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Influence of zinc solubilizing microbial cultures and zinc fertilizers on yield, nutrient uptake and quality of soybean in Vertisol

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Abstract
Field experiment was conducted during *Kharif* season of 2017 at Research Farm, Department of Soil Science and Agricultural Chemistry at Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani on zinc deficient Vertisol to study the zinc solubilization potential of different microorganisms in soybean crop. The experiment consist of sixteen treatment in which four laboratory pre-evaluated zinc solubilizing microbial cultures (Control, *Pseudomona strita*, *Bacillus megaterium*, and *Trichoderma viride*) and four graded doses of ZnSo4 (0,10,20,30, kg ha^{-1}) were used in the factorial randomized block design. The results emerged out indicated significant increase in yield, nutrient uptake and quality of soybean was improved in the plots treated with *Pseudomon strita* along with 30 kg $ZnSO_4$ $ha^{-1}$and was found as the best combination in overall improvement of yield, nutrient uptake and quality of soybean.

Keywords: *Pseudomon strita*, *Bacillus megaterium*, *Trichoderma viride*, zinc solubilizing

Introduction
The poor productivity of soybean is mainly due to imbalance application of nutrients and use of traditional varieties. Under such situations, use of zinc solubilizing bacteria (ZSB) had shown advantage in enhancing soybean productivity. Microbial inoculants are cost effective, eco-friendly, and renewable sources of plant nutrients. Pseudomonas and PSB assume a great importance on account of their vital role in N2-fixation and P-solubilisation. The introduction of efficient strains of Zn-solubilizing species of *Bacillus megaterium*, *Pseudomonas striata* and *Trichoderma viride* the rhizosphere of crops and soils has been reported to help in increasing zincavailability in the soil. Macro-nutrients such as nitrogen, phosphorus and potassium play a crucial role in plant growth and yield. Soybean (*Glycine max L*) Merril is an important oil seed crop largely grown in United States of America, China, Brazil, Mexico and India. India plays an important role in international trade. Soybean generally refered as golden as well as wonder bean its seed is rich in soil (20%) and proteins (40-44%), amino acid lysine (5%). Major soybean growing states in India are Madhya Pradesh, Maharashtra, Gujarat, Rajasthan, Karnataka and Andhra Pradesh. Maharashtra ranks 2^{nd} in terms of production of soybean after Madhya Pradesh.

In India area, production and productivity of soybean during 2017 is 101.5 lakh ha, 91.4 lakh million tonnes and 900 kg ha^{-1}, respectively, in Maharashtra area, production and productivity of soybean during 2017 is 34.4 lakh ha, 31.8 lakh million tonnes and 925 kg ha^{-1}, respectively. (Anonymous, 2017) [1]. Futher, zinc is an essential micronutrient that plays a vital role in various metabolic processes in plants and its deficiency adversely affects the growth and development of crop plants (Cakmak, 2008) [3]. The crop and soil management practice mine large amount of zinc from the native pool of the soil for example, a harvest of 6.5 ton grain /ha^{-1}/year removed 416 g Zn ha^{-1}/year in soybean wheat cropping system (Prasad *et al* 2010) [12].

Material and Methods
The present investigation was carried at Research Farm, Department of Soil Science and Agricultural Chemistry at Vasantrao Naik Marathwada Krishi Vidyapeeth,Parbhani on Vertisol during 2017-18. The initial soil pH was 8.20, EC-0.22 dSm^{-1}, Organic Carbon- 4.43 g kg^{-1}, Calcium carbonate -4.05%, available nitrogen-145 kg ha^{-1}, Phosphorus -15.23, Potassium- 556 kg ha^{-1} and Sulphur-9.38 mg kg^{-1}.

The initial micronutrient status was DTPA Copper-2.38, Mangnease-7.34, Zinc-0.58 and Ferrous – 3.15 mg kg^{-1}. The soil was clayey in texture, moderately alkaline in reaction, medium in available nitrogen, phosphorus and sufficient in available potassium and low in sulphur and iron. One gram fine powder of dry matter/grain sample (defatted) was taken in conical flask and digested with the diacid mixture (HNO_3): $HClO_4$) in ratio of (10:4). After complete digestion, the content was cooled and filtered in volumetric flask by washing with hot distilled water until filtrate became free of acid and 100 ml volume was made. The extract was used for determination of phosphorus, potassium and sulphur where as, for determination of nitrogen content from plant and grain, 0.5 g sample + H2SO4 (10 ml) + H2O2 (2.5 ml) + catalyst mixture (1 g) were used for digestion and volume made to 100 ml. The extract was used for nitrogen analysis.The nitrogen content in seed was determined by Micro-Kjeldhal's method, the protein content was calculated by multiplying per cent nitrogen with the factor 5.74 for soybean (AOAC, 1993). Protein yield (kg ha^{-1}) was calculated by multiplying the respective protein content with respective grain yield using following formula. Protein yield (kg ha^{-1}) = Protein content in grain (per cent) x Grain yield (kg ha^{-1})/ 100.

The field experiment was carried out on soybean crop (Variety MAU-162) in kharif season during year 2017-18. After completion of preparatory tillage operations, the experiment was laid out in factorial randomized block design comprising (16) treatments and replicated (3) times.

The experiment consist of two factors

Factor-1- Zinc levels	Factor-2- Zinc mobilizing cultures
Zno- 0 kg ZnSo4 ha^{-1}	SO- Control
Zn1- 10 kg ZnSo4 ha^{-1}	S1- *Pseudomona strita*
Zn2- 20 kg ZnSo4 ha^{-1}	S2- *Bacillus megaterium*
Zn3- 30 kg ZnSo4 ha^{-1}	S3- *Trichoderma Viride*

Seed treatment was done immediate before sowing with liquid zinc mobilizing cultures @ 100 ml 10 kg^{-1} seed. The crop was raised following recommended agronomic practices. The recommended dose of chemical fertilizer applied @ 30:60:30 NPK kg ha^{-1}.

The soil sample were collected after harvest of soybean for analysis of chemical properties and available nutrients status as per standard procedures.

Results and Discussion

Seed and straw yield of Soybean

The result represented in Table 1 indicated that significant increase of seed and straw yield due to addition of zinc mobilizing microorganisms. Zinc solubilizers influenced the seed yield which ranged between 1941 to 2345 ha^{-1} and straw yield 2731 to 2866 kg ha^{-1} showing significantly higher seed and straw yield in *Pseudomona strita* treated plots followed by *Bacillus megaterium a*nd *Trichoderma viride,* Whereas, significantly lower seed and straw yield per plot were noted in uninoculated control. Similarly graded levels of zinc in the form of zinc sulphate also increased the seed and straw yield with each incremental dose up to 30 kg $ZnSO_4$ kg ha^{-1}. The seed yield as influenced by Zn application ranged from 1741 to 2426 and straw yield 2591 to 2942 kg ha^{-1}. Zaidi and Singh (2001) observed that inoculation with *Bradyrhizobium Japonicum* strains SB-12 and difference isolates of *Pseudomona* as well as their possible combination significantly increased yield of soybean over control. This might be due to reduction in infection by soil pathogen and greater seedling emergence. Similarly, Goudar *et al*. (2008) [8] found that grain yield of soybean was significantly influenced by the seed inoculation of *Bradyrhizobium japonicum* strains along with micronutrients over uninoculated control. Further, Gupta (2006) [6] noted that the seed inoculation with *Rhizobium* + *PSB* + *Azotobacter* increased grain yield in chickpea.

Content and uptake

Zinc solubilizers influenced the N content and uptake**.** N content from seed and straw which ranged from (5.10 to 5.62 and 0.61 to 0.84%) and uptake from seed and straw which ranged from (99.51 to 134.04 and 16.58 to 23.64 kg/ha) showing significantly higher N content and uptake in *Pseudomona strita* treated plots follows by *Bacillus megaterium* and *Trichoderma viride*. Whereas, significantly lower N content and uptake per plot were noted in uninoculated control. Similarly graded levels of zinc in the form of zinc sulphate also increase the N content and uptake with each incremental dose up to 30 kg $ZnSO_4$ kg ha^{-1}. The N content from seed and straw and uptake from seed and straw as influenced by Zn application ranged from (content 5.27 to 0.66% and uptake 91.74 to 17.08) to (content 5.64 to 0.84 and uptake 137.46 to 24.86). Our results are conformity with Auti *et al*., (2013), they found that bioinoculants increased uptake of N might be due to effective root system and increased concentration of nutrients in soil solution. The increase in total N uptake might be attributed to more biological N fixation by PGPR and N assimilation. Thereafter, Kumar and Ismail (2017) reported that the combined application of *Rhizobium* + PSM and found more N and P uptake.

Zinc solubilizers influence the P content and uptake**.** P content from seed and straw which range from (0.40 to 0.33 and 0.64 to 0.44%) and uptake from seed and straw which range from (8.01 to 9.09 and 15.28 to 12.84 kg ha^{-1}) showing significantly higher P content and uptake in *Pseudomona striata* treated plots follows by *Bacillus megaterium* and *Trichoderma viride*. Whereas, significantly lower P content and uptake per plot were noted in uninoculated control. Similarly, graded levels of zinc in the form of zinc sulphate also increase the P content and uptake with each incremental dose up to 30 kg $ZnSO_4$ kg ha^{-1}. The P content from seed and straw and uptake from seed and straw as influenced by Zn application ranged from (0.48 to 0.34% and uptake 8.37 to 8.74 kg ha^{-1}) to (0.58 to 0.45% and uptake 14.56 to13.15 kg ha^{-1}). Menaria (2013) Showed that in comparison to fertility status of unfertilized plots and soil under no inoculation plots fertilized with N 20 + P 40 + K 20 + S 40 kg ha^{-1} and *Bradyrhizobium japonicum* + *PSB* treated plots had highest available N and P content in soils after harvest of the crop.

Zinc solubilizers influenced the K content and uptake from seed. K content from seed and straw which ranged betweem (1.37 to 0.63 and 1.74 to 1.79%) and uptake from seed and straw which ranged from (26.74 to 17.22 and 41.39to 22.72 kg ha^{-1}) showing significantly higher K content and uptake in *Pseudomona striata* treated plots follows by *Bacillus megaterium* and *Trichoderma viride*. Similarly, graded levels of zinc in the form of zinc sulphate also increase the K content and uptake with each incremental dose up to 30 kg $ZnSO_4$ kg ha^{-1}. The P content from seed and straw and uptake from seed and straw as influenced by Zn application ranged from (1.46 to 0.62% and uptake 25.40 to 16.15 kg ha^{-1}) ZnO to (1.69 to 0.79% and uptake 39.88 to 23.32 kg ha^{-1}) $ZnSO_4$ 30 kg ha-^{1}. Keram *et al.* (2012) [8] observed highest uptake K (90.96 kg ha^{-1}) with the application of 20 kg Zn ha^{-1} along with recommended dose of NPK compared to control. The increase in total N, K and Zn uptake could be attributed to synergistic effect between N and Zn and due to the positive interaction of K and Zn, respectively. Similarly, Zn application of 25kg ha^{-1} as $ZnSO_4$ recorded the highest uptake K (34.39 kg ha^{-1} in grain) (100.50 kg ha^{-1} in straw), in rice the lowest uptake was seen in control (Dixit *et al.*, 2012) [4].

Zinc solubilizers influenced the Zn content and uptake which ranged between (48.48 to 25.34 and 56.81 to 31.18 mg kg^{-1}) and uptake from seed and straw which ranged from (94.39 to 69.25 and 135.06 to 89.60 g ha^{-1}) showing significantly higher Zn content and uptake in *Pseudomona striata* treated plots follows by *Bacillus megaterium* and *Trichoderma viride*. Similarly, graded levels of zinc in the form of zinc sulphate also increase the Zn content and uptake with each incremental dose up to 30 kg $ZnSO_4$ kg ha^{-1}. The Zn content and uptake from seed and straw as influenced by Zn application ranged from (49.02 to 26.96% and uptake 85.25 to 69.77 g ha^{-1}) to (56.33 to 30.57% and uptake 137.67 to 89.31 g ha^{-1}). In the experiment enhanced Zn uptake might be due to solubilization of insoluble soil Zn by production of gluconic acids by the isolates used. Experimental results show that, inoculation of *Pseudomona striata* and *Bacillus megaterium* also increases nutrient content and uptake of zinc. Gurumurthy *et al.* (2009) noticed the higher uptake of Zn by soybean with the application of 50% RDF – N + 50% N through FYM + PSB in safflower grain and straw. Zn application of 25 kg ha^{-1} as $ZnSO_4$ recorded the highest uptake Zn (163.52 g ha^{-1} in grain) (131.42g ha^{-1} in straw) in rice the lowest uptake was seen in control (Dixit *et al.*, 2012) [4].

Protein content and protein yield of soybean

The results represent zinc solubilizers influenced the protein content and protein yield which ranged between 29.29 to 32.62 and 573.31 to 769.17 showing significantly higher protein content and protein yield in *Pseudomona striata* treated plots follows by *Bacillus megaterium* and *Trichoderma viride*. Similarly, graded levels of zinc in the form of zinc sulphate also increased the protein content and protein yield with each incremental dose up to 30 kg $ZnSO_4$ kg ha^{-1}. The protein content and protein yield as influenced by Zn application ranged from 30.26 and 525.98 to 32.39 and 791.72. Singh *et al.* (2005) revealed that application of *Rhizobium + Azotobacter + PSB +FYM* @ 5t ha^{-1} recorded maximum protein content and protein yield. However, increase in protein content and protein yield. Might be due to increased nitrogen uptake by soybean seed which increased protein content and yield of protein. Similar findings were also reported by Tanwar and Shaktawat (2003).

Conclusion

From the study, it can be concluded that, the incremental levels of zinc solublizers and $ZnSO_4$ caused significant results show that, inoculation of *Pseudomona striata* and *Bacillus megaterium* and *Trichoderma viride* also increases nutrient content and uptake of N, P, K, Zn and protein content as well as protein yield. Similarly, graded levels of zinc in the form of zinc sulphate also increased with each incremental dose up to 30 kg $ZnSO_4$ kg ha^{-1}.

Table 1: Seed and Straw yield of soybean as influenced by zinc mobilizing cultures and zinc levels

Treatment	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Zinc solubilizers (S)		
S0: Control	1941	2731
S1: *Pseudomona striata*	2345	2866
S2: *Bacillus megaterium*	2001	2817
S3: *Trichoderma viride*	2041	2786
S.Em.±	49.19	21.72
C.D. at 5%	142.0	62.73
Levels of $ZnSO_4$ (Zn)		
Zn0: $ZnSO_4$ 0 kg ha^{-1}	1741	2591
Zn1: $ZnSO_4$ 10 kg ha^{-1}	1967	2805
Zn2: $ZnSO_4$ 20 kg ha^{-1}	2195	2862
Zn3: $ZnSO_4$ 30 kg ha^{-1}	2426	2942
S.Em.±	49.19	21.72
C.D. at 5%	142.0	62.73
Interaction (SxZn)		
S.Em.±	98.38	43.45
C.D. at 5%	284.12	125.47
CV %	8.18	2.69

Table 1a; Interaction effect of zinc mobilizing cultures and graded level of zinc on seed yield and straw yield of soybean

Treatment	Zn0: $ZnSO_4$ 0 kg ha^{-1}	Zn1: $ZnSO_4$ 10 kg ha^{-1}	Zn2: $ZnSO_4$ 20 kg ha^{-1}	Zn3: $ZnSO_4$ 30 kg ha^{-1}
Seed yield (kg ha^{-1})				
S0: Control	1802	1896	1996	2072
S1: *Pseudomona striata*	1730	2053	2658	2940
S2: *Bacillus megaterium*	1723	1955	2046	2281
S3: *Trichoderma viride*	1709	1965	2079	2410
Interaction (SxZn)	S	Zn	SXZn	
SEm±	49.19	49.19	98.38	
CD at 5%	142.0	142.0	284.12	
Straw yield (kg ha^{-1})				
S0: Control	2622	2702.70	2744	2857
S1: *Pseudomona striata*	2507	2929.00	2972	3055

S2: *Bacillus megaterium*	2647	2805.07	2890	2927
S3: *Trichoderma viride*	2588	2786	2840	2930
Interaction (SxZn)	S	Zn	SXZn	
SEm±	21.72	21.72	43.45	
CD at 5%	62.73	62.73	125.47	

Table 2: Effect of zinc mobilizing cultures and zinc levels on content and uptake of nitrogen in soybean.

Treatment	N content %		N uptake (kg ha^{-1})		
	Seed	Straw	Seed	Straw	Total
Zinc solubilizers (S)					
S0: Control	5.10	0.61	99.51	16.58	116.09
S1: *Pseudomona striata*	5.68	0.84	134.04	23.64	157.67
S2: *Bacillus megaterium*	5.62	0.81	112.70	23.00	135.70
S3: *Trichoderma viride*	5.67	0.82	116.00	23.42	139.36
S.Em.±	0.036	0.009	2.788	0.285	2.818
C.D. at 5%	0.103	0.026	8.051	0.824	8.139
Levels of $ZnSO_4$ (Zn)					
Zn0: ZnSO4 0 kg ha^{-1}	5.27	0.66	91.74	17.08	108.76
Zn1: ZnSO4 10 kg ha^{-1}	5.56	0.76	109.72	21.45	131.15
Zn2: ZnSO4 20 kg ha^{-1}	5.61	0.81	116.07	21.72	137.72
Zn3: ZnSO4 30 kg ha^{-1}	5.64	0.84	137.46	24.86	162.32
S.Em.±	0.036	0.009	2.788	0.285	2.818
C.D. at 5%	0.103	0.026	8.051	0.824	8.139
Interaction (SxZn)					
S.Em.±	0.071	0.018	5.576	0.57	5.637
C.D. at 5%	0.205	0.051	16.102	1.647	16.277
CV %	2.23	4.02	8.36	4.56	7.12

Table 2a: Interaction effect on zinc mobilizing cultures and zinc levels on content and uptake of nitrogen in soybean

Treatment	Zn0: $ZnSO_4$ 0 kg ha^{-1}	Zn1: $ZnSO_4$ 10 kg ha^{-1}	Zn2: $ZnSO_4$ 20 kg ha^{-1}	Zn3: $ZnSO_4$ 30 kg ha^{-1}
N uptake in seed (kg ha^{-1})				
S0: Control	80.94	101.52	105.32	110.28
S1: *Pseudomona striata*	94.79	115.48	153.46	172.41
S2: *Bacillus megaterium*	96.51	110.75	115.50	128.04
S3: *Trichoderma viride*	94.73	111.11	119.06	139.11
Interaction	SXZn			
SEm±	5.576			
CD at 5%	16.102			
N uptake in straw (kg ha^{-1})				
S0: Control	14.62	16.10	17.26	18.33
S1: *Pseudomona striata*	16.40	22.42	26.50	29.26
S2: *Bacillus megaterium*	18.00	23.79	24.55	25.66
S3: *Trichoderma viride*	19.32	23.47	24.70	26.19
Interaction	SXZn			
SEm±	0.57			
CD at 5%	14.62			
Total N uptake (kg ha^{-1})				
S0: Control	95.56	117.62	122.58	128.61
S1: *Pseudomona striata*	111.19	137.87	179.96	201.66
S2: *Bacillus megaterium*	114.50	134.54	140.05	153.70
S3: *Trichoderma viride*	113.79	134.58	143.75	165.30
Interaction	SXZn			
SEm±	5.637			
CD at 5%	16.277			

Table 3. Effect of zinc mobilizing cultures and zinc levels on content and uptake of phosphrous in soybean

Treatment	P content %		P uptake (kg ha^{-1})		
	Seed	Straw	Seed	Straw	Total
Zinc solubilizers (S)					
S0: Control	0.40	0.33	8.01	9.09	17.09
S1: *Pseudomona striata*	0.64	0.44	15.28	12.84	28.11
S2: *Bacillus megaterium*	0.56	0.42	11.23	11.76	22.99
S3: *Trichoderma viride*	0.57	0.40	11.59	11.22	22.82
S.Em.±	0.007	0.003	0.337	0.139	0.388
C.D. at 5%	0.021	0.01	0.974	0.402	1.122

Levels of $ZnSO_4$ (Zn)					
Zn0: ZnSO4 0 kg ha^{-1}	0.48	0.34	8.37	8.74	17.11
Zn1: ZnSO4 10 kg ha^{-1}	0.53	0.39	10.53	11.02	21.55
Zn2: ZnSO4 20 kg ha^{-1}	0.57	0.42	11.59	10.93	22.52
Zn3: ZnSO4 30 kg ha^{-1}	0.58	0.45	14.56	13.15	27.71
S.Em.±	0.007	0.003	0.337	0.139	0.388
C.D. at 5%	0.021	0.01	0.974	0.402	1.122
Interaction (SxZn)					
S.Em.±	0.015	0.007	0.674	0.278	0.777
C.D. at 5%	0.042	0.02	1.948	0.804	2.243
CV %	4.67	2.96	10.13	4.29	5.91

Table 3a: Interaction effect on zinc mobilizing cultures and zinc levels on content and uptake of phosphrous in soybean

Treatment	**Zn0: $ZnSO_4$ 0 kg ha^{-1}**	**Zn1: $ZnSO_4$ 10 kg ha^{-1}**	**Zn2: $ZnSO_4$ 20 kg ha^{-1}**	**Zn3: $ZnSO_4$ 30 kg ha^{-1}**
P uptake in seed (kg ha^{-1})				
S0: Control	5.93	7.06	8.91	10.12
S1: *Pseudomona striata*	9.43	13.58	17.79	20.31
S2: *Bacillus megaterium*	8.95	10.48	11.93	13.56
S3: *Trichoderma viride*	9.16	11.01	11.94	14.26
Interaction	SXZn			
SEm±	0.674			
CD at 5%	1.948			
P uptake in straw (kg ha^{-1})				
S0: Control	7.46	9.05	9.55	10.28
S1: *Pseudomona striata*	9.40	12.93	13.41	15.61
S2: *Bacillus megaterium*	9.26	11.95	12.68	13.17
S3: *Trichoderma viride*	8.83	10.15	12.37	13.55
Interaction	SXZn			
SEm±	0.278			
CD at 5%	0.804			
Total P uptake (kg ha^{-1})				
S0: Control	13.40	16.11	18.46	20.40
S1: *Pseudomona striata*	18.83	26.50	31.20	35.92
S2: *Bacillus megaterium*	18.21	22.43	24.61	26.73
S3: *Trichoderma viride*	17.99	21.17	24.31	27.80
Interaction	SXZn			
SEm±	0.777			
CD at 5%	2.243			

Table 4: Effect of zinc mobilizing cultures and zinc levels on content and uptake of potassium in soybean

Treatment	**K content %**		**K uptake (kg ha^{-1})**		
	Seed	**Straw**	**Seed**	**Straw**	**Total**
Zinc solubilizers (S)					
S0: Control	1.37	0.63	26.74	17.22	43.97
S1: *Pseudomona striata*	1.74	0.79	41.39	22.72	64.12
S2: *Bacillus megaterium*	1.53	0.73	30.74	20.49	51.23
S3: *Trichoderma viride*	1.61	0.74	30.10	20.82	50.92
S.Em.±	0.021	0.005	1.047	0.195	1.064
C.D. at 5%	0.061	0.014	3.024	0.563	3.074
Levels of $ZnSO_4$ (Zn)					
Zn0: ZnSO4 0 kg ha^{-1}	1.46	0.62	25.40	16.15	41.55
Zn1: ZnSO4 10 kg ha^{-1}	1.50	0.71	28.59	20.03	48.63
Zn2: ZnSO4 20 kg ha^{-1}	1.60	0.76	32.84	20.10	52.94
Zn3: ZnSO4 30 kg ha^{-1}	1.69	0.79	39.88	23.32	63.20
S.Em.±	0.021	0.005	1.047	0.195	1.064
C.D. at 5%	0.061	0.014	3.024	0.563	3.074
Interaction (SxZn)					
S.Em.±	0.043	0.009	2.094	0.39	2.129
C.D. at 5%	NS	0.027	6.048	1.126	6.147
CV %	4.71	2.25	11.25	3.32	7.01

Table 4a: Interaction effect on zinc mobilizing cultures and zinc levels on content and uptake of potassium in soybean

Treatment	Zn0: $ZnSO_4$ 0 kg ha^{-1}	Zn1: $ZnSO_4$ 10 kg ha^{-1}	Zn2: $ZnSO_4$ 20 kg ha^{-1}	Zn3: $ZnSO_4$ 30 kg ha^{-1}
K uptake in seed (kg ha^{-1})				
S0: Control	23.29	25.61	27.58	30.49
S1: *Pseudomona striata*	26.58	35.30	48.71	54.99
S2: *Bacillus megaterium*	25.21	28.54	31.50	37.72
S3: *Trichoderma viride*	26.53	24.93	32.62	36.30
Interaction	SXZn			
SEm±	2.094			
CD at 5%	6.048			
K uptake in straw (kg ha^{-1})				
S0: Control	14.74	16.96	17.90	19.29
S1: *Pseudomona striata*	15.93	22.42	25.30	27.24
S2: *Bacillus megaterium*	17.02	20.28	21.66	23.00
S3: *Trichoderma viride*	16.92	20.48	22.13	23.75
Interaction	SXZn			
SEm±	0.39			
CD at 5%	1.126			
Total K uptake (kg ha^{-1})				
S0: Control	38.03	42.57	45.48	49.78
S1: *Pseudomona striata*	42.51	57.72	74.01	82.23
S2: *Bacillus megaterium*	42.23	48.82	53.16	60.72
S3: *Trichoderma viride*	43.45	45.41	54.76	60.05
Interaction	SXZn			
SEm±	2.129			
CD at 5%	6.147			

Table 5: Effect of zinc mobilizing cultures and zinc levels on content and uptake of zinc in soybean

Treatment	Zn content %		Zn uptake (g ha^{-1})		
	Seed	Straw	Seed	Straw	Total
Zinc solubilizers (S)					
S0: Control	48.48	25.34	94.39	69.25	163.63
S1: *Pseudomona striata*	56.81	31.18	135.06	89.60	224.66
S2: *Bacillus megaterium*	52.93	29.13	106.34	81.69	188.03
S3: *Trichoderma viride*	53.82	29.82	110.44	83.12	193.56
S.Em.±	0.448	0.236	2.837	0.967	3.085
C.D. at 5%	1.292	0.681	8.192	2.791	8.908
Levels of $ZnSO_4$ (Zn)					
Zn0: ZnSO4 0 kg ha^{-1}	49.02	26.96	85.25	69.77	155.03
Zn1: ZnSO4 10 kg ha^{-1}	51.97	28.41	102.44	79.84	182.27
Zn2: ZnSO4 20 kg ha^{-1}	54.71	29.54	111.48	79.15	190.63
Zn3: ZnSO4 30 kg ha^{-1}	56.33	30.57	137.67	89.31	226.98
S.Em.±	0.448	0.236	2.837	0.967	3.085
C.D. at 5%	1.292	0.681	8.192	2.791	8.908
Interaction (SxZn)					
S.Em.±	0.895	0.472	5.673	1.933	6.17
C.D. at 5%	NS	1.363	16.384	5.582	17.816
CV %	2.92	2.83	8.81	4.14	5.55

Table 5a: Interaction effect on zinc mobilizing cultures and zinc levels on content and uptake of zinc in soybean

Treatment	Zn0: $ZnSO_4$ 0 kg ha^{-1}	Zn1: $ZnSO_4$ 10 kg ha^{-1}	Zn2: $ZnSO_4$ 20 kg ha^{-1}	Zn3: $ZnSO_4$ 30 kg ha^{-1}
Zn uptake in seed (g ha^{-1})				
S0: Control	81.11	89.97	100.52	105.96
S1: *Pseudomona striata*	87.40	115.67	157.74	179.44
S2: *Bacillus megaterium*	86.76	101.93	110.20	126.47
S3: *Trichoderma viride*	85.74	102.17	115.06	138.79
Interaction	SXZn			
SEm±	5.673			
CD at 5%	16.384			
Zn uptake in straw (g ha^{-1})				
S0: Control	63.08	68.51	70.64	74.77
S1: *Pseudomona striata*	73.58	90.00	95.54	99.28
S2: *Bacillus megaterium*	72.65	80.64	85.67	87.80
S3: *Trichoderma viride*	69.79	80.24	87.07	95.38

Interaction	SXZn			
SEm±	1.933			
CD at 5%	5.582			
Total Zn uptake (g ha^{-1})				
S0: Control	144.19	158.45	171.16	180.73
S1: *Pseudomona striata*	160.98	205.67	253.27	278.72
S2: *Bacillus megaterium*	159.41	182.56	195.87	214.27
S3: *Trichoderma viride*	155.53	182.41	202.13	234.18
Interaction	SXZn			
SEm±	6.17			
CD at 5%	17.816			

Table 6. Effect of zinc mobilizing cultures and zinc levels on protein content and protein yield of soybean

Treatment	Protein Content %	Protein yield (kg ha^{-1})
Zinc solubilizers (S)		
S0: Control	29.29	573.31
S1: *Pseudomona striata*	32.62	769.17
S2: *Bacillus megaterium*	32.24	647.70
S3: *Trichoderma viride*	32.57	665.58
S.Em.±	0.204	15.639
C.D. at 5%	0.589	45.162
Levels of $ZnSO_4$ (Zn)		
Zn0: $ZnSO_4$ 0 kg ha^{-1}	30.26	525.98
Zn1: $ZnSO_4$ 10 kg ha^{-1}	31.90	630.66
Zn2: $ZnSO_4$ 20 kg ha^{-1}	32.17	707.40
Zn3: $ZnSO_4$ 30 kg ha^{-1}	32.39	791.72
S.Em.±	0.204	15.639
C.D. at 5%	0.589	45.162
Interaction (SxZn)		
S.Em.±	0.408	31.278
C.D. at 5%	1.177	90.325
CV %	2.23	8.16

Table 6a: Interaction effect of zinc solubilizers and graded levels of zinc on protein content and protein yield of soybean

Treatment	Zn0: $ZnSO_4$ 0 kg ha^{-1}	Zn1: $ZnSO_4$ 10 kg ha^{-1}	Zn2: $ZnSO_4$ 20 kg ha^{-1}	Zn3: $ZnSO_4$ 30 kg ha^{-1}
Protein Content %				
S0: Control	25.79	30.53	30.28	30.55
S1: *Pseudomona striata*	31.47	32.29	33.11	33.61
S2: *Bacillus megaterium*	31.97	32.31	32.41	32.27
S3: *Trichoderma viride*	31.81	32.45	32.87	33.13
Interaction (SxZn)	S	Zn	SXZn	
SEm±	0.204	0.204	0.408	
CD at 5%	0.589	0.589	1.177	
Protein yield (kg ha^{-1})				
S0: Control	465.26	591.05	604.14	632.77
S1: *Pseudomona striata*	544.20	662.64	880.57	989.28
S2: *Bacillus megaterium*	550.98	631.44	661.70	746.70
S3: *Trichoderma viride*	543.50	637.50	683.19	798.15
Interaction (SxZn)	S	Zn	SXZn	
SEm±	15.639	15.639	31.278	
CD at 5%	45.162	45.162	90.325	

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