. India has 33 per cent of boron deficient soils while, 39% of soils found in Bihar, 68% of soils in West Bengal, 24.5% in Uttar Pradesh, 21% in Tamil Nadu, 1.5% in Harayana and 32% in Karnataka (Anon., 2015). The work on soil fertility atlas for Karnataka as reported by ICRISAT and Department of Agriculture, Government of Karnataka, indicated that available boron in the soil is mainly deficient (< 0.58 ppm) in districts of Bidar, Hasan, Tumkur, Koppal Kolar and Chamrajnagar. However the above information is lacking hence an experiment was conducted to find out the optimum dose and method of application of sulphur and boron in kharif Niger

Material and Methods

The field experiment was conducted at the Main Agricultural Research Station, College of Agriculture, Dharwad, situated at 15°26' N latitude, 75°07' E longitude and at an altitude of 678 m above mean sea level. The location of the experimental site is situated under Northern Transitional Zone (Zone-8) of Karnataka. The soil of the experimental site was clay loam with the clay content of 60.4% . The soil pH was 7.6 with organic carbon 0.43% , medium in available nitrogen 298.6 kg ha^{-1}, medium in available phosphorus 29.3 kg ha^{-1}, medium in available potassium 270 kg ha^{-1}, lower in available sulphur 8.7 ppm and lower in available boron 0.34 ppm. Electrical conductivity of soil was 0.28 dS m^{-1}. The experiment was laid out in split plot design with three replications. The main plots comprised of five sulphur levels [S_1: Control (No sulphur), S_2: Sulphur @ 10 kg ha^{-1}, S_3: Sulphur @ 20 kg ha^{-1}, S_4: Sulphur @ 10 kg ha^{-1} + Sulphur Oxidizing Biofertilizer and S_5: Sulphur @ 20 kg ha^{-1}+ Sulphur Oxidizing Biofertilizer] and sub plots were comprised of three stages of boron applications [B_1: Control (No boron), B_2: Solubor (0.2%) spray at branching stage (45 DAS) and B_3: Solubor (0.2%) spray at branching and flowering stages (55 DAS)]

Niger variety (Dharwad Niger Selection – 4) was sown at 30 × 10 cm spacing using a seed rate of 1.5 kg ha^{-1}. FYM was applied at the rate of 5 t ha^{-1} uniformly to the experimental field. The recommended dose of nitrogen, phosphorus and potassium were applied at the rate of 20:40:20 kg N, P_2O_5 and K_2O per hectare in the form of urea, diammonium phosphate and muriate of potash. Sulphur was applied in the form of phosphogypsum (19% S) at 10 and 20 kg ha^{-1} at the time of sowing as per the treatments and foliar spray of 0.2% solubor (15% B) branching and flowering stages was done. Seed treatment was done with sulphur oxidising biofertilizer at the rate of 100 g kg^{-1} seeds using gum arabica sticker solution and dried in shade. This was done one day before sowing as per treatments. The other recommended pacakage of practice were followed to raise the crop.

The rainfall received during 2016 was well distributed in 55 rainy days. The rainfall received during experiment period (July- October) was 343.6 mm in 18 rainy days. The rainfall received in the month of July (150.20 mm), August (112.20 mm), September (36.40 mm) and October (44.8 mm) ensured adequate stored moisture for germination, emergence and early establishment of seedlings. The adequate quantity and uniform distribution of rainfall ensured proper growth and development of niger. The mean maximum temperature during cropping period was ranged from 26.27 ºC (July) to 29.76 ºC (October), while the minimum temperature was ranged from 18.81 ºC (October) to 20.96 ºC (July). This did not vary compared to average of 66 years. The mean relative humidity varied from 75.61 per cent in the month of October to 92.71 per cent in the month of August 2016. In general, niger crop requires 18 to 23 ºC temperature and water requirement is 35 to 45 cm for normal growth and development. Plant protection measures were taken as per package of practices during experimentation period.

Niger was sown on 4th july and harvested on 8th October 2016. Growth and yield parameters were recorded as per the standard procedure. The data collected on different parameters were subjected to statistical analysis as per the standard procedures.

Results and Discussion

Effect of Sulphur on seed yield, quality and nutrient uptake

Niger seed yield was improved due to sulphur application alone at different levels or in combination with sulphur oxidizing bacteria (Table 2). This increase in the yield was significant. Lowest seed yield was in the treatment without sulphur and the soil is deficient in sulphur with 8.7 ppm. Response of applied sulphur was more in deficient soils. Seed yield increased by 14.8 per cent with 10 kg sulphur ha^{-1} and by 22.7 per cent when sulphur rate was increased to 20 kg sulphur ha^{-1} in comparison to without sulphur. Combining the sulphur biofertilizer *Thiobacillus* in combination with fertilizers further improved the seed yield. Sulphur biofertilizer improved the yield in the range of 9.79 to 13.27 per cent. The increase in yield under sulphur fertilization was obvious from the fact that application of sulphur improved overall nutritional environment of the rhizosphere as well as in the plant system. The per cent increase was more at lower levels than at higher levels of sulphur. This response was further improved when biofertilizer treatment was done. Further, these results are also in confirmation with the findings of Joseph *et al.* (2014), who revealed that increase in straw and seed yield of canola when seeds were inoculated with *Thiobacillus thiooxidans*. This might be due to the plant growth promoting activity of the inoculated sulphur oxidizing bacteria.

Oil content and oil yield of niger was improved due to sulphur application alone at different levels or in combination with sulphur oxidizing bacteria (Table 3). Oil content increased by 5.9 per cent with 10 kg sulphur ha^{-1}, 9.2 per cent with 20 kg sulphur ha^{-1}, 6.8 per cent with 10 kg sulphur ha^{-1} with sulphur oxidizing bacteria (38.60%) and 10.6 per cent with 20 kg sulphur ha^{-1} with sulphur oxidizing bacteria (39.77%) in comparison to without sulphur application. This could be attributed due to the influence of sulphur in rapid conversion of nitrogen to crude protein and finally to oil. The oil yield of niger varied because of the significant differences in seed yield and oil content of niger. Oil yield increased by 21.7 per cent with 10 kg sulphur ha^{-1} and by 34 per cent with 20 kg sulphur ha^{-1} in comparison to without sulphur and combining sulphur biofertilizer with sulphur further improved the oil yield in the range of 14.8 to 11.3 per cent. Application of sulphur oxidizing bacteria with sulphur increased the oil content and oil yield sunflower was reported by Amith *et al*. (2016) [2].

Improved yield (Table 1) attributes might be due to higher nutrient uptake by the plants. The uptake of nutrients by the crop is mainly by the function of dry matter and nutrient concentration in seed and stem. The sulphur content of seed was higher than the sulphur content of stem and it increased more probably due to more accumulation of sulphur in seeds than stem (Table 4). Significantly higher sulphur uptake by seed was recorded in the treatment which received 20 kg sulphur ha^{-1} with sulphur oxidizing biofertilizer (1.18 kg ha^{-1}) compared to all other treatments (Table 5). Total uptake of sulphur by niger was higher with sulphur @ 20 kg ha^{-1} with sulphur oxidizing biofertilizer (4.27 kg ha^{-1}) and this increase was by 107.3 per cent over no sulphur application. Similar increased uptake pattern was observed in 10 kg sulphur ha^{-1} with sulphur oxidizing biofertilizer (81.6%) over control. This is due to higher niger yield produced in these treatments as a result of higher plant growth and yield parameters. Similar kinds of results were reported by Vaghani *et al*. (2010) [10] in the crop sesame.

Effect of foliar application of boron on seed yield, quality and nutrient uptake

Seed yield of niger increased with foliar spray of solubor (0.2%) at branching and flowering (597 kg ha^{-1}) and it was on par with foliar spray at branching (578 kg ha^{-1}). The per cent increase in seed yield in foliar spray at branching and flowering over no foliar spray was 17 per cent. While spraying at branching alone resulted in 13.3 per cent increase (Table 2). The increase in yield might be due to the application of nutrients directly to the foliage, which increased the nutrient availability to the crop during critical stages. Foliar applications of boron significantly increased the yields of crop like sesame, sunflower, safflower *etc.* (Akshatha 2016; Mohammad *et al.*, 2012; and Kallol *et al.*, 2015) [7, 1, 5].

Oil content of niger did not differ significantly with the application of solubor (0.2%) . This may be due to deficiency of boron in soils was not adequate to cause greater and significant increase in oil content in other treatments over control treatment. Inadequate supply of boron decreases the oil production and impairs the quality of oil. Foliar spray at branching and flowering increased the oil yield (232 kg ha^{-1}). The per cent increase in oil yield over no foliar spray was 19.9 per cent. While spraying at branching alone resulted in 15.2 per cent (Table 3). This increase may be due to increase in the seed yield. These results were in conformity with the findings of Lalitha *et al.* (2008) [6].

Uptake of boron by niger was influenced by the foliar application of boron. Foliar spray of solubor (0.2%) at branching and flowering showed an increase of 36.4 per cent over no boron application. While spraying at branching resulted in 21.3 per cent (Table 7). It might due to foliar application of boron at 55 DAS coincided with the flowering and seed setting stages, resulting in higher boron content and uptake compared to no foliar application.

Interaction effect of sulphur and boron on seed yield, quality and nutrient uptake

Application of sulphur alone or sulphur with sulphur oxidizing biofertilizer and foliar application of boron increased the yield of niger (Table 2). Significantly higher seed yield was obtained with the application of 20 kg sulphur ha^{-1} + sulphur oxidizing biofertilizer along with foliar spray at branching and flowering stages, (683 kg ha^{-1}) and found on par with 10 kg sulphur ha^{-1} + sulphur oxidizing biofertilizer along with foliar spray at branching (630 kg ha^{-1}). This shows the synergistic effect of sulphur and boron favorably influencing the yield and yield attributes of niger. Sulphur activates floral primordial initiation and increase the grain yield while, vital activities such as transport of carbohydrates and cellular differentiation and development are being enhanced by the supply of boron.

Oil content and oil yield of niger increased with combined application of sulphur and foliar boron (Table 3). Oil content responded favorably with sulphur application at 20 kg ha^{-1} alone or 20 kg ha^{-1} combined with sulphur oxidizing biofertilizer. The treatment receiving no sulphur and no boron application was not efficient in increasing the oil content. While, application of 20 kg sulphur ha^{-1} + sulphur oxidizing biofertilizer along with foliar spray of boron at branching and flowering recorded the higher oil content (40.08%) . The increase in oil content by 12.2 per cent with sulphur @ 20 kg ha^{-1} with sulphur oxidizing biofertilizer along with foliar spray of boron at branching and flowering in comparison to without sulphur and boron application which is due to vital role played by sulphur in oil synthesis (Jaggi *et al.*, 2001). Higher oil yield of niger was obtained with the application of 20 kg sulphur ha^{-1} + sulphur oxidizing biofertilizer along with foliar spray at branching and flowering (273.02 kg ha^{-1}) and increase in oil yield over no sulphur and boron application was to the tune of 71.4 per cent which is due to combined application of sulphur and boron enhanced the yield of crop thereby increase in the oil yield of niger.

In the present study uptake of nutrients by niger was significantly influenced by the sulphur and boron application methods (Table 5 and 7). Significantly higher total sulphur uptake 4.62 kg ha^{-1} was recorded in the treatment receiving 20 kg sulphur ha^{-1} + sulphur oxidizing biofertilizer along with foliar spray at branching and flowering. It might be due to higher concentration of sulphur (0.2 and 0.17%) present in seed and stem and also higher seed and stalk yield of niger. Similar results were reported by Pati *et al.* (2011) [8]. Significantly higher total boron uptake 16.65 g ha^{-1} recorded in the treatment receiving 20 kg sulphur ha^{-1} + sulphur oxidizing biofertilizer along with foliar spray at branching and flowering might be due to involvement of boron in improving seed setting, seed weight and hence seed yield in presence of sulphur might have resulted in its increased the concentration in seed and stem and total uptake by whole plant. A similar result of increased boron uptake due to sulphur was reported by Shekhawat and Shivay (2008) [9] in the crop sunflower.

Table 1: Effect of Sulphur and boron nutrition on number of capitulum per plant, seed weight per plant and 1000 seed weight of Niger

Sulphur levels	Number of capitulum per plant				Seed weight per plant (g)				1000 seed weight (g)			
	Boron application				Boron application				Boron application			
	B_1	B_2	B_3	Mean	B_1	B_2	B_3	Mean	B_1	B_2	B_3	Mean
S_1	46.10^{c}	46.17^{c}	46.30^{c}	46.19^{b}	2.95^{d}	3.11^{cd}	3.19^{b-d}	3.08^{d}	3.15^{a}	3.15^{a}	3.16^{a}	3.15^{a}
S_2	46.33^{c}	46.53^{c}	46.71^{c}	46.52^{b}	3.22^{b-d}	3.62^{a-d}	3.74^{a-d}	3.53^{c}	3.16^{a}	3.20^{a}	3.27^{a}	3.21^{a}
S_3	45.96^{c}	47.50^{bc}	49.20^{a-c}	47.55^{b}	3.42^{a-d}	3.85^{a-c}	3.92^{a-c}	3.73^{bc}	3.17^{a}	3.22^{a}	3.26^{a}	3.2^{a}
S_4	46.31^{c}	49.23^{a-c}	51.03^{ab}	48.86^{ab}	3.51^{a-d}	4.02^{ab}	4.10^{a}	3.88^{ab}	3.17^{a}	3.26^{a}	3.33^{a}	3.25^{a}
S_5	46.50^{c}	52.23^{a}	52.28^{a}	50.34^{a}	3.54^{a-d}	4.16a	4.23^{a}	3.98^{a}	3.19^{a}	3.36^{a}	3.38^{a}	3.31^{a}
Mean	46.24^{b}	48.33^{a}	49.11^{a}		3.33^{b}	3.75^{a}	3.84_{a}		3.17^{a}	3.24^{a}	3.28^{a}	
	S levels	B application	S x B		S levels	B application		S x B	S levels	B application		S x B
S. Em.±	0.79	0.53	1.19		0.06	0.11		0.25	0.06	0.10		0.22

Note: Sulphur levels
S_1: Control (No sulphur)
S_2: Sulphur @ 10 kg per hectare
S_3: Sulphur @ 20 kg per hectare
S_4: Sulphur @ 10 kg per hectare + Sulphur Oxidizing Biofertilizer
S_5: Sulphur @ 20 kg per hectare + Sulphur Oxidizing Biofertilizer

Boron application
B_1: Control (No boron)
B_2: Solubor (0.2%) spray at branching stage
B_3: Solubor (0.2%) spray at branching and flowering stages

Initial status
S: 19.48 kg ha^{-1}
B: 0.76 kg ha^{-1}

Table 2: Effect of sulphur and boron nutrition on seed yield, stalk yield and harvest index of niger

Sulphur levels	Seed yield (kg ha^{-1})				Stalk yield (kg ha^{-1})				Harvest index (%)			
	Boron application				Boron application				Boron application			
	B_1	B_2	B_3	Mean	B_1	B_2	B_3	Mean	B_1	B_2	B_3	Mean
S_1	445^{g}	469^{fg}	484^{e-g}	466^{d}	1650^{f}	1661^{ef}	1691^{d-f}	1667^{d}	21.21^{h}	21.99^{h}	22.35^{gh}	21.85^{d}
S_2	491^{e-g}	547de	568^{cd}	535^{c}	1706^{c-f}	1746^{b-f}	1770^{a-f}	1741^{c}	22.30^{gh}	23.87^{d-f}	24.28^{d-f}	23.48^{c}
S_3	529^{d-f}	587^{b-d}	601^{b-d}	572^{b}	1740^{b-f}	1783^{a-e}	1804^{a-d}	1776^{bc}	23.40^{fg}	24.74^{c-e}	24.97^{b-d}	24.37^{b}
S_4	540de	630^{a-c}	646^{ab}	606^{ab}	1744^{b-f}	1831^{a-d}	1842^{ab}	1806^{ab}	23.65^{ef}	25.59^{a-c}	25.95^{ab}	25.06^{ab}
S_5	543de	658^{ab}	683^{a}	628^{a}	1747^{b-f}	1851^{ab}	1884^{a}	1827^{a}	23.72^{ef}	26.21^{a}	26.61^{a}	25.51^{a}
Mean	510^{b}	578^{a}	597^{a}		1717^{b}	1774^{a}	1798^{a}		22.86^{b}	24.48^{a}	24.83^{a}	
	S levels	B application	S x B		S levels	B application	S x B		S levels	B application	S x B	
S. Em.±	10.87	9.74	21.78		14.7	16.7	37.2		0.25	0.17	0.37	

Table 3: Effect of Sulphur and boron nutrition on oil content and oil yield of Niger

Sulphur levels	Oil content (%)				Oil yield (kg ha^{-1})			
	Boron application				Boron application			
	B_1	B_2	B_3	Mean	B_1	B_2	B_3	Mean
S_1	35.72^{b}	35.95^{ab}	36.17^{ab}	35.95^{b}	159.25^{g}	168.84^{g}	175.03^{fg}	167.71^{d}
S_2	37.21^{ab}	38.41^{ab}	38.69^{ab}	38.10^{ab}	182.16^{e-g}	210.34^{d-f}	219.97^{cd}	204.15^{c}
S_3	38.94^{ab}	39.06^{ab}	39.73^{ab}	39.24^{ab}	206.18^{d-f}	228.95^{b-d}	238.31^{a-d}	224.48^{bc}
S_4	38.07^{ab}	38.51^{ab}	39.23^{ab}	38.60^{ab}	206.12^{d-f}	243.24^{a-d}	253.73^{a-c}	234.36^{ab}
S_5	39.27^{ab}	39.97^{a}	40.08^{a}	39.77^{a}	213.75^{de}	262.94^{ab}	273.02^{a}	249.90^{a}
Mean	37.84^{a}	38.38^{a}	38.78^{a}		193.49^{b}	222.86^{a}	232.01^{a}	
	S levels	B application	S x B		S levels	B application	S x B	
S. Em.±	1.02	0.54	1.20		7.29	5.00	11.17	

Note: Sulphur levels
S_1: Control (No sulphur)
S_2: Sulphur @ 10 kg per hectare
S_3: Sulphur @ 20 kg per hectare
S_4: Sulphur @ 10 kg per hectare + Sulphur Oxidizing Biofertilizer
S_5: Sulphur @ 20 kg per hectare + Sulphur Oxidizing Biofertilizer

Boron application
B_1: Control (No boron)
B_2: Solubor (0.2%) spray at branching stage
B_3: Solubor (0.2%) spray at branching and flowering stages

Table 4: Effect of Sulphur and boron nutrition on content of Sulphur (%) in Niger seed and stem at harvest

Sulphur levels	Seed				Stem			
	Boron application				Boron application			
	B_1	B_2	B_3	Mean	B_1	B_2	B_3	Mean
S_1	0.09^{g}	0.10^{g}	0.11^{fg}	0.10^{e}	0.09^{f}	0.10^{ef}	0.10^{ef}	0.10^{e}
S_2	0.13^{ef}	0.13^{ef}	0.13^{ef}	0.13^{d}	0.11^{e}	0.11^{e}	0.12^{d}	0.11^{d}
S_3	0.15^{de}	0.15^{de}	0.16^{cd}	0.15^{c}	0.13^{cd}	0.13^{cd}	0.14^{c}	0.13^{c}
S_4	0.16^{cd}	0.17^{b-d}	0.17^{b-d}	0.17^{b}	0.15^{b}	0.14^{c}	0.17^{a}	0.15^{b}
S_5	0.18^{a-c}	0.19^{ab}	0.20^{a}	0.19^{a}	0.17^{a}	0.16^{a}	0.17^{a}	0.17^{a}
Mean	0.14^{b}	0.15^{a}	0.15^{a}		0.13^{b}	0.13^{b}	0.14^{a}	
	S levels	B application	S x B		S levels	B application	S x B	
S. Em.±	0.003	0.003	0.007		0.001	0.001	0.003	

Note: Sulphur levels
S_1: Control (No sulphur)

Boron application
B_1: Control (No boron)

S_2: Sulphur @ 10 kg per hectare
S_3: Sulphur @ 20 kg per hectare
S_4: Sulphur @ 10 kg per hectare + Sulphur Oxidizing Biofertilizer
S_5: Sulphur @ 20 kg per hectare + Sulphur Oxidizing Biofertilizer

B_2: Solubor (0.2%) spray at branching stage
B_3: Solubor (0.2%) spray at branching and flowering stages

Table 5: Effect of sulphur and boron nutrition on uptake of sulphur by niger seed and stem at harvest

Sulphur levels	Sulphur (kg ha^{-1})											
	Seed				Stem				Total			
	Boron application				Boron application				Boron application			
	B_1	B_2	B_3	Mean	B_1	B_2	B_3	Mean	B_1	B_2	B_3	Mean
S_1	0.40^{j}	0.48^{ij}	0.52^{ij}	0.47^{e}	1.56^{j}	1.58^{ij}	1.65^{ij}	1.60^{e}	1.96^{k}	2.06^{k}	2.18^{jk}	2.06^{e}
S_2	0.61^{hi}	0.70^{gh}	0.72^{f-h}	0.68^{d}	1.82^{hi}	1.97^{gh}	2.17^{fg}	1.99^{d}	2.43^{ij}	2.67^{hi}	2.89^{gh}	2.67^{d}
S_3	0.79^{e-g}	0.88^{d-f}	0.94^{c-e}	0.87^{c}	2.23^{ef}	2.33^{d-f}	2.47^{c-e}	2.34^{c}	3.02^{g}	3.21^{fg}	3.41^{ef}	3.21^{c}
S_4	0.87^{d-g}	1.09^{bc}	1.11^{bc}	1.02^{b}	2.53^{cd}	2.58^{c}	3.05^{b}	2.72^{b}	3.40^{ef}	3.66^{de}	4.16^{bc}	3.74^{b}
S_5	0.97^{cd}	1.24^{ab}	1.34^{a}	1.18^{a}	2.93^{b}	3.05^{b}	3.29^{a}	3.09^{a}	3.89^{cd}	4.28^{b}	4.62^{a}	4.27^{a}
Mean	0.73^{b}	0.88^{a}	0.93^{a}		2.21^{b}	2.30^{b}	2.53^{a}		2.94^{c}	3.18^{b}	3.45^{a}	

	Seed S levels	Seed B application	Seed S x B	Stem S levels	Stem B application	Stem S x B	Total S levels	Total B application	Total S x B
S. Em.±	0.02	0.02	0.05	0.03	0.03	0.08	0.04	0.05	0.11

Note: Sulphur levels
S_1: Control (No sulphur)
S_2: Sulphur @ 10 kg per hectare
S_3: Sulphur @ 20 kg per hectare
S_4: Sulphur @ 10 kg per hectare + Sulphur Oxidizing Biofertilizer
S_5: Sulphur @ 20 kg per hectare + Sulphur Oxidizing Biofertilizer

Boron application
B_1: Control (No boron)
B_2: Solubor (0.2%) spray at branching stage
B_3: Solubor (0.2%) spray at branching and flowering stages

Table 6: Effect of sulphur and boron nutrition on content of boron (ppm) in niger seed and stem at harvest

Sulphur levels	Seed				Stem			
	Boron application				Boron application			
	B_1	B_2	B_3	Mean	B_1	B_2	B_3	Mean
S_1	5.50^{hi}	6.22^{e-g}	6.91^{a-d}	6.21^{b}	4.48^{e}	5.02^{c-e}	5.70^{ab}	5.07^{c}
S_2	5.71^{g-i}	6.24^{d-g}	6.83^{a-e}	6.26^{b}	4.50^{e}	5.26^{b-d}	5.73^{ab}	5.16^{bc}
S_3	5.24^{i}	6.72^{b-f}	7.15^{a-c}	6.37^{ab}	4.62^{e}	5.32^{b-d}	5.87^{ab}	5.27^{a-c}
S_4	5.71^{g-i}	6.66^{c-f}	7.38^{ab}	6.58^{ab}	4.85^{de}	5.43^{b-d}	6.08^{a}	5.45^{ab}
S_5	6.06^{f-h}	6.67^{c-f}	7.48^{a}	6.74^{a}	4.89^{de}	5.59^{a-c}	6.12^{a}	5.53^{a}
Mean	5.64^{c}	6.50^{b}	7.15^{a}		4.67^{c}	5.32^{b}	5.90^{a}	

	Seed S levels	Seed B application	Seed S x B	Stem S levels	Stem B application	Stem S x B
S. Em.±	0.14	0.09	0.20	0.09	0.09	0.19

Note: Sulphur levels
S_1: Control (No sulphur)
S_2: Sulphur @ 10 kg per hectare
S_3: Sulphur @ 20 kg per hectare
S_4: Sulphur @ 10 kg per hectare + Sulphur Oxidizing Biofertilizer
S_5: Sulphur @ 20 kg per hectare + Sulphur Oxidizing Biofertilizer

Boron application
B_1: Control (No boron)
B_2: Solubor (0.2%) spray at branching stage
B_3: Solubor (0.2%) spray at branching and flowering stages

Table 7: Effect of sulphur and boron nutrition on uptake of boron by niger seed and stem at harvest

Sulphur levels	Boron (g ha^{-1})											
	Seed				Stem				Total			
	Boron application				Boron application				Boron application			
	B_1	B_2	B_3	Mean	B_1	B_2	B_3	Mean	B_1	B_2	B_3	Mean
S_1	2.45^{h}	2.91^{f-h}	3.34^{e-g}	2.90^{c}	7.39^{g}	8.33^{e-g}	9.63^{cd}	8.45^{d}	9.83^{i}	11.24^{g-i}	12.97^{d-f}	11.35^{c}
S_2	2.81^{gh}	3.42^{d-f}	3.88^{c-e}	3.37^{b}	7.70$_{g}$	9.19^{d-f}	10.14^{b-d}	9.01^{cd}	10.51^{hi}	12.61^{d-g}	14.02^{cd}	12.38^{b}
S_3	2.77^{gh}	3.94^{cd}	4.30^{bc}	3.67^{b}	8.04^{fg}	9.49^{c-e}	10.57^{a-c}	9.36^{bc}	10.81^{hi}	13.43^{c-e}	14.86^{bc}	13.03^{b}
S_4	3.09^{fg}	4.20^{c}	4.77^{ab}	4.02^{a}	8.47^{e-g}	9.96^{b-d}	11.20^{ab}	9.88^{ab}	11.56^{f-h}	14.15^{cd}	15.97^{ab}	13.89^{a}
S_5	3.30^{fg}	4.39^{bc}	5.11^{a}	4.27^{a}	8.54^{e-g}	10.35^{a-d}	11.53^{a}	10.14^{a}	11.84^{e-h}	14.74^{bc}	16.65^{a}	14.41^{a}
Mean	2.88^{c}	3.77^{b}	4.28^{a}		8.03^{c}	9.46^{b}	10.62^{a}		10.91^{c}	13.23^{b}	14.89^{a}	

	Seed S levels	Seed B application	Seed S x B	Stem S levels	Stem B application	Stem S x B	Total S levels	Total B application	Total S x B
S. Em.±	0.10	0.08	0.18	0.17	0.18	0.41	0.24	0.23	0.51

Note: Sulphur levels
S_1: Control (No sulphur)
S_2: Sulphur @ 10 kg per hectare
S_3: Sulphur @ 20 kg per hectare
S_4: Sulphur @ 10 kg per hectare + Sulphur Oxidizing Biofertilizer
S_5: Sulphur @ 20 kg per hectare + Sulphur Oxidizing Biofertilizer

Boron application
B_1: Control (No boron)
B_2: Solubor (0.2%) spray at branching stage
B_3: Solubor (0.2%) spray at branching and flowering stages

Conclusion

Application of sulphur @ 10 kg ha^{-1} with sulphur oxidizing biofertilizer along with foliar application of boron at branching was found suitable for getting optimum niger seed yield (630 kg ha^{-1}), oil content (38.51%) and oil yield (243.24 kg ha^{-1}). Application of sulphur @ 20 kg ha^{-1} with sulphur oxidizing biofertilizer along with foliar application of boron at branching and flowering was recorded higher total sulphur uptake (4.62 kg ha^{-1}) and total boron uptake (16.65 g ha^{-1}).

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