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Influence of different levels of sulphur and biofertilizers on soil properties and yield of mulched Groundnut (*Arachis hypogaea* L.) in lateritic soils of Konkan region

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Abstract
A field trial was conducted during two consecutive *Rabi* seasons of the year 2017-18 and 2018-19 to study the effect of different levels of sulphur and biofertilizers and on soil properties and yield of mulched Groundnut (*Arachis hypogaea* L.) in lateritic soils (Alfisols) of Konkan region. The experiment was conducted at Research Farm of Department of Agronomy, College of Agriculture, Dapoli Dist. Ratnagiri in Maharashtra. The experiment was undertaken with 16 treatments comprising four levels of sulphur i.e. 0, 15, 30, 45 kg ha^{-1} and biofertilizers consisting without biofertilizer, *Rhizobium,* phosphorous solubilizing bacteria and sulphur oxidizing microorganisms along with 100 per cent recommended dose of fertilizers.
It was revealed from the study that, the application of 45 kg ha^{-1} sulphur significantly improved the chemical properties of soil except soil pH, while, those were significantly improved due to 0 kg ha^{-1} sulphur. However, the application of sulphur oxidizing microorganisms @ 5 L in 200 L water ha^{-1} through drenching significantly improved the available potassium of the soil whereas, the application of rhizobium @ 20 g kg^{-1} seed through seed treatment improved pH, organic carbon and available nitrogen in soil. The electrical conductivity and available phosphorous content in soil was improved due to application of phosphorous solubilizing bacteria @ 25 g kg^{-1} seed through seed treatment. Thus the combined application of sulphur @ 45 kg ha^{-1} along with sulphur oxidizing microorganisms @ 5 L in 200 L water ha^{-1} through drenching during *Rabi* season is beneficial for getting maximum yield of groundnut for the Konkan region of Maharashtra.

Keywords: Groundnut, yield, Physico-chemical properties, nitrogen, phosphorous, potassium

Introduction
Among the oil seed crops, groundnut (*Arachis hypogaea* L.) is an important oilseed crop in India which occupies first position in terms of area and second position in terms of production. It is also called as the 'King of oilseeds' and 'poor man's almond'. It is originated from Brazil in South America. In the world, groundnut is cultivated in more than 100 countries on 26.54 m hectare area with an annual production of 43.91 m tonnes and productivity of 1655 kg ha^{-1}. China is the largest producer as well as consumer of groundnut in the world followed by India, United States, Nigeria and Sudan (Anonymous, 2020). In India, groundnut is grown on 4.77 M hectare area with the production of 7.40 M tonnes. Groundnut is the third major source of edible oil in India with a production of 8.94 M tones in 2017-18. In Maharashtra state it is cultivated on an area of 0.33 M ha having 0.42 M tones of production with a productivity of 1275 kg ha^{-1} (Anonymous 2019) [1]. In Konkan region, groundnut is grown on an about 20,000 ha area with 1.8 t ha^{-1} productivity (Waghmode *et al*. 2017) [10].
Out of seventeen essential elements for the growth and development of plants, sulphur has important role in the nutrition of oilseed crops. It is one of the most important nutrients for all plants and animals and is considered as the fourth major nutrient after nitrogen, phosphorous and potassium for agricultural crops. Insufficient availability of sulphur to oil seed crops not only declines their growth and yield but can also deteriorate nutritional quality of the produce (Hawkesford, 2000) [3].
Biofertilizers are the products containing one or more species of microorganisms which have the ability to fixes, solubilise, mobilize the nutritionally important elements from non-usable to usable form as well as excretion of plant growth promoting substances through biological processes (Kumar *et al*. 2017) [6].

It plays an important role in the increasing availability of nitrogen, phosphorous and sulphur. *Rhizobium* increases the biological fixation of atmospheric nitrogen and enhances nitrogen availability to crop. The inoculation of phosphorous solubilizing bacteria secrets phosphate solubilizer which helps in conversion of unavailable to available form of phosphorus which intern increase in yield of crops by 10-30 per cent (Tilak and Annapurna 1993) [9]. *Thiobacillus thiooxidants* is sulphur oxidizing bacteria, which oxidized decreased sulfur compounds including sulfides, elemental sulfur and thiosulfate to sulfate (Ren *et al*., 2009) [8].

Therefore, keeping the above facts in view, the present investigation entitled influence of different levels of sulphur and biofertilizers on soil properties and yield of mulched groundnut (*Arachis hypogaea* L.) in lateritic soils of Konkan region was undertaken during the year 2017-18 and 2018-19.

Material and Methods

Groundnut, variety *Konkan Trombay Tapora* was taken as a test crop during the *Rabi* season of the year 2017-2018 and 2018-2019 with a spacing of 20 x 10 cm and the gross plot size was 3.0 m x 4.2 m. The field experiment was laid out in factorial randomized block design and was replicated thrice. The experiment was undertaken with 16 treatments comprising four levels of sulphur i.e. 0, 15, 30, 45 kg ha^{-1} and biofertilizers consisting without biofertilizer, *Rhizobium*, phosphorous solubilizing bacteria and sulphur oxidizing microorganisms along with 100 per cent recommended dose of fertilizer application.

After harvesting, the mature pods obtained from each net plot was dried in the sun till constant weight was obtained and then it was recorded as dry pod yield per hectare. The pH of the soil was determined with pH meter having glass and calomel electrode using 1:2.5 of soil: water suspension ratio (Jackson, 1973) [5]. Electrical conductivity of the soil was determined by using Systronic Conductivity Meter-306 with 1:2.5 of soil: water suspension ratio (Jackson, 1973) [5]. Organic carbon content in the soil was determined by following Walkley and Black wet digestion method (Black, 1965) [11]. Available nitrogen of the soil was determined by alkaline permanganate (0.32% $KMnO_4$) method (Subbiah and Asija, 1956) [22]. Available phosphorous of the soil was determined by Brays No. 1 method as outlined by Bray and Kurtz (1945) [12]. Available potassium of the soil was determined by using neutral normal ammonium acetate as an extractant on Systronics Flame Photometer-128 as described by Jackson (1973) [5]. The experimental data was analyzed statistically by using Factorial Randomized block design (Panse and Sukhatme, 1967) [7].

Result and Discussion

Table 1: Initial chemical properties of soil

Sr. No.	Chemical properties	2017-18	2018-19
1	pH (1: 2.5)	5.17	5.12
2	Electrical conductivity (dS m^{-1})	0.16	0.23
3	Organic Carbon (g kg^{-1})	9.26	9.57
4	Available N (kg ha^{-1})	285.38	297.92
5	Available P_2O_5 (kg ha^{-1})	11.67	11.86
6	Available K_2O (kg ha^{-1})	280.50	291.98

The soil of the experimental plot at the initial stage i.e. before the commencement of the experiment, was acidic in reaction and showed low electrical conductivity. Further, the soil was found to be high in organic carbon and K_2O while medium in available nitrogen and sulphur and low in available P_2O_5.

Effect of different levels of sulphur and biofertilizers on physico-chemical properties of soil

The data regarding the physico-chemical properties of soil as influenced by biofertilizers and different levels of sulphur have been presented in the Table 2.

Table 2: Effect of biofertilizers and different levels of sulphur on physic-chemical properties of soil under mulched groundnut

Treatments	pH					Electrical Conductivity (dSm^{-1})					organic carbon (g kg^{-1})				
2017-18															
	B_0	B_1	B_2	B_3	Mean	B_0	B_1	B_2	B_3	Mean	B_0	B_1	B_2	B_3	Mean
S_0	5.81	5.88	5.84	5.67	5.80	0.16	0.16	0.18	0.18	0.17	14.56	14.17	14.43	15.47	14.66
S_1	5.80	5.83	5.74	5.66	5.76	0.20	0.22	0.21	0.22	0.21	14.82	16.38	15.60	14.43	15.31
S_2	5.75	5.78	5.72	5.61	5.72	0.24	0.20	0.21	0.23	0.22	15.86	13.78	14.82	14.82	14.82
S_3	5.64	5.71	5.70	5.58	5.66	0.19	0.20	0.19	0.25	0.21	15.47	15.21	15.21	16.77	15.67
Mean	5.75	5.80	5.75	5.63	5.73	0.20	0.20	0.19	0.22	0.20	15.18	14.89	15.02	15.37	15.11
	B	S	B x S			B	S	B x S			B	S	B x S		
S.E.±	0.05	0.05	0.11			0.012	0.012	0.025			0.73	0.73	1.45		
C.D.@ 5%	NS	NS	NS			NS	NS	NS			NS	NS	NS		
2018-19															
Treatments	B_0	B_1	B_2	B_3	Mean	B_0	B_1	B_2	B_3	Mean	B_0	B_1	B_2	B_3	Mean
S_0	5.72	5.76	5.70	5.56	5.69	0.18	0.22	0.23	0.21	0.21	14.69	15.34	15.60	15.73	15.34
S_1	5.68	5.74	5.64	5.55	5.65	0.18	0.24	0.22	0.22	0.21	14.95	16.77	15.99	15.99	15.93
S_2	5.63	5.66	5.61	5.50	5.60	0.19	0.23	0.26	0.20	0.22	15.99	16.51	16.25	16.64	16.35
S_3	5.59	5.60	5.53	5.47	5.55	0.20	0.24	0.25	0.28	0.24	16.64	17.55	17.03	17.94	17.29
Mean	5.66	5.69	5.62	5.52	5.62	0.19	0.23	0.24	0.23	0.22	15.57	16.54	16.22	16.58	16.23
	B	S	B x S			B	S	B x S			B	S	B x S		
S.E.±	0.06	0.06	0.12			0.014	0.014	0.028			0.38	0.38	0.75		
C.D.@ 5%	NS	NS	NS			0.039	NS	NS			NS	1.09	NS		

1. Effect on soil pH

A perusal of data presented in Table 3 regarding soil pH revealed that the variation in soil pH was observed due to biofertilizers and different levels of sulphur application. The data indicated that the soils are acidic in nature. The acidic nature of soils might be attributed to leaching of soluble salts due to heavy precipitation. The pH of lateritic soils of Konkan region ranged from 4.75 to 6.50 (Anonymous, 1990) [23].

The application of biofertilizers showed non-significant effect on soil pH and the application of B_1 treatment comprizing *Rhizobium* @ 20 g kg^{-1} seed through seed treatment showed numerically highest soil pH (5.80 and 5.69 during 2017-18 and 2018-19, respectively) as compared B_0, B_2 and B_3 treatment. It was observed from the above data that the application of sulphur oxidizing microorganisms decreases the pH of soil because of the excretion of different organic acids during oxidation of sulphur in soil and formation of sulphuric acid during sulphur oxidation thus, decreased the soil pH.

Due to the addition of sulphur, and the differences within treatments were statistically non-significant in both the years. However, the highest soil pH 5.80 and 5.69 was observed due to S_0 level of sulphur application @ 0 kg ha^{-1} and the lowest soil pH 5.66 and 5.55 was observed with the application of S_3 level of sulphur @ 45 kg ha^{-1} in the year 2017-18 and 2018-19, respectively. The above results indicated that the pH values slightly decreased with increasing levels of sulphur during all the growth stages of groundnut during both the years. Which might be due to the decrease in soil pH with sulphur application also may be due to the formation of sulphuric acid during sulphur oxidation which increase the hydrogen ion concentration in the soil solution and thus, decreased the soil pH. The above results are in agreement with the findings of Solanki *et al*. (2018) [20] under mustard crop and Dileepkumar and Singh (2019) [14] under groundnut.

2. Effect on electrical conductivity of soil

The electrical conductivity of soil showed non-significant effect due to application of biofertilizers and it was ranged from 0.19 to 0.22 dSm^{-1} in the year 2017-18. However, in the year 2018-19, the electrical conductivity of soil showed the significant effect due to application of biofertilizers and it varied from 0.19 to 0.24 dSm^{-1}. Application of B_2 treatment containing phosphorous solubilizing bacteria @ 25 g ka^{-1} seed through seed treatment was found to be significant regarding electrical conductivity (0.24 dSm^{-1}) of soil over B_0 treatment whereas it was at par with B_1 and B_3 treatment during the year 2018-19. In general, lateritic soils are free from soluble salts due to high rainfall. The slight increase in electrical conductivity may be due to production of CO_2 during decomposition of organic matter, which lowers the soil pH and causes dissolution of minerals releasing ions such as Ca^{++}, Mg^{++} and Na^{+} in soil solution. Application of sulphur oxidizing microorganisms increased the electrical conductivity of the soil due to the liberation of organic acids by sulphur solubilizing bacteria and fungi and the production of sulphuric acid by oxidation of sulphur through microbes such as *Thiobacillus spp*. This might have ultimately increased the solubility of salts Gomah *et al*. (2014).

The application of sulphur levels did not showed any significant effect on electrical conductivity of soil and the application of sulphur level (S_2) @ 30 kg ha^{-1} contributed maximum electrical conductivity (0.22 dSm^{-1}) of soil during the year 2017-18. While, the application of sulphur level (S_3) @ 45 kg ha^{-1} showed highest electrical conductivity (0.24 dSm^{-1}) of soil in the year 2018-19. Gomah *et al*. (2014) [15] observed that the increase in electrical conductivity of soil increased the sulphur levels due to the production of sulphuric acid by the oxidation of elemental sulphur.

3. Effect on organic carbon content in soil

In general, organic carbon content of lateritic soil of Konkan region is in the range of "very high" as per the classification of organic carbon proposed by Bangar and Zende (1978) [13].

The maximum organic carbon (15.37 and 16.58 g kg^{-1} in the year 2017-18 and 2018-19, respectively) content in soil was recorded in the treatment B_3 receiving application of sulphur oxidizing microorganisms @ 5 L in 200 L water ha^{-1} through drenching during both the years of experimentation. Sulphur oxidizing bacteria indicated the increasing trend of organic carbon content in soil which might be due to the role of sulphur oxidizing bacteria on root growth and development as well as the highest biomass production of groundnut. Extra radical hyphae, fungal spore and bacterial population in the treated plants attributed to the increased organic carbon content in soil was also reported by Sandhya *et al.* (2014) [19].

The application of graded doses of sulphur did not showed significant effect on organic carbon content in soil during the year 2017-18. By the application of sulphur @ 45 kg ha^{-1}, it noticed significantly superior organic carbon (17.29 g kg^{-1}) content in soil over S_0 and S_1 levels whereas it was at par with S_2 level of sulphur application in the year 2018-19. The linear increase in organic carbon content in soil may be due to the higher sulphur levels, as well as due to the higher biomass production resulting in addition of large quantities of root and stubbles which perhaps built up organic carbon in the soil. The above results are in agreement with the findings of Gajghane *et al*. (2015).

Effect of different levels of sulphur and biofertilizers on available macronutrient in soil

The data regarding available macronutrient content in soil under groundnut as affected by biofertilizers and different levels of sulphur are illustrated in Table 3.

Table 3: Effect of biofertilizers and different levels of sulphur on available macronutrients in soil under mulched groundnut

Treatments	Available Nitrogen (kg ha^{-1})					Available Phosphorous (kg ha^{-1})					Available Potassium (kg ha^{-1})				
2017-18															
	B_0	**B_1**	**B_2**	**B_3**	**Mean**	**B_0**	**B_1**	**B_2**	**B_3**	**Mean**	**B_0**	**B_1**	**B_2**	**B_3**	**Mean**
S_0	274.92	297.92	304.19	296.87	293.48	10.45	11.89	13.00	13.48	12.21	245.65	295.68	247.52	204.96	248.45
S_1	279.10	294.78	288.51	306.28	292.17	11.33	11.65	13.80	13.16	12.49	185.55	238.93	330.77	284.85	260.03
S_2	266.56	304.19	285.38	279.10	283.81	12.05	13.32	15.40	14.12	13.72	242.67	279.25	269.92	363.63	288.87
S_3	272.83	307.33	301.06	295.83	294.26	12.92	14.12	16.36	14.60	14.50	279.63	302.40	266.19	317.71	291.48
Mean	273.35	301.06	294.78	294.52	290.93	11.69	12.75	14.64	13.84	13.23	238.37	279.07	278.60	292.79	272.21
	B		S	B x S		B		S	B x S		B		S	B x S	
S.E.±	5.28		5.28	10.55		0.66		0.66	1.31		5.92		5.92	11.84	
C.D.@ 5%	15.24		NS	NS		1.90		NS	NS		17.10		17.10	34.21	
2018-19															
Treatments	**B_0**	**B_1**	**B_2**	**B_3**	**Mean**	**B_0**	**B_1**	**B_2**	**B_3**	**Mean**	**B_0**	**B_1**	**B_2**	**B_3**	**Mean**

S_0	257.15	293.74	265.51	269.70	271.53	10.85	14.68	15.88	15.24	14.16	267.68	283.36	273.65	291.57	279.07
S_1	263.42	285.38	279.10	296.87	281.19	13.48	15.40	17.07	16.59	15.64	285.23	299.04	278.13	304.64	291.76
S_2	275.97	288.51	287.47	294.78	286.68	11.41	16.44	18.35	16.20	15.60	275.89	308.75	302.40	310.99	299.51
S_3	269.70	300.01	291.65	286.42	286.94	12.05	13.80	18.75	14.76	14.84	290.08	306.88	293.44	328.16	304.64
Mean	266.56	291.91	280.93	286.94	281.59	11.95	15.08	17.51	15.70	15.06	279.72	299.51	286.91	308.84	293.74
	B	S	B x S			B	S	B x S			B	S	B x S		
S.E.±	3.42	3.42	6.83			0.88	0.88	1.76			4.58	4.58	9.16		
C.D.@ 5%	9.86	9.86	NS			2.54	NS	NS			13.22	13.22	NS		

1. Effect on available nitrogen content in soil

The data regarding available nitrogen content in soil was found to be significant during both the years of experimentation. In the year 2017-18, the highest available nitrogen (301.06 kg ha^{-1}) content in soil was observed by the application of B_1 treatment comprizing *Rhizobium* @ 20 g kg^{-1} seed as seed treatment which was significant over B_0 treatment i.e. without biofertilizers application. Mohapatra and Dixit (2010) [16] reported the increase in available nitrogen in soil due to growing legume groundnut, higher amount of nitrogen fixation by *Rhizobium* under more favorable condition of soil and secretion of nitrogen from the nodules. While, during the year 2018-19, the treatment B_1 recorded statistically significant value of available nitrogen (291.91 kg ha^{-1}) content over rest of the treatments except the treatment B_3 i.e. sulphur oxidizing microorganisms @ 5 L in 200 L water ha^{-1} through drenching which was at par with B_1 treatment. It was observed from the data that the availability of nitrogen in soil was increased due to the beneficial effect of sulphur oxidizing microorganisms on rootzone which were imperative for productive nodulation as well as due to enhancement of the process of mineralization and nitrification with the addition of FYM and sulphur solubilizing bacteria.

From the data it could be observed that the available nitrogen content in soil varied from 283.81 to 294.26 kg ha^{-1} and it was found statistically non-significant during the year 2017-18. In the year 2018-19, nitrogen content in soil was ranged from 271.53 to 286.94 kg ha^{-1} and the S_3 level comprizing 45 kg ha^{-1} sulphur recorded highest available nitrogen (286.94 kg ha^{-1}) content in soil, which was significant over S_0 level of sulphur application and it was at par with S_3 and S_2 level of sulphur application. Increased sulphur content in plant increases the root nodulation which increases the symbiotic nitrogen fixation as the key enzyme of soil nitrogen fixation is nitrogenase and nitrogenase enzyme is exceptionally rich in sulphur.

2. Effect on available phosphorous content in soil

The application of B_2 treatment consisting phosphorous solubilizing bacteria @ 25 g kg^{-1} seed recorded statistically significant available phosphorus (14.64 and 17.51 kg ha^{-1}) content in soil over B_0 treatment during both the years of experimentation. While, the treatments B_1 and B_3 were found to be statistically at par with B_2 during both the years of experimentation. In addition to phosphate solubilization, these microbes can mineralize organic phosphorus into a soluble form and make them available to the crops.

The effect of various levels of sulphur on available phosphorus content in soil was found to be statistically non-significant and it ranged from 12.21 to 14.50 and 14.16 to 15.64 kg ha^{-1} during the year 2017-18 and 2018-19, respectively.

3. Effect on available potassium content in soil

From the data regarding the application of biofertilizers significantly influences the available potassium content in soil at harvest stage of groundnut. During the year 2017-18, the application of sulphur oxidizing microorganisms @ 5 L in 200 L water ha^{-1} through drenching (B_3) recorded the maximum available potassium (292.79 kg ha^{-1}) content in soil whereas, it was found to be at par with the treatment B_1 by the application of *Rhizobium* @ 20 g kg^{-1} seed through seed treatment and B_2 treatment consisting phosphorous solubilizing bacteria @ 25 g kg^{-1} seed. However, the significantly highest available potassium (308.84 kg ha^{-1}) content in soil was found with the treatment B_3 and it was at par with the treatment B_1 in the year 2018-19. Starkey (1950) [21] reported that the sulphur undergoes relatively rapid oxidation by various microorganisms of particular importance i.e. those *Bacillus thiooxidants* further, synergistic effect of applied sulphur was recorded on soil exchangeable potassium. In the year 2017-18, the application of different sulphur levels showed significant effect on available potassium content in soil at harvest stage and it varied from 248.45 to 291.48 kg ha^{-1}. The application of sulphur @ 45 kg ha^{-1} (S_3) noted the significantly highest available potassium (291.48 kg ha^{-1}) content in soil and it was statistically at par with the S_2 level of sulphur @ 30 kg ha^{-1}. The variation in available potassium content in soil during the year 2018-19 was observed from 279.07 to 304.64 kg ha^{-1} due to application of graded levels of sulphur. The application of highest level of sulphur i.e. S_3 @ 45 kg ha^{-1} recorded significantly superior available potassium (304.64 kg ha^{-1}) content in soil over only S_0 level of sulphur application and it was at par with S_1 and S_2 levels of sulphur application during the year 2018-19. The increase in available potassium content in soil was observed by increasing levels of sulphur application which may be due to the fact that the sulphur increases the root growth and organic matter content in soil which increases the cation exchange capacity of soil. Therefore, the increased cation exchange capacity of soil reduces the leaching losses of potassium and thereby increases the availability of potassium in soil.

Available potassium content in soil was significantly influenced during the year 2017-18 and did not influenced significantly during the year 2018-19 by the application of biofertilizers and different doses of sulphur. The significantly superior available potassium (363.63 kg ha^{-1}) content in soil was recorded with the application of S_2B_3 treatment combination comprizing sulphur @ 30 kg ha^{-1} with sulphur oxidizing microorganisms @ 5 L in 200 L water ha^{-1} through drenching and the application of sulphur @ 15 kg ha^{-1} with phosphorous solubilizing bacteria @ 25 g kg^{-1} seed through seed treatment (S_1B_2) was at par with each other during the years 2017-18.

Effect of biofertilizers and different levels of sulphur application on pod yield (q ha^{-1}) of groundnut under mulch

The perusal of data presented in Table 4 furnished that the pod yield of groundnut was significantly influenced due to biofertilizers and different levels of sulphur application.

Table 4: Effect of biofertilizers and different levels of sulphur on the pod yield (q ha^{-1}) of mulched Groundnut

Treatments	2017-18					2018-19				
	B_0	B_1	B_2	B_3	Mean	B_0	B_1	B_2	B_3	Mean
S_0	34.02	41.19	39.95	40.74	38.97	34.63	43.48	43.40	40.93	40.61
S_1	34.58	42.07	40.62	43.95	40.30	36.82	42.70	43.77	45.18	42.12
S_2	39.31	46.76	44.72	48.19	44.75	41.03	49.54	45.95	52.75	47.32
S_3	42.36	49.71	46.34	50.66	47.27	45.28	51.12	48.81	54.30	49.88
Mean	37.57	44.93	42.91	45.89	42.82	39.44	46.71	45.48	48.29	44.98
	S	B	S x B			S	B	S x B		
S.E.±	0.85	0.85	1.71			1.20	1.20	2.39		
C.D.@ 5%	2.47	2.47	4.94			3.46	3.46	6.92		

Significantly superior pod yield (45.89 q ha^{-1}) of groundnut was noticed due to the application of B_3 treatment receiving sulphur oxidizing microorganisms @ 5 L in 200 L water ha^{-1} through drenching over rest of the treatments except B_1 treatment consisting *Rhizobium* @ 20 g kg^{-1} seed through seed treatment which was at par with B_3 treatment during the year 2017-18. During the year 2018-19, the application of B_3 treatment recorded significantly highest pod yield (48.29 q ha^{-1}) of groundnut over B_0 treatment whereas, B_3 treatment was at par with B_1 and B_2 treatments. The significantly higher pod yield of groundnut was registered under sulphur oxidizing microorganisms followed by *Rhizobium* and phosphorous solubilizing bacteria. Sakari *et al*. (2012) [18] showed that the application of *Thiobacillus bacterium* increased the seed yield of canola.

The highest pod yield (47.27 q ha^{-1}) of groundnut was recorded due to the application of S_3 level of sulphur application @ 45 kg ha^{-1} and it was significantly superior over rest of the treatments in the year 2017-18. However, in the year of 2018-19 the application of S_3 level of sulphur noticed significantly highest pod yield (49.88 q ha^{-1}) of groundnut and it was on par with S_2 level of sulphur application @ 30 kg ha^{-1}. The response to sulphur application was significant in respect of pod yield of groundnut which was mainly ascribed due to the role of sulphur in various metabolic and enzymatic processes including photosynthesis, respiration and legume-*Rhizobium* symbiotic nitrogen fixation and protein formation. Pancholi (2014) [17] also reported that the every increase in level of sulphur up to 60 kg ha^{-1}, significantly improved the pod yield of groundnut over preceding levels.

It was evident that significantly highest pod yield (50.66 q ha^{-1}) of groundnut was noticed due to application of treatment combination of S_3B_3 comprizing sulphur @ 45 kg ha^{-1} along with sulphur oxidizing microorganisms @ 5 L in 200 L water ha^{-1} through drenching which was at par with S_3B_1, S_2B_3, S_2B_1, and S_3B_2 treatment combinations in the year 2017-18. Similarly, application of S_3B_3 treatment combination recorded the significantly highest pod yield (54.30 q ha^{-1}) of groundnut during the year 2018-19 and it was at par with the S_2B_3, S_3B_1, S_2B_1, and S_3B_2 treatment combinations indicating equal effect of biofertilizers and different levels of sulphur application. This may be due to the addition of elemental sulphur with sulphur oxidizing bacteria have maintained the favorable supply of nutrient particularly to its available form for optimum growth and yield attributing characters including assimilation of nitrogen by plants. Similar findings in the sulphur nutrition have also been reported by Ismail *et al.* (2013) [4].

Conclusion

On the basis of the result highlighted, the applications of 45 kg ha^{-1} sulphur significantly improved the physic-chemical properties of soil except pH and available nitrogen, phosphorous and potassium while, those are significantly higher due to 0 kg ha^{-1} sulphur application. Application of sulphur oxidizing microorganisms @ 5 L in 200 L water ha^{-1} through drenching significantly improved the available potassium, bacterial population and nitrate reductase activity of soil whereas, application of rhizobium @ 20 g kg^{-1} seed through seed treatment improved the pH, organic carbon and available nitrogen content in soil. The electrical conductivity and available phosphorous content in soil were improved due to application of phosphorous solubilizing bacteria @ 25 g kg^{-1} seed through seed treatment. The yield of groundnut were significantly improved with the application of sulphur @ 45 kg ha^{-1} along with sulphur oxidizing microorganisms @ 5 L in 200 L water ha^{-1} through drenching during both the years of experimentation.

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