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Effect of sulphur and bio fertilizers on growth attributes of sesame (*Sesamum indicum* L.) and soil fertility in red and lateritic soils of West Bengal, India

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ABSTRACT

A field experiment was conducted on sesame during pre-kharif season of 2016 in red and lateritic soils of West Bengal at the farm of Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan to study the effect of combined application of sulphur and biofertilizers on growth attributes of sesame (*Sesamum indicum* L) and soil fertility of red and lateritic soil. The experiment was laid out in randomized block design with three replicants and thirteen treatments. The results of the study showed that highest plant height (cm) and dry weight (gm-2) was recorded in treatment of integrated application of sulphur @ 45 kg ha-1 and co-inocultion of PSB + Azotobacter followed by sulphur @ 45 kg ha-1 + single inoculation of Azotobacter, sulphur @ 45 kg ha-1 + single inoculation of PSB at 30 DAS, 60 DAS and at harvest. There was no significant difference of soil pH and EC among the different level of sulphur application along with bio fertilizers Azotobacter and PSB in advancement of the age of the crop plants up to its harvest and after harvest. The study showed integrated use of biofertilizers and chemical fertilizers in sesame helps in growth of plant, dry matter accumulation and in addition to that it also helps in improving physical condition of soil by improving soil fertlity. The study conclude higher growth in sesame plant, improvement in soil fertility leads to overall profit to the farmers. Hence, it is recommended for integrated use of biofertilizers and chemical fertilizers in sesame cultivation in red and lateritic belt of West Bengal and other part of country where ever the soil of this kind is available.

1. Introduction

The oil seed crops play the second important role in the Indian agricultural economy next to food grains in terms of area and production. As Indian climate is suitable for the cultivation of oilseeds crop; large varieties of oilseeds are cultivated here. The government of India has been pursuing several development programs to meet the requirement of increasing demand of oilseeds in the country owing to increase in population, improvement in standard of living, increasing industrial requirements. The concerted efforts of these development programs/schemes register significant improvement in annual growth of yield and area under oilseed crops. Although country is having increasing production trend in domestic oil seeds but only 50 per cent of the total requirement is met from domestic production and nearly half of the requirement is still being made through imports (Hegde *et al.,* 2012). Among the oilseed crops, sesame (*Sesamum indicum* L.) is one of the world most important and oldest known oil seed crops (Abou Gharbia *et al.,* 1997). Sesame is a member of the padaliaceae plant family. Its cultivation has started since 1500 BC in the Middle East, Asia & Africa (Ali *et al.,* 2007). The sesame oil has also been reported to show remarkable stability to oxidation due to the present of lignins (Lee *et al.,* 2008). It is one of the important oilseed crops in West Bengal and mainly

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grown in marginal land with minimum care. In West Bengal it is locally known as, 'til' and is the second important edible oil crop (Mondal *et al.,* 1997). Sesame is mainly cultivated in summer, kharif and post-kharif season in West Bengal with an area of about 0.182 m ha (Anonymous, 2012). The area, production and productivity of sesame are higher in summer season than those of post-kharif and kharif seasons (Anonymous, 2006). But the productivity of sesame in general is much lower than its potential yield. Lower productivity may be due to the fact of sub-optimal rate of fertilizer, poor management and cultivation of sesame in marginal and sub-marginal lands where deficiency of macronutrients such as nitrogen, phosphorus, potassium and micronutrients are predominant. This indicates the scope and need to increase the productivity of sesame. There are several studies showed that integrated use of bio fertilizers and chemical fertilizers in sesame helps in maintaining stability of crop production, besides improving soil physical conditions (Deshmukh *et al.,* 2002 and Verma *et al.,* 2012). Higher yield of sesame can be obtained by integrated use of fertilizer along with FYM, vermicompost and Nitrogen fixing bacteria (Purushottam, 2005 and Jaishankar & Wahab, 2005). Nitrogen fixing bacteria increases dry matter production and growth of sesame (Senthil kumar *et al.,* 2000 and Verma *et al.,* 2012). Thus, understanding is needed about uptake of nitrogen, phosphorus and potassium and their utilization by sesame in soils of low nutrient status has important implications for its improved growth and soil fertility.

2. Materials and Methods

A field experiment was carried out to study the effect of sulphur and bio fertilizers on soil properties and growth of Sesame (Sesamum indicum L.) in red and lateritic soils of West Bengal was conducted during pre-kharif season of 2016. The Agricultural Farm is located at the heart of the lateritic belt of West Bengal which comes under sub-humid and sub-tropical climate. The initial soil analysis revealed that the soil of the experimental plot was sandy-loam in texture which contains high percentage of sand and low percentage of clay. The soil was slightly acidic (pH 5.10), low in soil organic carbon (0.40%), very low in available nitrogen (115.52 kg/ha), medium in available phosphorus (50.40 kg/ha), low in available potassium content (32.48 kg/ha) and available sulphur (12.6 kg/ha). The field experiment was carried out in Randomized Block design with three replications and total thirteen treatments. As per the treatments specification, fertilizers were applied in the form of urea, diammonium phosphate (DAP), murate of potash (MOP) for the source of nitrogen, phosphorus and potassium respectively. Magnesium sulphate (26.63% S) was used for O5: K2O for sesame was applied for each plot at the rate of 60:40:40 kg ha-1 as urea, DAP and MOP. As per treatment sulphur was applied @ 0, 30, 45 and 60 kg ha-1 from zinc sulphate (15 % S). Phosphorus, potassium and sulphur was applied as basal dose and nitrogen as split doses. The fertilizer was weighted separately as per need of the treatment for individual plots. Required quantity of fertilizer as per treatment was applied uniformly in the plots through broadcast method of application. Seed were soaked in clean water for better germination. The soaked seeds were treated with bio fertilizers like PSB and Azotobacter as per treatment and dried in the shade before sowing. The bio fertilizers were treated with seed @ 60 kg ha-1. Sesame was sown on 17th Feb, 2016 at 30 cm apart row spacing by making shallow furrows with the help of tines in 5 cm soil depth. The seed rate was 4 kg ha-1. After sowing, seeds were covered with loose soil for compaction of soil and better germination. The observation for the growth attributes and soil properties were taken at various stages of experiment. The soil attributes, available nutrient status of soil, total uptake of nutrients, growth of attributes plant were analyzed following standard procedures (Sahu *et al.,* 2017)

3. Results and Discussion

Data generated out of field experiments and laboratory analysis during the course of investigation was subjected to statistical analysis. In order to investigate the effect of sulphur and bio fertilizers on growth attributes of sesame (Sesamum indicum L.) and soil properties of red and lateritic soils of West Bengal. Availability of nutrients, organic carbon, plant height and Dry Matter Accumulation (DMA) were analyzed at 30 and 60 days after sowing (DAS). After harvesting of crop plant height and dry matter accumulation was studied and soil properties like pH, EC, organic carbon, available nutrient status (N,P,K) in the soil was studied which is discussed in the subsequent section of the paper.

Growth Attributes

Plant height

Results pertaining to the height of sesame plants (cm) recorded at different growth stages are presented in table 1. Perusal of the table revealed that all the treatments increased the plant height progressively (4.83 to 8.97 cm, 42.67 to 74.47 cm and 47.75 to 77.73 cm) at the advancement of the crop growth stages up to harvest, respectively. Irrespective of strains, co-inoculation with PSB + Azotobacter and fertilizers as basal always recorded more plant height in comparison to the uninoculated control both at 30 DAS, 60 DAS and harvest stage. The basal application of sulphur @ 45 kg ha-1 along with combined seed inoculation of Azotobacter and PSB gave highest height of crop plants (*i.e.* 8.97, 74.47 and 77.73 cm) at 30, 60 DAS and harvest as compared to uninoculated control (4.83, 42.67 and 47.75 cm), respectively. The comparision with uninoculated control showed all the treatments increased the mean plant height of crop by 1.17 to 1.87, 1.08 to 1.75 and 1.08 to 1.63 fold at 30, 60 DAS and at harvest, respectively. It is also vivid from the table that single inoculation of PSB, Azotobacter and co-inoculation of PSB + Azotobacter in all the treatments except control increased the mean plant height by (1.16 to 1.59, 1.17 to 1.6 and 0.95 to 1.31 fold), (1.28 to 1.62, 1.16 to 1.48 and 1.09 to 1.39 fold.) and (1.22to 1.51, 1.09 to 1.35 and 1.06 to 1.31 fold) at 30, 60 DAS and at harvest, respectively. The results depicts that irrespective of days of growth, there was significant difference in height of crop plants among all the treatments.

The highest plant height (cm) was recorded in treatment of integrated application of sulphur @ 45 kg ha-1 and co-inocultion of PSB + Azotobacter followed by sulphur @ 45 kg ha-1 + single inoculation of Azotobacter, sulphur @ 45 kg ha-1 + single inoculation of PSB at both 30 and 60 DAS (table 1). The treatment with sulphur @ 45 kg ha-1 and co-inocultion of PSB + Azotobacter and sulphur @ 45 kg ha-1 + single inoculation of Azotobacter increased plant height by the range of 14.3 to 74.5 per cent and 9.7 to 67.6 per cent at 60 DAS, respectively and treatment with sulphur @ 45 kg ha-1 and co-inocultion of PSB + Azotobacter and sulphur @ 45 kg ha-1 + PSB increased range of 14 to 62.8 per cent and 11.4 to 59.1 per cent at harvest, respectively as compared to uninoculated control.

The treatment of sulphur @ 45 kg ha-1 along with dual inoculation of PSB and Azotobacter increased plant height (cm) by 74.5, 62.1, 47.7, 39.1, 27.1, 18.5 and 14.3 per cent at 60 DAS and by 62.8, 50.6, 34.6, 31.5, 23.4, 180.7 and 14 per cent at harvest over uninoculated control (42.67 cm & 47.75 cm), only PSB inoculation (45.93 cm and 51.6 cm), only Azotobacter inoculation (50.43 cm & 57.77 cm), dual inoculation of PSB + Azotobacter (53.53cm and 59.13 cm), sulphur @ 15 kg ha-1 along with single inoculation of PSB (58.6 cm & 62.97cm), sulphur @ 15 kg ha-1 along with single inoculation of Azotobacter (62.87 cm and 65.47 cm) and sulphur @ 15 kg ha-1 along with duel inoculation of PSB + Azotobacter (65.16 cm and 68.2), respectively. Thus perusal of the table 1 depicts that the application of sulphur and bio fertilizers influenced the plant height of sesame. Maximum significant variation is 8.3 fold in height is observed during 60 DAS as comparison to 30 DAS. Increase in plant height with increasing in sulphur level might be resulted from synthesis of sulphur containing amino acids, proteins and activity of proteolytic enzymes which also supports the study of Pavani *et al.* (2013). Seed inoculation of bio fertilizers Azotobacter + PSB @ 60 g kg-1 seed might be stimulated to increase in plant height and recorded higher plant height at all growth stages. This showed a strong synergistic effect between Azotobacter and PSB. Inoculation of PSB which are known to produce growth hormones (Sattar and Gaur, 1987) are likely to favor increase plant height. The beneficial role of free living nitrogen fixing microorganisms (Azotobacter) for enhancing plant growth through their ability in nitrogen fixation as well as the effect of their metabolites secretion on the crop may also be attributed for the same.

Table 1. Effect of treatments on plant height of sesame

Treatments	Plant height (cm)		
	At 30 Days	At 60 Days	At Harvest
Control	4.83	42.67	47.75
S @ 0 kg ha^{-1} + PSB	5.63	45.93	51.60
S @ 0 kg ha^{-1} + *Azotobacter*	5.60	50.43	57.77
S @ 0 kg ha^{-1} + PSB + *Azotobacter*	6.87	53.53	59.13
S @ 15 kg ha^{-1} + PSB	6.53	58.60	62.97
S @ 15 kg ha^{-1} + *Azotobacter*	6.93	62.87	65.47
S @ 15 kg ha^{-1} + PSB + *Azotobacter*	7.20	65.16	68.20
S @ 30 kg ha^{-1} + PSB	6.53	68.83	73.47
S @ 30 kg ha^{-1} + *Azotobacter*	7.53	65.53	70.66
S @ 30 kg ha^{-1} + PSB + *Azotobacter*	7.90	69.20	71.83
S @ 45 kg ha^{-1} + PSB	8.00	68.16	75.97
S @ 45 kg ha^{-1} + *Azotobacter*	8.27	71.50	73.83
S @ 45 kg ha^{-1} + PSB + *Azotobacter*	8.97	74.47	77.73
Sem (±)	0.426	2.12	2.462
CD 5%	1.243	6.18	7.185
CV %	10.56	5.99	6.47
RBD(0.05)	S	S	S

These results are in agreement with Jaishankar and Wahab (2005), Imayavaramban *et al.* (2002) and Varma *et al.* (2012). It may be concluded that the height of crop plants was increased in the range of 14 to 62.8 per cent by using integrated use of sulphur fertilizer along with single or dual inoculation of PSB and Azotobacter up to harvest stage.

Dry matter accumulation (DMA) (gm^{-2})

The dry matter accumulation increased with the advancement of the age of the crop plants up to its harvest by using the different treatments of seed inoculations and basal application of fertilizers (table 2). All the treatments increased the DMA of crop plants (9 to 21 gm^{-2}, 103 to 145 gm^{-2} and 205 to 346 gm^{-2}) at different growth stages of 30, 60 DAS and harvest, respectively. Irrespective of strains, co-inoculation with each other and fertilizers as basal always recorded more DMA in comparison to the uninoculated control at all growth stages of crop. The basal application of sulphur @ 45 kg ha^{-1} along with combined seed inoculation of Azotobacter and PSB increased the DMA of crop plants (*i.e.* 21, 145 and 346 gm^{-2}) at 30, 60 DAS and harvest as compared to uninoculated control (9, 103 and 205 gm^{-2}), respectively (table 2). The result was compared with uninoculated control, all the treatments increased the mean DMA of crop plants by 1.11 to 2.33, 1.06 to 1.41 and 1.07 to 1.69 fold at 30, 60 DAS and harvest, respectively. Compared to single inoculation of PSB, *Azotobacter* and co-inoculation of PSB + *Azotobacter*, all the treatments except control increased the mean DMA of crop plants by (1.20 to 2.1, 1.04 to 1.33 and 1.07 to 1.57 fold), (1.08 to 1.75, 1.03 to 1.28 and 1.05 to 1.47 fold) and (0.92 to 1.62, 1.03 to 1.25 and 0.93 to 1.40 fold) at 30, 60 DAS and harvest, respectively. Irrespective of days of growth, there were no significant difference of DMA of crop plants among all the treatments.

The highest dry weight in gm^{-2} was recorded in treatment of integrated application of sulphur @ 45 kg ha^{-1} and co-inoculation of PSB + *Azotobacter* followed by sulphur @ 45 kg ha^{-1} + single inoculation of *Azotobacter*, sulphur @ 45kg ha^{-1} + single inoculation of PSB at both 60 DAS and harvest (table 2). The treatment with sulphur @ 45 kg ha^{-1} and co-inoculation of PSB + *Azotobacter* and sulphur @ 45 kg ha^{-1} + single inoculation of PSB increased DMA of plants by the range of 13.3 to 40.8 per cent and 7 to 33 per cent at 60 DAS and range of 39.5 to 68.8 per cent and 23.8 to 49.8 per cent at harvest as compared to uninoculated control, single inoculation of PSB & *Azotobacter* and sulphur @ 15 kg ha^{-1} with single inoculation of PSB & *Azotobacter*, respectively. The treatment sulphur @ 45 kg ha-1 along with dual inoculation of PSB and Azotobacter increased DMA in gm-2 by 40.8, 33.0, 28.3, 25.0, 21.8, 13.3 and 4.3 per cent at 60 DAS and by 68.8, 57.3, 46.6, 39.5, 50.4, 51.8 and 37.8 per cent at harvest over uninoculated control (103 &205 gm-2), only PSB inoculation (109 and 220 gm-2), only Azotobacter inoculation (113 and 236 gm-2), dual inoculation of PSB + Azotobacter (116 and 248 gm-2), sulphur @ 15 kg ha-1 along with single inoculation of PSB (119 and 230 gm-2), sulphur @ 15 kg ha-1 along with single inoculation of Azotobacter

Table 2. Effect of treatments on plant Dry Matter Accumulation (DMA)

Treatments	Dry Matter Accumulation (gm^{-2})		
	30Days	60Days	Harvest
Control	9	103	205
S @ 0 kg ha^{-1} + PSB	10	109	220
S @ 0 kg ha^{-1} + *Azotobacter*	12	113	236
S @ 0 kg ha^{-1} + PSB + *Azotobacter*	13	116	248
S @ 15 kg ha^{-1} + PSB	12	119	230
S @ 15 kg ha^{-1} + *Azotobacter*	14	128	228
S @ 15 kg ha^{-1} + PSB + *Azotobacter*	16	139	251
S @ 30 kg ha^{-1} + PSB	15	129	261
S @ 30 kg ha^{-1} + *Azotobacter*	16	136	249
S @ 30 kg ha^{-1} + PSB + *Azotobacter*	17	133	270
S @ 45 kg ha^{-1} + PSB	19	137	307
S @ 45 kg ha^{-1} + *Azotobacter*	18	142	333
S @ 45 kg ha^{-1} + PSB + *Azotobacter*	21	145	346
Sem (±)	1.01	4.51	12.62
CD 5%	2.96	13.16	36.84
CV %	11.90	6.15	8.40
RBD(0.05)	NS	NS	NS

(128 and 228 gm-2) and sulphur @ 15 kg ha-1 along with duel inoculation of PSB + Azotobacter (139 and 251 gm-2), respectively due to synthesis of sulphur containing amino acids, proteins, activity of proteolytic enzymes and a strong synergistic effect between Azotobacter and PSB inoculations. It may be concluded that the DMA of crop plants was increased in the range of 4.3 to 40.8 per cent by using integrated use of sulphur fertilizer along with single or dual inoculation of PSB and Azotobacter which corroborates the study of Senthil *et al.* (2000); Sahu *et al.* (2017).

Soil properties (pH, EC and organic carbon)

Analysis of the data on pH, EC and organic carbon of soil after harvesting of sesame is presented in table 3. Perusal of the table clearly depicts that the pH of soil increased slightly over initial value (*i.e.* 5.10) and ranged receiving 5.25 to 5.35 at harvest. The result showed that either in single inoculation or combined inoculation of bio fertilizers *Azotobacter* and PSB with different level of sulphur application gave the more or less same results of soil pH at harvest. Similarly observation on EC value indicates increased from the initial value obtained 0.11 dSm^{-1} after the harvesting of sesame. The value of soil EC ranges from 0.31 dSm^{-1} to 0.35 dSm^{-1} and showed that different treatments gave the more or less same results at harvest. There was no significant difference of soil pH and EC among the different level of sulphur application along with bio fertilizers *Azotobacter* and PSB. The analysis on organic carbon content at 30, 60 DAS and harvest stage indicates increased values from the initial value (0.45%). The ranges of organic carbon content in soil for 30, 60 DAS and harvest stage varies from 0.41 to 0.57 per cent but the difference among those treatments were found to be statistically non-significant. However, moderate changes occur in organic carbon content in soil between 30 DAS and harvest while bio fertilizers and different levels of sulphur in soil are added. This results indicates important role of sulphur to increase the organic carbon content of soil.

Available nitrogen status in soil (kg ha-1)

An analysis of nitrogen content in soil (kg ha-1) at different growth stages of the crop were carried out and are presented in table 4. Perusal of the table highlights that the nitrogen content decreased gradually with the advancement of the crop up to harvest stage. Irrespective of strains, co-inoculation with each other and fertilizers as basal recorded more available nitrogen status in soil as comparison to the uninoculated control both at 30, 60 DAS and harvest stage. There was significant difference in content of available nitrogen in soil with different treatments due to application of nitrogen fixing bio fertilizer Azotobacter. The table 4 depicts that the seed inoculation with bio fertilizers mainly with nitrogen fixing bacteria *i.e.* Azotobacter exerted significant effect on available nitrogen content in soil. This increase in nitrogen content may be attributed in increase microbial activity under different treatments which favored nitrogen mineralization. The decreased available nitrogen status in the absolute control treatment may be due to the removal of native soil nitrogen in the absence of external supply of nitrogen through fertilizers.

Table 3. Effect of treatments on soil properties

Treatments	Soil properties				
	pH	EC	Organic carbon (%)		
	(1:2)	(dS m^{-1})	30 days	60 days	Harvest
Control	5.31	0.32	0.51	0.42	0.47
S @ 0 kg ha^{-1} + PSB	5.25	0.31	0.54	0.45	0.45
S @ 0 kg ha^{-1} + *Azotobacter*	5.30	0.33	0.40	0.55	0.49
S @ 0 kg ha^{-1} + PSB + *Azotobacter*	5.26	0.32	0.61	0.48	0.43
S @ 15 kg ha^{-1} + PSB	5.30	0.33	0.52	0.47	0.43
S @ 15 kg ha^{-1} + *Azotobacter*	5.30	0.34	0.42	0.46	0.47
S @ 15 kg ha^{-1} + PSB + *Azotobacter*	5.32	0.33	0.42	0.48	0.57
S @ 30 kg ha^{-1} + PSB	5.32	0.32	0.65	0.53	0.42
S @ 30 kg ha^{-1} + *Azotobacter*	5.35	0.33	0.43	0.49	0.41
S @ 30 kg ha^{-1} + PSB + *Azotobacter*	5.35	0.34	0.55	0.48	0.51
S @ 45 kg ha^{-1} + PSB	5.25	0.33	0.54	0.49	0.50
S @ 45 kg ha^{-1} + *Azotobacter*	4.27	0.31	0.57	0.52	0.51
S @ 45 kg ha^{-1} + PSB + *Azotobacter*	5.25	0.35	0.57	0.47	0.45
Sem (±)	0.28	12.33	0.05	0.03	0.03
CD 5%	0.82	38.00	0.16	0.07	0.11
CV %	9.30	5.99	18.33	8.96	14.16
RBD(0.05)	NS	NS	NS	NS	NS

Available phosphorus status in soil (kg ha-1)

Estimation of available phosphorus content in soil (kg ha-1) at different growth stages of the crop are presented in table 4. The result highlights a declining trend in available phosphorus status with the advancement of crop growth stages and increasing phosphorus content with different treatments as comparison to control (figure 4). The highest available phosphorus content in soil were gradually decreased by 11.32 per cent at 60 DAS and by 17.79 per cent at harvest over the previous stage of the crop. Increase in available phosphorus content could be attributed to the favorable effect of sulphur fertilization on phosphorus absorption, as sulphur mobilizes soil phosphorus in available form for plant use due to action of acid produced by the added sulphur (Singh *et al.,* 2006). The seed inoculation with bio fertilizers mainly with Phosphate solubilizing bacteria (PSB) could be ascribed to their solubilizing effect on native insoluble phosphorus fractions through release of various acids, thus resulting into a significant effect in available phosphorus content in soil (Urkurkar *et al.,* 2010).

Available potassium status in soil (kg ha-1)

The available potassium content in soil decreased with the advancement of the age of the crop plants up to its harvest by using the different treatments of seed inoculations and basal application of fertilizers (table 4). Irrespective of strains, co-inoculation with PSB + Azotobacter and fertilizers as basal recorded more available potassium status in soil as comparison to the uninoculated control both at 30, 60 DAS and harvest stage. Results given in table 4 revealed that the application of higher dose of sulphur (@ 45 kg ha-1) with combined seed inoculation of PSB and Azotobacter gave the highest available potassium status *i.e.* 73.92, 67.37 and 63.46 kg ha-1 at 30, 60 DAS and harvest stage, respectively. The comparison with uninoculated control showed all the treatments increased the mean available potassium content in soil by 1.10 to 2.00, 1.09 to 2.15 and 1.16 to 3.21 fold at 30, 60 DAS and harvest, respectively. The minimum available potassium content in soil was found in control *i.e.* 36.96, 31.36 and 19.78 kg ha-1 at 30, 60 DAS and harvest stage, respectively. The result highlights a declining trend in available potassium status with the advancement of crop growth stages and increasing potassium content with different treatments as comparison to control. The highest available potassium content in soil were gradually decreased by 9.72 per cent at 60 DAS and by 6.1 per cent at harvest over the previous stage of the crop. It may be concluded that the available potassium content in soil was increased in the range of 5.9 to 81.7 per cent by using integrated use of sulphur fertilizer along with single or dual inoculation of PSB and Azotobacter.

Table 4. Effect of treatments on available nutrient status in soil

Treatments	Available Nitrogen (kg ha^{-1})			Available Phosphorus (kg ha^{-1})			Available Potassium (kg ha^{-1})		
	30 days	60 days	Harvest	30 days	60 days	harvest	30 days	60 days	harvest
Control	100.35	83.63	66.90	57.87	45.55	27.63	36.96	31.36	19.78
S @ 0 kg ha^{-1} +PSB	142.17	133.80	91.99	69.44	56.75	35.84	40.69	35.57	22.89
S @ 0 kg ha^{-1} + *Azotobacter*	183.98	150.53	100.35	61.60	55.25	30.99	42.93	34.17	25.86
S @ 0 kg ha^{-1} + PSB + *Azotobacter*	167.25	133.80	108.71	66.83	60.85	39.95	50.03	45.92	27.36
S @ 15 kg ha^{-1} + PSB	158.89	142.17	117.08	75.79	67.20	49.28	60.85	53.39	34.00
S @ 15 kg ha^{-1} + *Azotobacter*	192.34	150.53	133.80	70.56	64.96	44.80	62.35	55.12	42.56
S @ 15 kg ha^{-1} + PSB +*Azotobacter*	175.62	158.89	142.17	79.52	73.17	52.64	69.81	65.16	38.50
S @ 30 kg ha^{-1} + PSB	200.70	175.62	146.35	96.32	78.40	61.97	60.48	53.36	31.73
S @ 30 kg ha^{-1} + *Azotobacter*	209.07	192.34	158.89	80.64	77.28	58.61	63.09	56.75	37.04
S @ 30 kg ha^{-1} +PSB + *Azotobacter*	204.89	183.98	163.07	89.60	85.87	70.56	70.19	64.37	34.77
S @ 45 kg ha^{-1} +PSB	217.43	188.16	175.62	99.31	87.36	73.92	63.84	59.44	39.47
S @ 45 kg ha^{-1} + *Azotobacter*	225.79	198.54	183.98	86.61	80.27	64.21	69.07	65.71	49.54
S @ 45 kg ha^{-1} + PSB+ *Azotobacter*	250.88	234.15	200.70	101.83	91.47	77.65	73.92	67.37	63.46
Sem (±)	13.66	13.512	10.154	0.98	0.58	0.783	1.172	1.72	3.10
CD 5%	39.88	39.436	29.635	2.86	1.69	2.287	3.421	5.01	9.06
CV %	12.66	14.30	12.776	2.13	1.41	2.564	3.454	5.62	14.97
RBD(0.05)	S	S	S	S	S	S	S	S	S

Available sulphur status in soil (kg ha^{-1})

The available sulphur content increased with the different treatments by using of seed inoculations and basal application of sulphatic fertilizers (Table 5). All the treatments increased the available sulphur content (9.58 to 48.55 kg ha^{-1}, 7.06 to 42.34 kg ha^{-1}, and 5.04 to 33.77 kg ha^{-1}) at different growth stages of 30, 60 DAS and harvest, respectively. Irrespective of strains, co-inoculation with each other and fertilizers as basal always recorded more sulphur availability in comparison to the uninoculated control at all growth stages of crop. The basal application of sulphur @ 45 kg ha^{-1} along with combined seed inoculation of Azotobacter and PSB increased sulphur content in soil (48.55, 42.34 and 33.77 kg ha^{-1}) at different growth stages as compared to uninoculated control (9.58, 7.06 and 5.04 kg ha^{-1}), respectively. The comparison with uninoculated control showed all the treatments increased the mean available sulphur status by 1.47 to 5.07, 1.43 to 6 and 1.37 to 6.7 fold at 30, 60 DAS and harvest, respectively. Compared to single inoculation of PSB, *Azotobacter* and co-inoculation of PSB + *Azotobacter*, all the treatments except control increased the mean available sulphur content by (1.81 to 3.44, 1.33 to 2.54 and 1.22 to 2.31 fold), (2.05 to 4.2, 1.58 to 3.23 and 1.18 to 2.42 fold.) and (2.34 to 4.9, 1.75 to 3.65 and 1.41 to 2.96 fold) at 30, 60 DAS and harvest, respectively. Irrespective of days of growth, there were significant difference of available sulphur content among all the treatments. The highest available sulphur content in kg ha^{-1} was recorded in treatment of integrated application of sulphur @ 45 kg ha^{-1} and co-inocultion of PSB + *Azotobacter* followed by sulphur @ 45 kg ha^{-1} + single inoculation of *Azotobacter*, sulphur @ 45 kg ha^{-1} + single inoculation of PSB, sulphur @ 30 kg ha^{-1} and co-inocultion of PSB + *Azotobacter* and then sulphur @ 30 kg ha^{-1} + single inoculation of *Azotobacter*, at both 30, 60 DAS and harvest (table 9). The minimum available sulphur content in soil was found in control *i.e.* 9.58, 7.06 and 5.04 kg ha^{-1} at 30, 60 DAS and harvest stage, respectively. The study showed integrated use of organic manures, biofertilizers and chemical fertilizers in sesame helps in growth, dry matter accumulation beside it also helps in improving physical condition of soil by improving soil fertility which also corruborates the previous study of Deshmukh *et al.* (2002) and Verma *et al.* (2012). The study also corroborates the findings of Purushottam (2005); Jaishankar & Wahab (2005); Senthil *et al.* (2000) in connection to archiement of better growth in sesame plant and higher dry matter accumulation in use of biofertlizers with nitrogen fixing bacteria. The finding of integrated use of sulphur and co-inoculation of biofertilizers mainly with PSB+*Azotobacter* resulting into more plant height in cm and dry weight in gm^{-2} when the rate of the nutrient application is below the normal rate. Thus higher growth in sesame plant, improvement in soil fertility leads to overall profit to the farmers. Thus, it may be recommended for the farmers of red and lateritic belt of West Bengal and other part of country where ever the soil of this kind is available.

Table 5. Effect of treatments on available sulphur status in soil

Treatments	Available Sulphur (kg ha^{-1})		
	30Days	60Days	Harvest
Control	9.58	7.06	5.04
S @ 0 kg ha^{-1} + PSB	14.11	10.08	6.89
S @ 0 kg ha^{-1} + *Azotobacter*	19.15	13.10	9.24
S @ 0 kg ha^{-1} + PSB + *Azotobacter*	21.00	17.47	11.42
S @ 15 kg ha^{-1} + PSB	25.54	20.66	16.13
S @ 15 kg ha^{-1} + *Azotobacter*	28.56	24.02	18.65
S @ 15 kg ha^{-1} + PSB + *Azotobacter*	32.76	27.55	20.83
S @ 30 kg ha^{-1} + PSB	35.28	30.24	22.34
S @ 30 kg ha^{-1} + *Azotobacter*	37.80	33.77	24.86
S @ 30 kg ha^{-1} + PSB + *Azotobacter*	40.82	34.78	26.04
S @ 45 kg ha^{-1} + PSB	43.51	36.96	29.40
S @ 45 kg ha^{-1} + *Azotobacter*	45.36	40.49	31.25
S @ 45 kg ha^{-1} + PSB + *Azotobacter*	48.55	42.34	33.77
Sem (±)	0.360	0.40	0.724
CD 5%	1.050	1.15	2.113
CV %	2.014	2.63	6.370
RBD(0.05)	S	S	S

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