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Research Article

AGRONOMIC PERFORMANCE OF SUNFLOWER AS INFLUENCED BY SULPHUR NUTRITION AND SULPHUR OXIDISING MICROORGANISMS

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Abstract- Field experiment was conducted during *kharif* 2014 at STCR Farm, M.P.K.V., Rahuri (Maharashtra). Twenty treatment combinations consists of four levels of sulphur (0, 15, 30 and 45 kg S ha^{-1} respectively) and five sulphur oxidizing microorganisms (*Thiobacillus thiooxidans, Thiobacillus ferroxidans, Aspergillus awamori, Aspergillus niger and* consortium respectively) were laid out in Factorial randomized block design with three replications. The sulphur application @ 45 kg ha^{-1} to *kharif* sunflower significantly increased seed and oil yield (19.89 q ha^{-1} and 812.48 kg ha^{-1}).The yield contributing characters of sunflower *viz*., number of leaves, leaf area, plant height, head diameter, number of filled, unfilled and total grain per capitulum were significantly influenced by the 45 kg ha^{-1} sulphur application. *Thiobacillus ferroxidans* sulphur oxidising microorganism was found beneficial for all the yield attributing characters except number of unfilled grains per capitulum. The interaction effects were significant.
Keywords- Sulphur oxidising microorganisms, inceptisol*, Thiobacillusferroxidans, Thiobacillusthiooxidans*, *Aspergillus awamori*, *Aspergillus niger*

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Introduction

Sunflower (*Helianthus annus* L.) holds great promise as an oilseed crop because of its short duration, photo-insensitivity, and wide adaptability to different agro-climatic regions and soil type. It can be grown at any time of the year and can serve as an ideal catch crop during the period when the land is otherwise fallow. Spring sunflower best suits such conditions, with chance of area expansion and horizontal intensification for improving oilseed production in India. Sunflower can play an important role in meeting out the shortage of edible oils in the country. It covers area in India is 0.69 million hectares with a total production of 0.55 million tones and average productivity is 791 kg ha^{-1}. While in Maharashtra 0.06 million hectares area under sunflower with a total production of 0.04 million tones with average productivity of 623 kg ha^{-1}[1].The existing yield is very low, mainly because of the suboptimal soil fertility. Sulphur is consider as the fourth essential nutrient equally important to that of N, P, and K. however , sulphur deficiency in soils have been reported during last three decades due to the continuous use of sulphur free fertilizers and intensive cultivation with high yielding varieties [2]. So, the crop plants have become increasingly dependent on the soil to supply the sulphur that they need for the synthesis of proteins and a number of essential vitamins and co- factors [3]. Which are responsible for the growth and yield attributing characters of sunflower.

Plants absorbs the sulphur in the form of sulphate, which undergoes a series of transformation prior to its incorporation into the original compounds. The soil microbial biomass is the key driving force behind all sulphur transformations in the soil. The biomass acts as both a source and sink for inorganic sulphate. it make available sulphate from elemental sulphur or any reduced forms of sulphur, through oxidation process in the soil. Looking to the importance of sulphur nutrition of sunflower and use of different sulphur oxidizing microorganism. In views of these, a field experiment was conducted to study the effect of sulphur nutrition and sulphur oxidising microorganisms on growth and yield attributing characters of sunflower.

Materials and Methods

Field experiments on sunflower was conducted during *kharif* 2014 at Soil Test Crop Response Research Scheme, Research Farm, Department of Soil Science and Agriculture Chemistry, Mahatma Phule Krushi Vidyapeeth, Rahuri. The soils of experimental area are grouped under inceptisol soil order and belongs to *pather* soil series which comprises member of fine montmorillionite hypertheromic family of *Vertichaplustepts*. The soils of the dominant type of clay mineral having high swell-shrink property pH (1:2.5) 8.32, EC 0.32 dSm^{-1}, Organic carbon 0.54 %, 147.44 kg ha^{-1}(0.32%)$KMnO_4$-N, 15.14 kg ha^{-1}(0.5 M) $NaHCO_3$-P, 470.23 kg ha^{-1} N *N*NH4O Ac -K and 9.60 mg kg^{-1} Sulphate sulphur. The experiment was laid out in a factorial randomized block design replicated thrice with twenty treatments *viz*., four sulphur levels *i.e.* 0, 15, 30 and 45 kg S ha^{-1} and five sulphuroxidising microorganisms *i.e Thiobacillus thiooxidans*, *Thiobacillus ferroxidans, Aspergillus niger, Aspergillus awamori* and Consortium. The sunflower crop was sown with a spacing of 60 cm × 30 cm. Recommended dose of sunflower (60:30:30kg ha^{-1} N: P_2O_5: K_2O) was applied through urea, daiamonium phosphate and muriate of potash. Sulphur through elemental sulphur was applied as per treatments 15 days before sowing by mixing with 5 t ha^{-1} FYM. The treatment of sulphur oxidizing microorganism was carried out by taking 200 seeds of sunflower in to petriplate and a pinch of charcoal and glucose was added, then 8 mL of culture broth 10^9 × cfu was added and the seeds were shaken to mix the culture well. Other agronomic management practices were followed as per the standard recommendations. Growth attributing characters *viz.* number of leaves, leaf area, plant height were recorded at 30 days after sowing and at button stage. For yield attributing characters the mature heads were plucked at mature stage and measured the with meter scale. The seeds of each head separated with stick beating a week after sun drying and measured it. Total chlorophyll was determined by colorimetric method [4] while oil content in seed was extracted by petroleum ether extraction method [5].

Result and Discussion

Seed yield of sunflower

The seed yield of sunflower was found significantly higher in sulphur application @ 45 kg ha^{-1} (19.89 q ha^{-1}) followed by 30 and 15 kg ha^{-1} sulphur application (18.32 and 17.11 q ha^{-1}) [Table-1]. The increased levels of sulphur application significantly increased the yield of sunflower. The increased yield might be associated with the addition sulphur in soil forms organic acids on the oxidation of sulphur these acids decreased the soil pH in rhizosphere and enhanced the nutrient availability and increased seed yield of sunflower [6]. The interactions between levels of sulphur and sulphur oxidising microorganisms showed significant effects on seed yield of sunflower. The interactions between *Thiobacillus ferroxidans* and *Thiobacillus thiooxidans* with all the levels of sulphur application recorded higher seed yield of sunflower. It was higher at sulphur application @ 45 kg ha^{-1} followed 30 and 15 kg ha^{-1}.

Table-1 *Effect of sulphur levels, sulphur oxidising microorganisms and their interaction on yield of sunflower grown on Inceptisol*

Treatments	Grain Yield (q ha^{-1})	Oil yield (kg ha^{-1})
Sulphur levels		
L_0 : 0 kg ha^{-1}	15.05	569.79
L_1 : 15 kg ha^{-1}	17.11	656.58
L_2 : 30 kg ha^{-1}	18.32	708.35
L_3 : 45 kg ha^{-1}	19.89	812.48
SE $\pm$	0.08	2.83
CD at 5 %	0.21	8.09
SOM		
M_1 : *T. thiooxidans*	17.93	706.10
M_2 : *T.ferroxidans*	17.98	699.44
M_3 :*A. awamori*	17.08	663.17
M_4 : *A. niger*	17.34	675.05
M_5 :Consortium	17.62	690.24
SE $\pm$	0.84	3.16
CD at 5 %	0.24	9.05
	Interactions (L x M)	
$L_0 M_1$	15.46	592.83
$L_0 M_2$	15.74	588.45
$L_0 M_3$	14.26	535.94
$L_0 M_4$	14.64	552.37
$L_0 M_5$	15.17	579.38
$L_1 M_1$	17.36	672.52
$L_1 M_2$	17.44	669.56
$L_1 M_3$	16.74	638.82
$L_1 M_4$	16.87	644.37
$L_1 M_5$	17.12	657.62
$L_2 M_1$	18.36	714.25
$L_2 M_2$	18.89	730.38
$L_2 M_3$	17.93	688.74
$L_2 M_4$	18.24	705.58
$L_2 M_5$	18.13	702.79
$L_3 M_1$	20.53	844.82
$L_3 M_2$	19.86	809.37
$L_3 M_3$	19.39	789.19
$L_3 M_4$	19.60	797.87
$L_3 M_5$	20.06	821.16
SE $\pm$	0.17	6.32
CD at 5 %	0.48	18.09

Oil yield of sunflower

The oil yield of sunflower was significantly higher in sulphur application @ 45 kg ha^{-1} (812.48 kg ha^{-1}) followed by 30 kg ha^{-1} (708.35 kg ha^{-1}). *Thiobacillus thiooxidans* sulphur oxidizing micro-organisms recorded significantly higher oil yield (706.10 kg ha^{-1}) followed by *Thiobacillus ferroxidans* and consortium (699.44 and 690.24 kg ha^{-1}) [Table-1]. The interactions between sulphur levels and sulphur oxidising microorganisms were significant for oil yield of sunflower. It was significantly the highest in interaction between *Thiobacillus thiooxidans* and 45 kg ha^{-1} sulphur application. It might be because of sulphur nutrition created favorable nutritional environment for the production of metabolites responsible for oil synthesis in plant. The sulphur is helps for the conversion of carbohydrate into oil.[7].

Number of leaves

The number of leaves at 30 days after sowing and button stage was significantly influenced by the graded levels of sulphur and sulphur oxidising microorganisms [Table-2]. Whereas, their interactions were non significant at 30 days after sowing and significant at button stage. The increased levels of sulphur application was increased the number of leaves of sunflower at 30 days after sowing and button stage. It was significantly higher in sulphur application @ 45 kg ha^{-1} at 30 and 45 days after sowing (15.56 and 21.10) followed by 30 kg ha^{-1} (13.29 and 18.63). The sulphur application @ 0 and 15 kg ha^{-1} was found to record the less number of leaves at 30days after sowing (10.27 and 11.18) and button stage (14.53 and 16.70) as compared to higher levels of sulphur application to sunflower. Similar results have been reported by [8].This might be because of each incremental levels of sulphur produce higher photosynthates and translocate to sink which ultimately increased plant growth attributes. The sulphur oxidising microorganisms were significantly increased the number of leaves at 30 days after sowing and button stage. It was significantly more in *Thiobacillus ferroxidans* at 30 days after sowing and button stage (13.03 and 18.62) followed by *Thiobacillus thiooxidans* (12.83 and 18.46), *Aspergillus niger* (12.81 and 17.33) and consortium (12.28 and 17.67) and the least in *Aspergillus awamori* (11.92 and 16.63). The interaction effects of sulphur levels and sulphur oxidising microorganisms were non significant for number of leaves at 30 days after sowing and significant at button stage. The interaction between *Thiobacillus ferroxidans* and levels of sulphur application @ 0, 15, 30 and 45 kg ha^{-1} were recorded significantly more number of leaves. But statistically on par with *Thiobacillus thiooxidan*s at 30 days after sowing and button stage.

Leaf area

The leaf area of sunflower at 30 days after sowing and button stage was significantly influenced by the levels of sulphur application, sulphur oxidising microorganisms and their interactions [Table-2]. The leaf area of sunflower was significantly increased with an increased levels of sulphur application at 30 days after sowing and button stage. It was significantly more in sulphur application @ 45 kg ha^{-1} at 30 days after sowing and button stage (10.17 and 10.85 dm^2). However, it was at par with 30 kg ha^{-1} sulphur application at 30 days after sowing (9.95 dm^2). The sulphur regulate the enzymatic and metabolic processes including photosynthesis and respiration which enhance the cell multiplication, cell elongation and cell expantion throughout the entire period of crop. [9]. *Thiobacillus ferroxidans* sulphur oxidising microorganism recorded significantly more leaf area at 30 days after sowing and button stage (10.02 and 10.85 cm^2). Whereas, remaining sulphur oxidising microorganism were found statistically on par with each other for leaf area of sunflower at 30 days after sowing. *Aspergillus awamori*, *Aspergillus niger*and consortium were on par with each other for leaf area of sunflower at button stage.The interaction effects of levels of sulphur application and sulphur oxidising microorganisms were non significant at 30 days after sowing for leaf area and significant at button stage. The leaf area of sunflower at button stage was found statistically on par with each other for all the interactions between sulphur oxidising microorganisms and levels of sulphur application. It was significantly increased with an increased levels of sulphur application from 0 to 45 kg ha^{-1}.

Plant height

The plant height of sunflower at 30 days after sowing, button stage and at harvest was significantly affected by the levels of sulphur application, sulphur oxidising microorganisms and their interactions [Table-2]. Sulphur application @ 45 kg ha^{-1} recorded significantly higher plant height at 30 days after sowing, button stage and at harvest (45.91, 67.29 and 195.09 cm respectively). It was statistically on par with 30 and 15 kg ha^{-1} sulphur application at 30 days after sowing (45.18 and 44.72 cm). The plant height at button stage and at harvest was statistically on par with each other in 0 and 15 kg ha^{-1} sulphur application. The plant height was increased with levels of sulphur might be due to the metabolic processes enhanced in the plant cell resulted in increasing meristimatic activities causing more apical growth [10]. *Thiobacillus thiooxidans* sulphur oxidising microorganism was recorded significantly higher plant height at 30 days after sowing, button stage and at harvest (45.25, 62.06 and 183.15 cm respectively). It was statistically on par with *Thiobacillus ferroxidans* at 30 days after sowing and button stage (45.20 and 53.30 cm). The remaining sulphur oxidising microorganism were on par with each other for plant height at 30 days after sowing, button stage and at harvest. The interaction effects of levels of sulphur and sulphur oxidising microorganism were significant for plant height at 30 days after sowing and buttan stage and non significant at harvest. *Thiobacillus thiooxidans* and *Thiobacillus ferroxidans* were on par with each other for plant height at 30 days after sowing with their interaction of 0, 15, 30 and 45 kg ha^{-1} respectively. It was increased with an increased levels of sulphur application. The interactions of *Aspergillus awamori*, *Aspergillus niger* and consortium with levels of sulphur application were on par with each other for plant height at 30 days after sowing. The interaction effects between sulphur oxidising microorganisms *viz*., *Thiobacillus thiooxidans* and *Thiobacillus ferroxidans* and levels of sulphur application were on par with each other for plant height except 45 kg ha^{-1} sulphur application at 45 days after sowing. The interactions of *Aspergillus awamori*, *Aspergillus niger*and consortium with levels of sulphur application were on par with each other for plant height at 45 days after sowing. The interaction effects for plant height at harvest was non significant.

Table-2 *Effect of sulphur levels, sulphur oxidising microorganisms and their interactions on growth attributing characters of sunflower grown on Inceptisol*

Period / Treatment	No. of leaves		Leaf area (dm^2)		Plant height (cm)		
	30 DAS	Button stage	30 DAS	Button stage	30 DAS	Button stage	At. har
Sulphur levels							
L_0: 0 kg ha^{-1}	10.27	14.53	9.15	9.68	42.20	53.30	163.49
L_1: 15 kg ha^{-1}	11.18	16.70	9.47	10.0	44.72	57.17	169.25
L_2: 30 kg ha^{-1}	13.29	18.63	9.95	10.53	45.18	60.66	182.48
L_3: 45 kg ha^{-1}	15.56	21.10	10.17	10.85	45.91	67.29	195.09
SE $\pm$	0.21	0.05	0.10	0.08	0.41	0.299	1.898
CD at 5 %	0.59	0.14	0.29	0.22	1.18	0.856	5.435
SOM							
M_1: *T. thiooxidans*	12.83	18.46	9.51	10.47	46.25	62.06	183.15
M_2: *T.ferroxidans*	13.03	18.62	10.02	10.85	45.24	61.39	176.43
M_3:*A. awamori*	11.92	16.63	9.52	9.88	42.74	57.13	174.02
M_4: *A. niger*	12.81	17.33	9.53	9.93	43.50	58.44	175.97
M_5:Consortium	12.28	17.67	9.84	10.19	44.79	59.01	178.31
SE $\pm$	0.23	0.06	0.11	0.09	0.46	0.33	2.12
CD at 5 %	0.66	0.16	0.32	0.25	1.32	0.96	6.08
	Interactions(LxM)						
$L_0 M_1$	11.33	15.00	9.12	9.83	44.33	54.83	166.33
$L_0 M_2$	11.56	15.83	9.31	9.85	43.00	55.50	168.11
$L_0 M_3$	9.22	13.00	9.00	9.49	39.17	50.17	158.67
$L_0 M_4$	9.89	14.17	9.09	9.50	41.17	52.33	160.67
$L_0 M_5$	9.33	14.67	9.23	9.72	43.33	53.67	163.67
$L_1 M_1$	10.89	17.00	9.34	10.04	43.83	57.50	176.44
$L_1 M_2$	11.22	17.33	9.54	10.36	44.67	58.89	154.39
$L_1 M_3$	11.00	16.17	9.29	9.68	44.50	55.28	169.00
$L_1 M_4$	11.78	16.33	9.32	9.79	44.50	56.83	171.44
$L_1 M_5$	11.00	16.67	9.84	10.10	46.11	57.33	174.95
$L_2 M_1$	13.67	19.17	9.75	10.85	46.67	62.00	183.56
$L_2 M_2$	13.89	19.33	10.42	11.42	47.61	62.83	185.17
$L_2 M_3$	12.22	17.83	9.82	9.99	43.00	59.33	179.95
$L_2 M_4$	13.89	18.33	9.79	9.95	44.17	59.89	181.39
$L_2 M_5$	12.78	18.50	9.96	10.43	44.44	56.26	182.34
$L_3 M_1$	15.44	22.67	9.83	11.14	50.17	73.89	206.28
$L_3 M_2$	15.44	22.00	10.81	11.78	45.67	68.33	198.06
$L_3 M_3$	15.22	19.50	9.96	10.37	44.28	63.72	188.45
$L_3 M_4$	15.67	20.50	9.93	10.47	44.17	64.72	190.39
$L_3 M_5$	16.00	20.83	10.32	10.50	45.28	65.79	192.28
SE $\pm$	0.46	0.11	0.22	0.17	0.92	1.91	4.25
CD at 5 %	NS	0.31	NS	0.49	2.64	2.56	NS

Head diameter

The application of sulphur to sunflower significantly influenced the head diameter [Table-3]. It was significantly more in sulphur application @ 45 kg ha^{-1} (21.54 cm) followed by 30 and 15 kg ha^{-1}(19.40 and 18.12 cm). The sulphur oxidising microorganism did not influenced the head diameter of sunflower. *Thiobacillus ferroxidans* recorded numerically more head diameter (19.11 cm) as compared to rest of the sulphur oxidising microorganisms. The interaction effects of sulphur levels and sulphur oxidising microorganisms were non significant for head diameter of sunflower.

Number of filled grains per capitulum

The number of filled grains per capitulum was significantly influenced by levels of sulphur, sulphur oxidising microorganisms and their interactions. The increased levels of sulphur application significantly increased the number of filled grains in sunflower [Table-3]. It was significantly more in sulphur application @ 45 kg ha^{-1} (670.36) followed by 30 kg ha^{-1} (617.51). *Thiobacillus ferroxidans* and *Thiobacillus thiooxidans* sulphur oxidising microorganisms was on par with each other for their number of filled grains per capitulum (608.55 and 604.52). It was the lowest in *Aspergillus awamori* (575.91). *Aspergillus niger* and consortium were on par with each other for filled grains per capitulum (585.26 and 593.82).The interaction between sulphur levels and sulphuroxidising microorganisms were significant for number of filled grains per capitulum. The interaction of *Thiobacillus thiooxidans* and sulphur level @ 45 kg ha^{-1} recorded significantly the highest number filled grains per capitulum (691.87).

Number of unfilled grains per capitulum

The sulphur levels, sulphur oxidising microorganisms and their interactions were significantly influenced the number of unfilled grains per capitulum [Table-3].The number of unfilled grains per capitulum was observed in sulphur application @ 45 kg ha^{-1} (201.25) followed by 30 kg ha^{-1} (185.34). It was the least in 0 kg ha^{-1} sulphur application (152.10). *Aspergillus niger* and consortium was found to record significantly less number of unfilled grains per capitulum (176.29 and 178.31) as compared to rest of microorganisms and on par with each other. *Thiobacillus thiooxidans* and *Thiobacillus ferroxidans* was found to record significantly more number of unfilled grains per capitulum (181.44 and 182.16). The least number of unfilled grains per capitulum was observed in *Aspergillus awamori* (172.38).

Total number of grains per capitulum

The total number of grains per capitula was significantly more in sulphur application @ 45 kg ha^{-1} (871.61) followed by 30 kg ha^{-1} (802.85) [Table-3]. The increased levels of sulphur application significantly increased the total number of grains per capitulum. Sulphur oxidising microorganisms *Thiobacillus thiooxidans* and *Thiobacillus ferroxidans* was found on par with each other for total number of grain per capitulum (785.96 and 790.51) and significantly superior over the rest of the sulphur oxidising microorganisms. The interaction effect of *Thiobacillus thiooxidans* and *Thiobacillus ferroxidans* with 0, 15 and 45 kg ha^{-1} sulphur application were on par with each other for total number of grains per capitulum. Similar results have been reported by [11]. The higher sulphur levels may have resulted in proper partitioning of photosynthates from source to sink resulting in improvement in yield attributing characters.

Table-3 *Effect of sulphur levels, sulphur oxidising microorganisms and their interactions on yield at tribuling characters of sunflower grown on Inceptisol*

Treatments	Head dia. (cm)	No. of filled grain per capitulum	No of unfilled grain per capitulum	Total No. of grain per capitulum
Sulphur levels				
L_0 : 0 kg ha^{-1}	15.96	507.81	152.10	659.91
L_1 : 15 kg ha^{-1}	18.12	578.61	173.77	752.37
L_2 : 30 kg ha^{-1}	19.40	617.51	185.34	802.85
L_3 : 45 kg ha^{-1}	21.54	670.36	201.25	871.61
SE $\pm$ CD at 5 %	0.20 0.58	2.50 7.15	0.83 2.37	3.27 9.36
SOM				
M_1 : *T. thiooxidans*	18.98	604.52	181.44	785.96
M_2 : *T.ferroxidans*	19.11	608.35	182.16	790.51
M_3 :*A. awamori*	18.48	575.91	172.38	748.28
M_4 : *A. niger*	18.67	585.26	176.29	761.55
M_5 :Consortium	18.54	593.82	178.31	772.13
SE $\pm$ CD at 5 %	0.23 NS	2.79 8.00	0.923 2.64	3.657 10.47
Interactions (L x M)				
$L_0 M_1$	16.52	521.40	156.50	677.90
$L_0 M_2$	16.80	52.13	157.93	690.07
$L_0 M_3$	15.12	480.73	144.37	625.10
$L_0 M_4$	15.95	793.47	148.17	641.63
$L_0 M_5$	15.43	511.30	153.53	664.83
$L_1 M_1$	18.20	585.03	175.63	760.67
$L_1 M_2$	17.80	594.53	178.50	773.03
$L_1 M_3$	18.45	564.33	169.43	733.77
$L_1 M_4$	18.22	571.97	171.97	743.93
$L_1 M_5$	17.93	577.17	173.30	750.47
$L_2 M_1$	19.42	619.77	185.90	805.67
$L_2 M_2$	20.20	637.47	191.23	828.70
$L_2 M_3$	18.95	604.23	181.43	785.67
$L_2 M_4$	19.17	614.87	184.60	799.47
$L_2 M_5$	19.28	611.20	183.53	749.73
$L_3 M_1$	21.77	691.87	207.73	899.60
$L_3 M_2$	21.65	669.27	200.97	870.23
$L_3 M_3$	21.40	654.33	194.27	848.60
$L_3 M_4$	21.38	660.73	200.43	861.17
$L_3 M_5$	21.50	675.60	202.87	878.47
SE $\pm$ CD at 5 %	0.57 NS	5.59 15.99	1.88 NS	7.31 20.94

Conclusion

The yield contributing characters of sunflower *viz*., number of leaves, leaf area, plant height, head diameter, number of filled, unfilled and total grain per capitulum were significantly influenced by the 45 kg ha^{-1} sulphur application. *Thiobacillus ferroxidans* sulphur oxidising microorganism was found beneficial for the yield attributing character.

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