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Effect of Zinc Application on Content and Uptake of Macronutrients by Soybean in a Vertisol of Central India

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ABSTRACT

The present study was conducted at the research Farm of Jawaharlal Nehru Krishi Vishwa Vidhyalaya, Jabalpur Madhya Pradesh (482004), India during July-November 2016.The soybean crop grown in vertisols in central India as an oil seed crop. Humans, animals, and plants all need zinc (Zn). The lack of Zn in Indian soil raises questions about how crops will be cultivated. Zn fertilizer is frequently applied on poor soils that are subjected to intensive cultivation. Still, not much is understood about the ideal Zn dosage. As a result, three frequency levels of Zn application were studied: Zn application in the first year alone, every year, and every other year, and five rates of Zn (0, 2.5, 5.0, 7.5, and 10.0 kg Zn ha^{-1}) were applied. The results showed that the contents of N and K in soybean seed and stover increased significantly as Zn levels increased, and the maximum contents were noted at 10 kg of Zn ha^{-1} application. However, it was on par with 7.5 kg of Zn ha^{-1}. Applying 5 kg of Zn ha^{-1} every other year greatly enhanced the uptake of N, P, K, and S by soybean crop. At 5.0 kg of Zn ha^{-1}, the soil had the highest levels of leftover N, P, and Zn. Thus, the best practice in a vertisol for improving macronutrient uptake by soybean and improving soil health.

Keywords: *Zinc fertilization, soybean, vertisol, macronutrient, content and uptake,fertility status*

1. Introduction

Soybean [*Glycine max* (L.) Merr.] one of the world's oldest and most valuable crop belongs to the Papilionaceae family, a subfamily of the Leguminaceae. It is a major oilseed crop due to its high production potential and covers approximately 30% of the world's demand for consumer vegetable oil. Although it is classified as an oilseed plant, from a botanical point of view, it is a legume, which makes its cultivation beneficial for the soil environment. Due to its symbiosis with the bacteria *Bradyrhizobium japonicum*, it fixes atmospheric N, enriching the soil with this component and reducing mineral N consumption. It is a leguminous crop that improves soil fertility and helps fix atmospheric N up to 200 kg ha^{-1} year^{-1} in the soil [6]. It is an essential source of nutrients, oil, and protein for both people and animals. It comprises 20% and 40% of oil and protein, respectively, worldwide [16]. The nutritional value of soybean is highly dependent on the presence of essential nutrients which plays a vital role in the quality of produce and deficiencies of these nutrients will drastically reduce their quality. With its demands being higher than current, there is a need for greater emphasis on these nutrient requirements of the plants for increasing the productivity of the crop.

The declined soil fertility is the main cause of the low productivity of the cultivated lands. So far, the emphasis has been to supplement the soil with the major nutrients *viz.*, N, P, K and the crop requirements for secondary and micronutrients could be met with soil reserve. Widespread nutrient deficits are the result of high-grade fertilizer use, restricted plant residue recycling, and the lag between nutrient removal and replacement. The usage of high-analysis fertilizers and ongoing crop removal has made the soil's sulfur shortage worse.

Zn is an essential micronutrient, a deficiency of which not only limits crop production but also affects nutritional quality and human health. It is a crucial element that plants need in trace levels for fertilization, reproductive development, and the activation of several enzymes. Auxin production is significantly influenced by it [12]. Lack of it impacts plant water uptake and transport and results in poor growth, production, and quality [13]; [21]. In India, the lives of more than one billion people rely on diets that lack sufficient Zn for adequate nutrition. It has been estimated that more than 50% of the Indian soils are Zn deficient. The large amounts of Zn are mined from native pools of soil. The harvest of 6.5 t grain ha^{-1} yr^{-1} removed 416 g Zn ha^{-1} yr^{-1} in soybean–wheat cropping systems [24]. In India, the major cause for increased Zn deficiency is the adoption of intensive cultivation, imbalanced nutrient application generally devoid of Zn and dispensing with organic manures, and the very nature of soils predominated with high pH, calcareous and low in organic matter content. It has been reported that a soybean crop yielding 2.5 t seed removes about 125 kg N, 23 kg P, 101 kg K, 22 kg S, 35 kg Ca, 19 kg Mg, 192 g Zn, 866 g Fe, 208 g Mn and 74 g Cu ha^{-1} from the soil [23]. Concerning fertilization, the main reasons for low soybean productivity are multi-nutrient deficiencies (such as those of N, P, S, Zn, Fe, and B), which result from farmers typically providing major crops with only N and P at amounts below recommended, and S deficiencies, which are caused by farmers preferring diammonium phosphate (DAP) as a source of P over single superphosphate (SSP). The relative uptake of N, P and K by indeterminate soybean under field conditions was studied in some research [14].

The crop soybean has a high requirement for N, a nutrient that is essential for the structure of proteins, amino acids, and chlorophylls.

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It also includes other nitrogen-containing substances like hormones and nucleic acids, which is why it is essential for plant metabolism and cell function. As 65 kg of N is exported to the seeds, about 80 kg of N is required to create 1.0 t of soybean seeds [25]. Consequently, roughly 480 to 640 kg N ha^{-1} is required to achieve yields between 6.0 and 8.0 t [5].
Soybean has a significant position as a crucial seed legume. Nutrient contents varied according to variety, environment, and farming methods. Determining the nutritional demand and applying nutrients more precisely requires an understanding of the nutrients' composition and uptake by soybean plants [3]. Zn deficiency is likely to become more widespread and intense which are mainly attributed to unfavorable soil conditions, rather than total Zn reserves. Fertilizers containing Zn have been widely accepted as prompt and convenient treatments to address Zn deficiency. Although several studies have been conducted on cereals. With this background, the experiment was conducted with aimed to improve the effectiveness of Zn application *via* soil in soybean.

2. Material and Methods

2.1 Location and treatment of experiment

A field experiment was conducted at the Research Farm of Jawaharlal Nehru Krishi Vishwa Vidhyalaya, Jabalpur Madhya Pradesh (482004), India during *kharif* season of 2016. The research site was situated at 23° 13′ North latitude and at 79° 57′ East longitudes in the South-East part of Madhya Pradesh at an elevation of 393 meters above mean sea level. The soil was *Typic Haplustert*, clayey in texture, having pH 7.67, EC 0.19 dSm^{-1}, organic carbon 0.61%, available N 230 kg ha^{-1}, available P 19 kg ha^{-1}, available K 270 kg ha^{-1}. Available S 13 (mg kg^{-1}) and DTPA extractable Zn 1.13 mg kg^{-1}.
The experiment consisted of frequencies of Zn application as the main treatment (single year application: Zn applied during *kharif* 2012; alternate year application: Zn applied during *kharif* 2012, 2014, and 2016 and each year application: Zn applied during *kharif* 2012, 2013, 2014, 2015 and 2016) and five levels of Zn (0, 2.5, 5, 7.5 and 10 kg ha^{-1} as sub treatments. Zinc sulphate was used as Zn source were applied to soybean. These fifteen treatments were randomly allocated in split plot design with three replications. The basal dose of 20 kg N, 80 kg P_2O_5 and 20 kg K_2O ha^{-1} was applied to soybean crop at the time of sowing. Soybean variety (JS-9752) was sown at 40 cm row to row distance at the rate of 100 kg seed ha^{-1}.

2.2 Chemical analysis of plant samples

One gram of seed/stover was taken in 100 ml conical flask and 15 ml diacid mixture of HNO_3 and perchloric acid (10:4) was added into each flask and the whole mass was digested on a hot plate to get white solution. The digestate was transferred in 50 ml volumetric flask and volume was made up to the mark with distilled water. The P content in plant extract was determined by the Vanado-molybdate phosphoric acid yellow colour method using blue filter [17].K content in the plant was determined using flame photometer as described by [4].S content was determined by turbidity metric method (based on measurements of turbidity of barium sulphate precipitate).
The N content in the plant was estimated by the micro Kjeldahl digestion and distillation method [1] using KEL PLUS (Pelican equipment's) system. Nutrient uptake by soybean was calculated in kg ha^{-1} in relation to yield ha^{-1} by using the following formula:
Nutrient uptake (kg ha^{-1}) = Nutrient content (%) X yield (kg ha^{-1}) /100
Nutrient uptake (g ha^{-1}) = Nutrient content (mg kg^{-1}) X yield (kg ha^{-1}) /1000

2.3 Soil analysis

The surface (0-15cm) soil samples were collected from the experimental site before the sowing of soybean crop. The soil samples were air-dried and crushed with wooden pestle and mortar and sieved through 2.0 mm sieve. The material passed through the sieve was used for the determination of various factors. The pH and EC of soil sample were determined by using 1:2.5 soil water extract [15]. The organic carbon was estimated by chromic acid wet digestion [34], available N by alkaline permanganate method [32] available P by using 0.5 M $NaHCO_3$[20], available K by neutral normal NH_4OAC method (Black, 1965) followed by flame photometry. The available sulphur was extracted by 0.15 percent $CaCl_2$ solution and the concentration of sulphur was determined by the turbidimetric method using spectrophotometer [7] and the soil available Zn was extracted by 0.005 M DTPA (Diethylene Triamine Penta Acetic Acid pH 7.3), 0.01 M $CaCl_2$ and 0.1 M tri ethanol amine (TEA) and determined by atomic absorption spectrophotometer [18].

2.4 Statistical analysis

The data pertaining to zinc content in plants, N, P, K were statistically analyzed as per [22] using the method of analysis of variance and means were tested at 5% level of significance and the data were interpreted.

3. Results and Discussion

3.1 Nitrogen content and uptake

The data (Tables 1 and 2) make it clear that applying Zn at varying intervals first year only, every year, or alternate year did not significantly increase the concentration of N content in seed and stover. The highest was seen (6.36 and 1.59% in seed and stover, respectively) with 10 kg of Zn ha^{-1} treatment, which was statistically equivalent to 5 and 7.5 kg of Zn ha^{-1} application. Nevertheless, it is increased significantly with higher amounts of Zn. The highest N uptake by soybean was calculated at the Zn application on alternate years (95.96 and 53.72 kg ha^{-1} by seed and stover, respectively). This was identical for Zn application on each year, but it was much higher than Zn application in single years.
Moreover, 5 kg Zn ha^{-1} application produced the maximum N uptake by seed and stover (97.02 and 51.57 kg ha^{-1}). When 2.5, 5.0, 7.5, and 10 kg of Zn ha^{-1} were applied compared to the control, the uptake of N increased significantly, although the results were statistically at par among themselves. The synthesis of protein, fat, and carbohydrates may have increased as a result of Zn application stimulating the enzymes proteinase, dehydrogenase, and peptidase [2]. According to [31], green gram with 5.0 kg Zn ha^{-1} showed a noteworthy increase in N content and absorption.

3.2 Phosphorus content and uptake

Based on the data shown in Tables 1 and 2, it was found that applying Zn at certain frequencies and levels resulted to a minor rise in P content in seed and stover, but not significantly. Among the various Zn levels, 5 kg Zn ha^{-1} recorded the highest P uptake (6.87 and 6.00 kg ha^{-1}), while control showed the lowest P uptake (5.29 and 5.02 kg ha^{-1}) by seed and stover uptake, respectively. However, the uptake of P (6.85 and 6.1 kg ha^{-1}) by seed and stover significantly increased with alternate year, which was on par with each year Zn application.

Additionally, the treatment of 2.5, 5.0, 7.5, and 10 kg Zn ha^{-1} resulted in significantly increased total and seed P uptake than the control, although these were comparable to each other. On the other hand, P uptake was lower at doses greater than 5 kg of Zn ha^{-1} treatment. Because $Zn_3(PO_4)_2$ molecules are inaccessible to plants, this decrease in P might have an antagonistic impact between Zn and P [30]. The authors[10] [19] and [35] revealed, in line with the current findings.

3.3 Potassium content and uptake

A perusal of the data in Tables 1 and 2 shows that the K content of seed and stover increased when Zn levels increased. Although these levels were comparable to each other, the maximum was found at 10 kg Zn ha^{-1}. Zn was applied alternatively, although at the same rate each year, which resulted in a considerable increase in K uptake by seed (32.91 kg ha^{-1}) and stover (72.95 kg ha^{-1}). Additionally, seed and stover K-uptake (33.24 and 71.68 kg ha^{-1}, respectively) was the highest at 5 kg Zn ha^{-1}. While no Zn showed the lowest K-uptake (25.91 and 54.89 kg ha^{-1}) by seed and stover, respectively. The advantageous function of Zn in raising the CEC of roots promoted increased nutrient uptake from the soil. Furthermore, the plants may have absorbed more nutrients from the soil due to zinc's favorable effects on chlorophyll production, regulation of auxin levels, and stimulation of most physiological and metabolic processes. As a result, beneficial effects of Zn on photosynthesis and metabolic processes enhanced the amount of photosynthates produced and their translocation to other plant components, including grain, which in turn raises the nutrient content in the stover and seed. The results agreed with the conclusions obtained by [11] and [28]. According to [9], chickpea showed a considerable increase in K content and uptake at 5 kg Zn ha^{-1}. This could be because of the mineral's increased availability in the soil, which would allow the crop to absorb more of it.

3.4 Sulphur content and uptake

The data clearly showed that applying varied Zn frequencies did not result in a significant rise in S content in seed and stover. Nevertheless, 10 kg Zn ha^{-1} produced the highest S content in seed and stover, a finding that was statistically insignificant. On the other hand, S uptake by seed and stover (4.98 and 5.86 kg ha^{-1}) increased significantly with Zn application in the alternate year, which was comparable to Zn application in each year. Data indicated that S uptake by seed and stover was considerably boosted by applying increasing quantities of zinc at 2.5, 5, 7.5, and 10 kg ha^{-1}. At 5 kg Zn ha^{-1}, S uptake was the highest (5.01 and 5.57 kg ha^{-1}) compared to no Zn application. Nevertheless, the effects of these treatments were comparable to one another. The results were consistent with the finding of [26].

3.5 Fertility status of soil after harvest of crop

The data on soil characteristics, *viz.,* soil reaction (pH), electrical conductivity (EC), organic carbon (OC), and available N, P, K, S, and Zn, as affected by the once, alternate, and every year application of Zn at 2.5, 5.0, 7.5, and 10 kg ha^{-1} presented in Table 3, which indicated that the frequencies of Zn application at 2.5, 5.0, 7.5, and 10 kg ha^{-1} have no effect on pH, EC, and OC content in soil over control. The treatment did not affect the pH, EC, and OC significantly. However, a slight change in the pH of EC and OC was recorded. The highest OC values were recorded with 10 kg Zn ha^{-1} (5.73 g kg^{-1}), while the lowest were under control (5.40 g kg^{-1}). This could be ascribed to the high buffering capacity of the soil. It appeared that no substantial changes occurred due to treatments. This increase in organic carbon content due to the use of fertilizers can be attributed to the higher contribution of biomass to the soil in the form of crop stubbles and residues.

The highest N content (227.92 kg ha^{-1}) was recorded under 5.0 kg Zn ha^{-1}. Further, the application of 10 and 7.5 kg Zn ha^{-1} recorded significantly higher available N content (227.71 and 224.73 kg N ha^{-1}) than that of the control (210.08 kg N ha^{-1}). The data on available P content in soil is found to be non-significant with the frequencies and levels of Zn application. However, each-year application of Zn was found to be non-significant over the single-year application. The data on available K after crop harvest indicated that the highest K content (266.49 kg ha^{-1}) was achieved with the application of 5.0 kg Zn ha^{-1}. However, it was similar to 7.5 and 10.0 kg Zn ha^{-1},but both and 5 kg Zn ha^{-1} applications were significant over 0 and 2.5 kg Zn ha^{-1} fertilization. Application of 2.5 kg of Zn ha^{-1} did not affect the K content significantly. However, a slight change in the K content was recorded. The data on available S content in soil is found to be non-significant with the frequencies and levels of Zn application. A similar finding was also reported by[33].

Zn content (1.20 mg kg^{-1}) was to be recorded with a once-year Zn application, which was increased with alternate and each-year applications up to 1.34 and 1.60 mg kg^{-1}, respectively. Each-year Zn application was found to be significantly superior to single- and alternate-year Zn applications. The increasing levels of Zn successively and significantly increased the available Zn content in the soil after the harvest of soybean. The lowest Zn content (1.14 mg kg^{-1}) was found at control, and the maximum (1.47 mg kg^{-1}) was observed at 10 kg Zn ha^{-1}. Similar findings on available Zn reported by [29] and [8]. [28] explained that the higher values might be due to the highest content of organic carbon as well as the finer fraction of soils, leading to an increase in the surface area for ion exchange and hence contributing to the higher amount of DTPA-Zn in soil.

4. Conclusion

Based on the conducted experiment, it was suggested that applying 5 kg Zn every other year would greatly improve soil health and increase the amount of nutrients N and K as well as the uptake of N, P, K, and S by soybean in a Vertisol in Jabalpur, Madhya Pradesh.

5. Acknowledgment

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6. Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest

Table 1 Effect of frequency and rate of zinc application on macronutrient contents in seed and stover of soybean

Treatment		N (%)		P (%)		K (%)		S (%)	
		Seed	Stover	Seed	Stover	Seed	Stover	Seed	Stover
Frequencies									
F1 (Single)		6.18	1.53	0.44	0.18	2.17	2.15	0.32	0.16
F2 (Alternate)		6.28	1.58	0.45	0.18	2.12	2.12	0.32	0.17
F3 (Each)		6.26	1.56	0.44	0.19	2.22	2.22	0.31	0.17
SEm±		**0.051**	**0.017**	**0.012**	**0.003**	**0.033**	**0.065**	**0.013**	**0.010**
CD(P=0.05)		**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Zn Levels (kg ha^{-1})									
0		5.99	1.52	0.43	0.18	2.08	2.02	0.31	0.15
2.5		6.22	1.53	0.44	0.19	2.13	2.17	0.32	0.17
5		6.30	1.57	0.44	0.18	2.15	2.17	0.32	0.16
7.5		6.32	1.58	0.46	0.19	2.17	2.24	0.31	0.17
10		6.36	1.59	0.45	0.17	2.27	2.25	0.31	0.17
SEm±		**0.041**	**0.017**	**0.011**	**0.004**	**0.035**	**0.039**	**0.010**	**0.008**
CD(P=0.05)		**0.118**	**0.050**	**NS**	**NS**	**0.100**	**0.111**	**NS**	**NS**
FXZn*	SEm±	0.071	0.030	0.020	0.007	0.060	0.067	0.017	0.015
	CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
FXZn**	SEm±	0.121	0.044	0.030	0.008	0.085	0.143	0.030	0.023
	CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

**Comparison of two Zn levels at the same frequency*
***Comparison of two frequencies at the same or different levels of Zn*

Table 2 Effect of frequency and rate of zinc application on nutrients uptake by soybean

Treatment	Nutrient uptake by soybean (kg ha^{-1})							
	N		P		K		S	
Frequencies	**Seed**	**Stover**	**Seed**	**Stover**	**Seed**	**Stover**	**Seed**	**Stover**
F1 (Single)	79.18	43.47	5.66	5.09	27.9	60.97	4.15	4.54
F2 (Alternate)	95.96	53.72	6.85	6.1	32.91	72.95	4.98	5.86
F3 (Each)	93.05	46.82	6.56	5.54	32.41	65.76	4.6	4.92
SEm±	**2.22**	**1.84**	**0.265**	**0.247**	**1.207**	**3.54**	**0.207**	**0.277**
CD(P=0.05)	**8.727**	**7.235**	**1.041**	**0.972**	**4.745**	**10.8**	**0.704**	**1.088**
Zn Levels (kg ha^{-1})								
0	74.41	41.44	5.29	5.02	25.91	54.89	3.89	4.17
2.5	89.36	49.08	6.29	**5.73**	31.24	68.91	4.56	5.28
5	**97.02**	**51.57**	**6.87**	6.00	33.24	71.68	5.01	5.57
7.5	93.4	47.17	6.83	5.57	31.9	66.73	4.61	5.21
10	92.78	50.75	6.49	5.56	33.06	70.57	4.56	5.37
SEm±	**2.512**	**2.164**	**0.308**	**0.282**	**1.056**	**3.267**	**0.186**	**0.37**
CD(P=0.05)	**7.176**	**6.182**	**0.88**	**0.806**	**3.018**	**9.332**	**0.532**	**1.058**
FXZn*SEm±	4.351	3.748	0.534	0.489	1.83	5.658	0.322	0.642
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
FXZn**SEm±	5.904	4.978	0.713	0.66	2.916	9.388	0.504	0.797
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

**Comparison of two Zn levels at the same frequency*
***Comparison of two frequencies at the same or different levels of Zn*

Table 3 Effect of frequency and rate of zinc application on fertility status of soil after harvest of soybean

Treatment	Physic-chemical properties			Avail. nutrients (kg ha^{-1})			S (mg kg^{-1})	DTPA Zn (mg kg^{-1}) after harvest
	pH	EC (dS m^{-1})	OC (g kg^{-1})	N	P	K		
Frequencies								
F1 (Single)	7.68	0.19	5.58	219.56	17.38	263.68	11.63	1.2
F2 (Alternate)	7.66	0.18	5.42	222.64	18.2	266.07	12.03	1.34
F3 (Each)	7.68	0.17	5.63	218.83	18.32	265.91	12.31	1.6
SEm±	**0.042**	**0.007**	**0.048**	**2.456**	**0.217**	**0.808**	**0.192**	**0.033**
CD(P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.128**
Zn Levels (kg ha^{-1})								
0	7.58	0.18	5.4	210.08	17.72	262.82	11.67	1.14
2.5	7.68	0.17	5.34	221.26	17.77	263.71	12.09	1.39
5	7.72	0.16	5.53	227.92	17.88	268.23	12.05	1.43
7.5	7.72	0.19	5.66	224.73	18.47	267.86	11.77	1.46
10	7.65	0.19	5.79	217.71	18	266.49	12.35	1.47
SEm±	**0.036**	**0.009**	**0.121**	**3.573**	**0.242**	**1.127**	**0.249**	**0.049**
CD(P=0.05)	**NS**	**NS**	**NS**	**10.206**	**NS**	**3.219**	**NS**	**0.141**
FXZn*SEm±	0.062	0.016	0.21	6.188	0.419	1.952	0.431	0.085
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
FXZn**SEm±	0.101	0.02	0.211	7.4	0.574	2.379	0.544	0.1
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Initial	**7.67**	**0.19**	**6.1**	**230.26**	**19.12**	**270.3**	**13.24**	**1.13**

**Comparison of two Zn levels at the same frequency*
***Comparison of two frequencies at the same or different levels of Zn*

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