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Effect of zinc on uptake of micronutrients by soybean (*Glycine Max*. L.) in swell shrink soil

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Abstract
A pot culture experiment was conducted during kharif season of 2013-14 at Nagarjun Medicinal Plant Garden, Dr. P.D.K.V-Akola, to assess the effect of zinc on uptake of micronutrients on soybean in swell shrink soil. The experiment was laid out completely randomised design (CRD) with five treatments and two replications. The treatments comprised of varied level of soil application of zinc at 0.0, 1.5, 3.0, 4.5 and 6.0 kg ha^{-1} in different soil samples. The results of pot culture study revealed that application of zinc @ 4.5 kg ha^{-1} had significantly influenced and improve the dry matter yield and uptake of zinc, iron, manganese and copper by soybean.

Keywords: Pot culture, zinc, swell shrink soil, dry matter, uptake

Introduction
Soybean (*Glycine max*. (L.) Merill) belongs to family papilionaceae, a subfamily of leguminaceae. Being a leguminous crop, it helps in fixing atmospheric nitrogen in soil and improves soil fertility. Therefore, soybean is called as “Gold of soil”. In India, at present area under soybean crop is 106.94 lakh ha with the production of 126.77 lakh MT. The productivity of soybean in India is low as compared to other countries. The main reasons in the productivity decline are untimely sowing inadequate and imbalanced nutrient application and moisture stress at critical stages. Among these factors mineral nutrition plays an important role. The plants require essential nutrients *viz.*, primary, secondary and micro nutrients. Micronutrients have assumed a greater importance in a modern agriculture. Among the micronutrients, zinc deserves special attention. Zinc deficiency is likely to become more wide spread and intense. The Zn deficiencies are mainly attributed to unfavourable soil conditions, rather than total Zn reserves. With this background, a pot culture experiment was conducted to assess the effect of zinc on uptake of micronutrients on soybean in swell shrink soil with the test variety JS-335.

Material and Methods
Experimental soil
The soils were selected have wide variation in the available zinc content. The soil sample used for conducting the study was air dried, broken with wooden mallet and sieved through 2 mm sieve for pot culture experiment. Particle size distribution was determined by Bouycous hydrometer method as suggested by Gee and Bauder (1986) [5]. The pH and EC of soil sample were determined by using 1:2.5 soil water extract (Jackson, 1973) [8] and calcium carbonate content was determined by rapid titration with acid.

The organic carbon was estimated by chromic acid wet digestion (Walkley and Black, 1934), available N by alkaline permanganate method (Subbiah and Asija, 1956), available P by using 0.5 M $NaHCO_3$ (Olsen *et al*, 1954), available K by neutral normal NH_4OAC method (Stanford and English, 1949) followed by flame photometry and available micronutrients by DTPA extraction and AAS method (Lindsay and Norvell, 1978). These soil samples were categorized as low, medium and high in zinc content. The data pertaining to zinc content in plants, N, P, K were statistically analyzed as per Panse and Sukhatme (1967) using method of analysis of variance and means were tested at 5% level of significance separately for soils under low, medium and high zinc content and the data were interpreted.

Pot culture experiment
The pot culture experiment was conducted during kharif (rainy) season of 2013 -14 at Nagarjun Medicinal Plant Garden, Dr. Panjabrao Deshmukh Krishi Vidyapeeth. Akola is situated in subtropical zones at the latitude of 22^0 42’ North and longitude of 77^0 02’ East, at the altitude of 307.42 m above mean sea level (MSL). The fifteen different soil samples from

Central Research Station and farmer's field of nearly same group (Swell-shrink soils) were collected based on texture, $CaCO_3$ and DTPA-Zn and grouped as low (7), medium (5) and high (3).
There are 5 treatments in the pot culture experiment. The experiment was laid out in completely randomised design (CRD) with two replications and a net mud pots having capacity of 7kg were used. The treatments were as follows:

Treatments	Details
T_1	Control
T_2	Zn @ 1.5 kg ha^{-1}
T_3	Zn @ 3.0 kg ha^{-1}
T_4	Zn @ 4.5 kg ha^{-1}
T_5	Zn @ 6.0 kg ha^{-1}

The experimental soil samples of about 5 kg were thoroughly filled in pots irrespective of low (07), medium (05) and high (03) zinc content. A uniform dose of 30:75:30 kg N (as Urea), P_2O_5 (as Dihydrogen orthophosphate) and K_2O ha^{-1} (as Potassium Chloride), as per RDF of soybean and Zn (as Zinc oxide) were applied to pots as fertilizer solution as per the treatment schedule. Seeds (5 seeds per pot) of soybean of variety JS-335 were sown at equal distance at 2.0 cm depth and watering was done with deionized water immediately after sowing. The earthen pots were kept as per treatments in shade net under control condition. Irrigation was given as and when required, weeding was done and plant protection measures were taken up against pest and diseases.
The soybean plants were harvested at 45 days after sowing. The plants were uprooted carefully without disturbing the root. The plant sample along with the roots were washed first in deionized water and then in distilled water to remove the soil from the roots. The roots were removed by cutting and air dried in oven by putting them in paper bags at 64°C temperature till they showed constant weight. After completion of drying the dry matter weight of sample was recorded.
Total nitrogen, phosphorus and potassium from plant samples was estimated by using Micro-Kjeldahl's (Piper, 1966), Vandomolybdate yellow colour method using spectrophotometer from Diacid extract by Piper (1966) and flame photometrically from Diacid extract by Piper (1966) respectively. Uptake can calculated by taking micronutrient concentrations in plant samples and dry matter.

Result and Discussion

Initial characteristics of the experimental soil

The soil samples from fifteen different locations were analyzed and all the composition and parameters varied from location to location (Table.1). Mechanical composition of experimental soils indicated that sand content ranged from 4.16 to 44.44 per cent, silt from 12.56 to 60.56 per cent and clay from 30.00 to 55.68 per cent with textural class from clay loam to clay. The pH of the soils ranged from 7.20 to 8.82, electrical conductivity ranged from 0.13 to 0.29 dS m^{-1} and organic carbon content of the soils varied from 2.34 to 6.81 g kg^{-1}. The available nitrogen, phosphorus and potassium varied from 134.4 to 358.4 kg ha^{-1}, 12.7 to 25.1 kg ha^{-1} and 337.3 to 731.4 kg ha^{-1} respectively. The micro nutrient contents were as follows: Fe - 5.02-11.4 mg kg^{-1}, Cu-1.97 to 4.36 mg kg^{-1}, Mn-11.90 to 22.15mg kg^{-1} and the seven soils were in low in zinc (< 0.60 mg kg^{-1}), five in medium (0.60-1.80 mg kg^{-1}) and three in high zinc (>1.80 mg kg^{-1}). Thus, the soils selected for pot culture experiment were neutral to slightly alkaline in reaction, low to moderate in organic carbon, low in available nitrogen, low to moderately high in available phosphorus, high to very high in available potassium and low to high in DTPA-zinc, low to medium in Fe, medium to high in Mn and Cu.

Effect of zinc application on dry matter yield of soybean

The average dry matter yield of soybean was recorded highest in the soils (2.79 g $plant^{-1}$) containing high zinc and medium (2.79 g $plant^{-1}$) and followed by low (2.67 g $plant^{-1}$) zinc containing soil (Table 2).
The increasing level of zinc application significantly increased the dry matter yield of soybean up to 4.5kg Zn ha^{-1} in all the soils. The application of zinc @ 4.5kg Zn ha^{-1} (T_4) showed significant increase in dry matter yield of soybean (2.67 g $plant^{-1}$) in low containing soils over control (1.43 g $plant^{-1}$). The application of zinc @ 6.0 kg Zn ha^{-1} (T_5) (2.44 g $plant^{-1}$) decreased the dry matter yield of soybean. However, the treatments comprising application of zinc 6.0 kg Zn ha^{-1} (T_5) showed reduction in the dry matter yield. This could be attributed to the adverse effect of excess zinc in crop productivity.
In the medium zinc containing soils application of zinc @ 1.5 to 4.5 kg Zn ha^{-1} (T_4) also recorded significantly superior dry matter over control (T_1). The application of zinc @ 6.0kg Zn ha^{-1}(T_5) found at par in respect of dry matter yield with 4.5 kg Zn ha^{-1}. Similarly in the high status soils, the application of zinc @ 4.5 kg Zn ha^{-1}(T_4) showed significant increase in dry matter yield of soybean.
The result obtained in the present investigation are in accordance with the results reported by Jha and Chandel (1987) [9] who reported that the 49.2 per cent increase in dry matter yield of soybean over control due to 4 mg kg^{-1} zinc application. Similarly Ghildayal *et al.* (1978) [6] reported that application of zinc @ 2.50, 5.00 mg Zn kg^{-1} soil significantly increased the dry matter production of pea.
The result indicated that the application of higher levels of zinc (6.0 kg Zn ha^{-1}) did not show significant effect on the dry matter yield of soybean grown in soils with low, medium and high zinc content. Increase in 49.2 per cent dry matter production with application of 4 mg kg^{-1} zinc in soybean crop was reported by Jha and Chandel (1987) [9]. Similarly Ghildayal *et al.* (1978) [6] reported that application of zinc @ 2.50, 5.00 mg kg^{-1} Zn in soil significantly increased the dry matter production of pea (Kadam *et al.*, 2002) [11]. It could be also be noticed that the magnitude of dry matter yield increase was higher from low to medium zinc containing soils (21.9%) as compared to medium to high zinc containing soils (20%).

Effect of soil zinc on its concentration in soybean

The zinc content in soybean plant ranged from 20.26 to 21.22 mg kg^{-1}under low zinc containing soils, 23.90 to 25.48 mg kg^{-1} in medium zinc containing soils which in high zinc containing soils it varied from 24.99 to 26.45 mg kg^{-1} (Table. 3a).
The application of zinc application to soybean grown with varying levels of zinc were found significant in increasing the zinc concentration in soybean under low, medium and high zinc content soil. The application of zinc @ 4.5 kg Zn ha^{-1} soil recorded the highest zinc concentration in high (26.45 mg kg^{-1}) zinc content soils followed by medium (25.48 mg kg^{-1}) and low (21.22 mg kg^{-1}) zinc content soils. It was also noticed that, the concentration of zinc in soybean plant increased with soil application of zinc up to Zn @ 4.5 kg ha^{-1} and reduced afterwards.

The higher dose of zinc application to soybean under varying zinc content soils significantly increased the zinc concentration in soybean plants. The results found in present investigation are in accordance with results reported by Kumar and Singh (1979) [12], they reported that the application of zinc significantly increased the concentration of zinc. Brar and Sekhon (1980) [3] reported significant increase in zinc concentration in peanut with the application of 20 kg Zn ha^{-1}. Similarly, Kadam *et al.* (2002) [11] reported that the significantly increased the concentration of zinc in soybean plant with application 5 kg Zn ha^{-1}.

Effect of soil application of zinc on the concentration of iron in soybean

The iron content in soybean plant ranged from 248.2 to 251.8 mg kg^{-1} under low zinc containing soils, 247.8 to 250.1mg kg^{-1} in medium zinc containing soils which in high zinc containing soils it varied from 245.3 to 247.3 mg kg^{-1} (Table. 3a).

The application of zinc to soybean grown on varying zinc containing soils showed the significant effect on iron concentration in soybean. The iron concentration in soybean grown on low, medium zinc content soils were on par at Zn @ 3.0 kg ha^{-1} soil (250.5 and 249.0mg kg^{-1}) and Zn @ 4.5 kg ha^{-1} soil (251.8 and 250.1mg kg^{-1}). Whereas, 1.5, 3.0 and 4.5 kg ha^{-1} soil zinc application were on par in soybean grown on high zinc containing soils (246.2, 246.3 and 247.3 mg kg^{-1}) respectively.

The Zn application 4.5 kg ha^{-1} to low and medium zinc content soils and 3.0 kg ha^{-1} soil zinc application for high zinc content soils are useful for iron concentration in soybean.

The results have clearly indicated that an increase level of zinc application did not benefit the iron concentration in soybean grown on low medium and high zinc status soils. These results are in accordance with the observations reported by Sakal (1980) who observed that concentration of iron decrease with the increasing levels of zinc application, particularly at higher level. Similarly, Kadam *et al*. (2002) [11] reported that the increasing level of zinc application, concentration of iron decreased at higher level of zinc.

The decrease in concentration of iron in soybean can be attributed to soils having varied zinc contents. The zinc and iron has antagonistic effect which might have reflected in decreased iron concentration in soybean at higher level of zinc application.

Effect of soil zinc application on concentration of manganese in soybean

The manganese content in soybean plant ranged from 40.52 to 43.45 mg kg^{-1} under low zinc containing soils, 40.97 to 44.01 mg kg^{-1}in medium zinc containing soils which in high zinc containing soils it varied from 39.12 to 43.09 mg kg^{-1} (Table. 3b).

The data revealed that the concentration of manganese in soybean by different levels of zinc application grown on low, medium and high zinc contain soil were significant. The manganese concentration in soybean by application of zinc @ 4.5 and 6.0 kg ha^{-1} soil was found on par (43.45 and 42.46 mg kg^{-1}) in low zinc content soil. Similarly, in medium zinc containing soil the application of zinc @ 3.00, 4.5 and 6.00 kg ha^{-1} was on par (42.17, 44.01 and 43.33 mg kg^{-1}). In high zinc content soils 1.5, 3.0, and 4.5 kg ha^{-1} zinc application were at par (41.25, 43.09 and 42.55 mg kg^{-1}) for their manganese concentration in soybean plant.

The results clearly indicated that an increase in the levels of zinc application adversely affected the manganese concentration in soybean grown on low, medium and high zinc containing soils. The results are in accordance with observation of Gupta *et al*. (1987) [8].

The decrease in manganese concentration in plant might due to dilution effect resulting from marked increase in plant growth with zinc application. Similar results were recorded by Gupta *et al.* (1987) [8] they reported that Zn application of Zn @ 6.0 mg kg^{-1} slightly lowered the concentration of Mn in pigeon pea. Kadam *et al*. (2002) [11] reported that an increase in levels of zinc application adversely affected the manganese concentration in soybean plant.

Effect of soil zinc application on concentration of copper in soybean

The copper content in soybean plant ranged from 14.49 to 16.03 mg kg^{-1} under low zinc containing soils, 15.00 to 17.93 mg kg^{-1} in medium zinc containing soils which in high zinc containing soils it varied from 14.63 to 17.18 mg kg^{-1} (Table. 3b).

The concentration of copper in soybean was significant due to application of zinc to soybean grown on low, medium and high zinc status soils. However, the mean value for copper concentration in soybean was the highest in medium zinc (16.31 mg kg^{-1}) content soil and approximately similar in low (15.26 mg kg^{-1}) and high (15.86 mg kg^{-1}) zinc content soils. The average copper concentration in soybean due to different levels of zinc application grown in soils of varying zinc status ranged between 14.70 to 17.04 mg kg^{-1}. The highest concentration in soybean was observed due to 4.5 kg ha^{-1} soil zinc application in medium (17.93 mg kg^{-1}) and low (16.03 mg kg^{-1}) zinc containing soils. However, zinc application @ 4.5 kg ha^{-1}soil was found to increase copper concentration (17.18 mg kg^{-1}) in soybean grown on high zinc content soils. The application of Zn @ 4.5 kg ha^{-1} soil to medium and low zinc content soils and Zn @ 3.0 kg ha^{-1} soil to high zinc content soils seems to be beneficial for copper concentration in soybean. While, the higher zinc application significantly reduced the copper concentration of soybean in all the zinc containing soils. The results are in accordance with Brar and Sekhon (1978) [2] reported the synergistic effect of these nutrients at lower dose of zinc application in soybean. Kadam *et al.* (2002) [11] reported that higher zinc application to soybean crop decrease the copper concentration.

Effect of zinc application on uptake of zinc by soybean

The zinc uptake by soybean crop was recorded higher (0.067 mg plant^{-1}) in soils having high zinc content followed by medium (0.062 mg plant^{-1}) and low zinc status soils (0.043 mg plant^{-1}) (Table. 4a). The different levels of zinc application significantly increased the zinc uptake by soybean grown on soils with low, medium and high zinc status. The application of zinc @ 4.5 kg Zn ha^{-1} soil registered the significantly highest uptake of zinc over rest of levels of zinc but under medium zinc containing soils, the zinc application@ 4.5 kg ha^{-1} was found at par with Zn @ 6.0 kg ha^{-1}.

The varying level of zinc application significantly increased the zinc uptake by soybean grown on soils with low, medium and high zinc status. Similar, observations were also recorded by the Mishra and Singh (1996). Kadam *et al*. (2002) [11] reported that the significantly increasing the zinc uptake by soybean grown on Inceptisols with low medium and high zinc content varying levels of zinc application.

Effect of zinc application on uptake of iron by soybean

The data presented in Table. 4a revealed that the uptake of iron by soybean was increased significantly with the increasing level of zinc application to soybean grown on low, medium and high zinc content soils up to Zn @ 4.5 kg ha^{-1}. The magnitude of iron uptake by soybean due to different levels of zinc application grown on varying zinc content soils was in the order of high zinc content soils > medium zinc content soils > low zinc content soils. The increased of uptake of iron may be due to significant increase in dry matter yield of soybean at different levels of zinc. The application of Zn @ 4.5 kg ha^{-1} registered the maximum uptake of iron in low (0.67 mg plant^{-1}) and in medium zinc content soils (0.70 mg plant^{-1}). Which was on par with 6.0 kg ha^{-1} soil zinc application in low (0.61 mg plant^{-1}) and medium (0.68 mg plant^{-1}) zinc content soils. However, iron uptake by soybean grown on soils of high zinc status was maximum in 4.5 kg ha^{-1} soil zinc application (0.69 mg plant^{-1}).

The results showed that the uptake of soybean in Zn @ 4.5 kg ha^{-1} soil was increased in soils of low and medium zinc status. Whereas, the 4.5 kg ha^{-1} soil zinc application improved the iron uptake by soybean grown on high zinc content soils. Thus, synergistic effect between these two nutrient elements at lower level or at optimum levels was observed as also evidenced by many workers (Chavan and Banarjee, 1980; Sinha and Sakal, 1983) [4].

Effect of zinc application on uptake of manganese by soybean

The application of Zn @ 4.5 and 6.0 kg ha^{-1} soil zinc was at par for manganese uptake by soybean grown on low (0.116 mg plant^{-1}) and medium (0.123 mg plant^{-1}) zinc status soils respectively (Table. 4b). Whereas 4.5 kg ha^{-1} soil zinc application recorded the highest (0.120 mg plant^{-1}) Mn uptake and was at par with 6.0 kg ha^{-1} soil (0.30 mg plant^{-1}) and 3.0 kg ha^{-1} soil (0.123 mg plant^{-1}) zinc application. The average values for Mn uptake by soybean crop were 0.086, 0.106 and 0.105 mg plant^{-1} in low medium and high zinc status soil, respectively.

Thus, in the present investigation the increased the uptake of manganese by soybean at lower levels of zinc (4.5 kg Zn ha^{-1} soil in low, medium and high zinc content soils) was observed. The higher levels decreased the uptake of manganese by soybean. This might be due to the antagonistic effect of these two nutrients elements at higher levels of zinc application. Similar results were also recorded by Gupta *et al*. (1987) [8] to observed that uptake of manganese increased significantly as a result of 4.5 kg ha^{-1} zinc by 6.0 kgha^{-1} zinc depressed the manganese uptake. Rajgopal and Mehta (1971) also observed increased uptake of manganese in maize plant @ 5 mg kg^{-1} zinc.

Effect of zinc application on uptake of copper by soybean

The zinc application @ 4.5 and 6.0 kg ha^{-1} soil was at par for the uptake of copper by soybean grown on low (0.043 and 0.038 mg plant^{-1}) and medium (0.046 and 0.041 mg plant^{-1}) zinc status soils (Table. 4b). The soils having high Zn status recorded the highest copper uptake at 4.5 kg ha^{-1} soil zinc application (0.044 mg plant^{-1}). The result indicates that the soybean responded to zinc application at lower levels for copper uptake. This might be due to synergistic effect of zinc and copper at lower level of zinc application with copper. The result of the present study are in consonance with those reported earlier by Sahu *et al*. (1996) they observed maximum uptake of copper by rice at 4.5 kg Zn ha^{-1} soil application. Kadam *et al.* (2002) [11] reported that soybean crop responded to zinc application at lower level for copper uptake.

Conclusion

From the study, it was concluded that among varied levels of zinc (Zn @ 0.0, 1.5, 3.0, 4.5, 6.0 kg ha^{-1}), The dry matter yield was significantly higher at 4.5 kg Zn ha^{-1} zinc level on low (2.05 g plant^{-1}), medium (2.50 g plant^{-1}) and high (2.55 g plant^{-1}) zinc containing soils in comparison with lower levels of zinc. The application of zinc up to 4.5 kg Zn ha^{-1} was beneficial in increasing the dry matter, micronutrient concentrations in plant and uptake of zinc, iron, manganese and copper were found significantly.

Table 1: Physical and chemical properties of soils

S. No.	pH (1:2.5)	EC (dS m^{-1})	Organic carbon (g kg^{-1})	$CaCO_3$ (%)	Available nutrient (kg ha^{-1})			Available micronutrients (mg kg^{-1})				Particle size analysis (%)			Textural class
					N	P	K	Zn	Fe	Mn	Cu	Sand	Silt	Clay	
1	7.69	0.21	5.51	2.75	246.4	15.20	647.7	0.43	7.72	16.60	2.19	17.16	33.56	49.28	Clay
2	7.20	0.24	3.20	3.25	358.4	16.21	681.1	0.23	7.01	17.60	1.98	12.92	50.08	37.00	clay loam
3	7.36	0.29	2.34	4.25	224.0	14.50	337.3	0.39	10.6	20.15	2.16	34.40	28.60	37.00	Clay loam
4	7.86	0.23	2.81	5.25	156.8	18.50	343.5	0.40	9.77	18.11	1.97	39.68	30.32	30.00	Clay loam
5	8.82	0.20	3.32	4.25	246.4	16.70	513.3	0.51	11.4	15.90	2.06	44.44	12.56	43.00	Clay
6	7.81	0.18	3.21	5.75	291.2	20.90	525.6	0.57	6.27	21.13	3.19	7.72	49.28	43.00	Clay loam
7	7.77	0.14	2.43	2.50	268.8	19.50	554.5	0.46	5.02	20.03	2.48	9.44	60.56	30.00	clay loam
8	7.80	0.18	3.50	7.50	246.4	23.00	627.4	0.71	5.94	21.84	2.97	16.76	37.16	46.08	Clay
9	8.14	0.15	3.62	7.54	224.0	16.00	425.2	1.18	9.38	22.15	3.78	31.32	32.60	38.08	Clay loam
10	8.19	0.16	4.34	3.75	313.6	18.90	370.3	0.73	8.92	19.22	4.0	23.48	30.44	46.08	Clay
11	8.32	0.13	5.16	8.25	134.4	25.10	731.4	0.78	10.4	12.20	3.67	9.64	34.88	55.68	Clay
12	8.10	0.16	4.01	2.50	201.6	22.90	337.6	1.06	9.43	14.10	4.36	4.16	46.56	49.28	Clay loam
13	8.02	0.16	6.57	8.75	336.0	20.50	728.0	1.86	5.53	11.90	3.23	18.00	32.00	50.00	Clay
14	7.94	0.17	6.81	4.25	268.8	23.90	726.9	2.05	8.70	18.01	3.13	8.40	42.32	49.28	Silty clay
15	7.98	0.19	6.18	8.13	224.0	12.70	705.6	1.84	6.08	13.8	4.21	7.92	39.60	52.48	Clay

Table 2: Effect of zinc application on dry matter yield of soybean

Treatments	Dry matter yield (g plant^{-1})			
	Soil zinc status			
	Low	Medium	High	Mean
T_1 : Zn @ 0.0 kg ha^{-1}	1.43	2.07	2.31	1.94

T_2 : Zn @ 1.5 kg ha^{-1}	1.65	2.30	2.43	2.13
T_3 : Zn @ 3.0 kg ha^{-1}	2.07	2.59	2.50	2.39
T_4 : Zn @ 4.5 kg ha^{-1}	2.67	2.79	2.79	2.75
T_5 : Zn @ 6.0 kg ha^{-1}	2.44	2.74	2.69	2.82
Mean	2.05	2.50	2.55	
SE (m)±	0.06	0.05	0.03	
CD at 5%	0.17	0.16	0.09	

Table 3 (a): Effect of zinc application on micronutrients concentration in soybean

Treatments	Zinc concentration (mg kg^{-1})			Mean	Iron concentration (mg kg^{-1})			Mean
	Soil zinc status				Soil zinc status			
	Low	Medium	High		Low	Medium	High	
T_1 : Zn @ 0.0 kg ha^{-1}	20.26	23.90	24.99	23.05	248.2	247.8	245.3	247.1
T_2 : Zn @ 1.5 kg ha^{-1}	20.71	23.94	26.39	23.68	249.3	248.1	246.2	247.8
T_3 : Zn @ 3.0 kg ha^{-1}	20.90	24.64	26.59	24.04	250.5	249.0	246.3	248.6
T_4 : Zn @ 4.5 kg ha^{-1}	21.22	25.48	26.45	24.36	251.8	250.1	247.3	249.7
T_5 : Zn @ 6.0 kg ha^{-1}	21.15	25.17	26.18	24.19	250.4	248.3	246.5	248.4
Mean	21.25	24.63	26.12		250.0	248.6	246.3	
SE (m)±	0.10	0.19	0.06		2.46	0.66	0.64	
CD at 5%	0.29	0.58	0.17		7.30	1.97	1.89	

Table 3 (b): Effect of zinc application on micronutrients concentration in soybean

Treatments	Manganese concentration (mg kg^{-1})			Mean	Copper concentration (mg kg^{-1})			Mean
	Soil zinc status				Soil zinc status			
	Low	Medium	High		Low	Medium	High	
T_1 : Zn @ 0.0 kg ha^{-1}	40.52	40.97	39.12	40.20	14.49	15.00	14.63	14.70
T_2 : Zn @ 1.5 kg ha^{-1}	41.13	41.30	40.21	40.88	14.97	15.63	15.23	15.27
T_3 : Zn @ 3.0 kg ha^{-1}	42.08	42.17	41.25	41.84	15.29	16.22	16.05	15.85
T_4 : Zn @ 4.5 kg ha^{-1}	43.45	44.01	43.09	43.52	16.03	17.93	17.18	17.04
T_5 : Zn @ 6.0 kg ha^{-1}	42.46	43.33	42.55	42.78	15.51	16.80	16.20	16.17
Mean	41.93	42.35	41.25		15.26	16.31	15.86	
SE (m)±	0.84	0.27	1.53		2.23	1.63	0.57	
CD at 5%	2.50	0.79	4.56		6.62	4.84	1.69	

Table 4 (a): Effect of zinc application on micronutrients uptake by soybean

Treatments	Zinc uptake (mg plant^{-1})			Mean	Iron uptake (mg plant^{-1})			Mean
	Soil zinc status				Soil zinc status			
	Low	Medium	High		Low	Medium	High	
T_1 : Zn @ 0.0 kg ha^{-1}	0.029	0.050	0.058	0.045	0.36	0.51	0.57	0.48
T_2 : Zn @ 1.5 kg ha^{-1}	0.034	0.055	0.064	0.051	0.41	0.57	0.60	0.53
T_3 : Zn @ 3.0 kg ha^{-1}	0.043	0.064	0.066	0.058	0.52	0.64	0.62	0.59
T_4 : Zn @ 4.5 kg ha^{-1}	0.056	0.071	0.074	0.067	0.67	0.70	0.69	0.69
T_5 : Zn @ 6.0 kg ha^{-1}	0.052	0.069	0.070	0.064	0.61	0.68	0.66	0.65
Mean	0.043	0.062	0.067		0.51	0.62	0.63	
SE (m)±	0.0005	0.0005	0.0006		0.0072	0.0072	0.013	
CD at 5%	0.0014	0.0015	0.0017		0.021	0.021	0.039	

Table 4 (b): Effect of zinc application on micronutrients uptake by soybean

Treatments	Manganese uptake (mg plant^{-1})			Mean	Copper uptake (mg plant^{-1})			Mean
	Soil zinc status				Soil zinc status			
	Low	Medium	High		Low	Medium	High	
T_1 : Zn @ 0.0 kg ha^{-1}	0.058	0.085	0.090	0.078	0.021	0.031	0.034	0.029
T_2 : Zn @ 1.5 kg ha^{-1}	0.068	0.095	0.098	0.087	0.025	0.036	0.037	0.033
T_3 : Zn @ 3.0 kg ha^{-1}	0.087	0.109	0.103	0.100	0.032	0.042	0.040	0.038
T_4 : Zn @ 4.5 kg ha^{-1}	0.116	0.123	0.120	0.120	0.043	0.050	0.048	0.047
T_5 : Zn @ 6.0 kg ha^{-1}	0.104	0.119	0.114	0.112	0.038	0.046	0.044	0.042
Mean	0.086	0.106	0.105		0.032	0.041	0.041	
SE (m)±	0.00073	0.00086	0.0011		0.0007	0.0006	0.0009	
CD at 5%	0.0022	0.0026	0.0033		0.002	0.002	0.003	

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