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Effect of Zinc Sources and Levels on Nutrient Uptake and Yield of Sunflower (*Helianthus annuus* L.) Hybrid in Alfisols

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Abstract An experiment was conducted with sunflower (*Helianthus annuus* L.) on Alfisols with three sources and ($ZnSO_4.H_2O$, $ZnSO_4.7H_2O$ and Zn-EDTA) and levels (10, 15 and 20 kg ha^{-1}) of zinc (Zn) to study the effect of Zn sources and levels on nutrient uptake and yield of sunflower hybrid DRSH-1 crop on Alfisols during year *kharif* 2014. The different doses (10, 15 and 20 kg ha^{-1}) of Zn were applied singly with recommended dose of fertilizer. Results indicated that application of 20 kg $ZnSO_4.H_2O$ ha^{-1} with 90:60:30 kg NPK ha^{-1} recorded higher seed yield and shoot yield. Total uptake of N, K, S and Zn was recorded significantly highest in the same treatment at 60 DAS, 90 DAS of shoot and seed.

Keywords Zinc, Nutrient uptake, Sunflower, Yield, Alfisols.

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Introduction

Oilseeds play an important role in the agricultural economy of India. Next to food grains oilseeds are important in area, production and value [1]. Apart from that they fulfill the energy requirements. The shortage of edible oils has become a problem in India with ever increasing demographic pressure. During 2013-14, the country imported about 11.0 M t of vegetable oils.

Sunflower (*Helianthus annuus* L.) is one of the important oilseed crops of India occupying a prominent place in the country's vegetable oil scenario. Among oilseed crops, sunflower has gained much popularity because of its short duration, photo-insensitivity, wider adaptability to different agro-climatic regions and soil types. In addition to higher seed multiplication ratio, its good quality oil containing more of unsaturated fatty acids and anti-cholesterol property, tolerance to drought and production of more oil per unit area and unit time than any other oilseed crops make it a potential oilseed crop especially under rainfed conditions. The seed quality in hybrid sunflower is greatly influenced by crop nutrition. Among the nutrients sulfur (S) and zinc (Zn) are consider important for sunflower to obtain increased growth, seed yield and better quality. Zinc deficiency severely affects growth and yield of oilseed crop. Zinc plays a vital role in growth and development of plant. Zinc is required for nitrogen metabolism, photosynthesis and participates in many other metabolic activities of plant life. Zinc controls the auxin content and regulators reproduction process in plants.

Sunflower is mainly grown in marginal and submarginal soils having low soil fertility under rainfed conditions. Zn deficiency is common in semi-arid soils where the farmers practice sunflower cultivation [2, 3]. Low solubility of Zn in soils rather than low total amount of Zn is the major reason for the widespread occurrence of Zn deficiency problem in crop plants. In the present study, influence of different sources and levels of Zn on nutrient uptake and seed yield of popular sunflower hybrid DRSH-1 was attempted.

Table 1. Dry matter and seed yield of sunflower hybrid DRSH-1.

Treatments	Dry matter yield (kg ha^{-1}) 60 DAS	90 DAS	Seed yield (kg ha^{-1})
T_1 Control (RDF-90-60-30 kg ha^{-1})	1474.0	1122	1122
T_2 RDF+$ZnSO_4.7H_2O$ @ 10 kg ha^{-1}	1589.5	1319	1319
T_3 RDF+$ZnSO_4.7H_2O$ @ 15 kg ha^{-1}	1634.1	1365	1365
T_4 RDF+$ZnSO_4$. $7H_2O$ @ 20 kg ha^{-1}	1728.7	1377	1377
T_5 RDF+$ZnSO_4$. H_2O @ 10 kg ha^{-1}	1569.5	1395	1395
T_6 RDF+$ZnSO_4$. H_2O @ 15 kg ha^{-1}	1782.0	1453	1453
T_7 RDF+$ZnSO_4$. H_2O @ 20 kg ha^{-1}	1868.0	1680	1680
T_8 RDF+Zn-EDTA @ 10 kg ha^{-1}	1521.3	1168	1168
T_9 RDF+Zn-EDTA @ 15 kg ha^{-1}	1540.0	1236	1236
T_{10} RDF+Zn-EDTA @ 20 kg ha^{-1}	1546.4	1283	1283
SEm ±	77.6	159.2	71.9
CD (p=0.05)	232.4	476.6	215.2

Materials and Methods

The experiment was carried out at Indian Institute of Oilseed Research, Rajendranagar and Hyderabad during *kharif*, 2014. The soil of the experimental site was sandy loam in texture, moderately alkaline with pH 8.3, E.C 0.082 dS m^{-1}, very low in Organic Carbon (0.26%), low in available N (150.68 kg ha^{-1}), very low in available P (9.56 kg ha^{-1}), medium in available K_2O (193.9 kg ha^{-1}), medium in sulfur (25.22 kg ha^{-1}) and deficient in DTPA extractable Zn (0.48 mg kg^{-1}). N, P and K were applied @ 90-60-30 kg ha^{-1} each in the form of urea, diammonium phosphate and muriate of potash, respectively. The experiment was laid out in randomized block design with three levels (10, 15 and 20 kg ha^{-1}) and three sources of Zn ($ZnSO_4.7H_2O$, $ZnSO_4.H_2O$ and Zn-EDTA) with ten treatments viz. T_1 (control), T_2 [RDF+$ZnSO_4.7H_2O$ (21% Zn) @ 10 kg ha^{-1}], T_3 (RDF+$ZnSO_4.7H_2O$ @ 15 kg ha^{-1}), T_4 (RDF+$ZnSO_4.7H_2O$ @ 20 kg ha^{-1}), T_5 [RDF + $ZnSO_4.H_2O$ (33% Zn) @ 10 kg ha^{-1}], T_6 (RDF+ $ZnSO_4.H_2O$ @ 15 kg ha^{-1}), T_7 (RDF+ $ZnSO_4.H_2O$ @ 20 kg ha^{-1}), T_8 [RDF+Zn-EDTA (12% Zn) @ 10 kg ha^{-1}], T_9 (RDF+Zn-EDTA @ 15 kg ha^{-1}) and T_{10} (RDF+Zn-EDTA @ 20 kg ha^{-1}) each replicated thrice during *kharif* season. Zinc levels and sources were applied as soil application.

Dry matter

Dry matter accumulation was recorded at 60 and 90 DAS by collecting five plants from each plot which were cut form the base at each stage and separated into leaf + stem and head. This is taken as shoot portion. They were shade dried and later oven dried at 65°C till constant weight was obtained. The oven dried weight of leaf; stem and head were recorded separately. The crop was harvested at physiological maturity when the outer bracts of the flower heads turned to brown, back of the heads turned to lemon yellow and when the seeds were easily detachable. The seed yield per plot was recorded after drying the produce and worked out on hectare basis. Seed sample was drawn from each net plot produce, for nutrient analy-

Table 2. Nitrogen, phosphorus, potassium, sulfur and zinc uptake by sunflower (hybrid DRSH-1) shoot.

		Nutrient uptake by shoot									
		N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})		S (kg ha^{-1})		Zn (kg ha^{-1})	
	Treatments	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS
T_1	Control (RDF-90-60-30 kg ha^{-1})	28.4	19.0	2.50	1.90	43.2	42.0	5.0	4.9	35.1	31.9
T_2	RDF+$ZnSO_4.7H_2O$ @ 10 kg ha^{-1}	32.73	31.1	4.31	4.33	50.2	68.8	6.4	7.4	71.9	63.9
T_3	RDF+$ZnSO_4.7H_2O$ @ 15 kg ha^{-1}	36.67	36.4	4.19	3.91	54.2	80.7	7.0	8.7	78.0	68.9
T_4	RDF+$ZnSO_4.7H_2O$ @ 20 kg ha^{-1}	44.44	50.1	3.58	3.72	64.0	115.6	7.6	11.0	98.6	85.8
T_5	RDF+$ZnSO_4.\ H_2O$ @ 10 kg ha^{-1}	35.18	31.6	4.75	4.49	49.6	74.8	7.2	7.5	68.8	61.8
T_6	RDF+$ZnSO_4.\ H_2O$ @ 15 kg ha^{-1}	47.16	57.1	4.63	4.42	59.5	121.9	8.7	12.0	114.3	100.0
T_7	RDF+$ZnSO_4.\ H_2O$ @ 20 kg ha^{-1}	51.22	65.4	4.57	4.14	70.4	142.0	9.9	12.5	120.7	105.0
T_8	RDF+ Zn-EDTA @ 10 kg ha^{-1}	33.09	26.0	4.37	2.99	47.5	63.4	5.5	6.3	49.5	45.0
T_9	RDF+ Zn-EDTA @ 15 kg ha^{-1}	33.86	34.5	3.78	2.89	54.0	61.3	5.7	7.8	56.8	51.3
T_{10}	RDF+ Zn-EDTA @ 20 kg ha^{-1}	36.25	35.3	3.73	2.64	56.4	76.6	5.8	7.9	66.4	56.9
	SEm ±	2.58	1.9	0.25	0.29	3.4	4.2	0.3	0.5	4.5	4.04
	CD (p=0.05)	7.73	5.7	0.75	0.87	10.3	12.7	1.0	1.6	13.5	12.1

sis. Standard analytical procedures were followed to analyze the nutrient concentration in the sunflower shoot and seed.

Nutrient uptake

Uptake of nitrogen (N), phosphorus (P), potassium (K), sulfur (S) and zinc (Zn) by sunflower shoot and seed from each treatment plot was worked out by multiplying the nutrient concentration with corresponding dry matter yield and expressed in kg ha^{-1} in case of N, P, K, S and for Zn g ha^{-1}.

Results and Discussion

Shoot yield

The highest shoot yield was noticed at T_7 (3541 kg ha^{-1}) followed by T_6 (3499.4 kg ha^{-1}) (Table 1). The Zn-EDTA treatments at 10, 15, 20 kg ha^{-1} 2394.4, 2423.5, 2471.8 kg ha^{-1} (T_8, T_9, T_{10}) and zinc sulfate monohydrate @ 10 kg ha^{-1} (T_5) does not shown any significant increase in shoot yield as compared to control. However, at higher levels with zinc sulfate monohydrate i.e. 15 and 20 kg ha^{-1} application significant increase in shoot yield was recorded. The results thus suggest that application of either 20 kg or 15 kg Zn ha^{-1} in the form of zinc sulfate monohydrate sources (Zn 33% and S 15%) achieved maximum dry matter production.

Plant dry matter production is a result of growth and environment interaction through leaves, stems, roots and reproductive parts that contribute to dry matter. Among the different sources and levels highest dry matter was produced with the application of zinc sulfate monohydrate as in T_7 at 60 DAS and 90 DAS (shoot yield) when compared to zinc sulfate heptahydrate, Zn-EDTA and lowest dry matter was recorded in control.

The significant effect of Zn on the growth of sunflower, in terms of dry matter production per plant can be attributed to enhanced metabolic function of micronutrients in the plant [4]. Positive effects of micronutrients on crops for such increases in dry weight due to addition of Zn. Further, the increase in dry matter might be due to enhancement of enzymatic activity by Zn application which probably might have stimulated the translocation of assimilates from roots to vegetative and reproductive plant parts as reflected in increased dry matter yield [5].

Seed yield

The results revealed that there was significant increase in seed yield of sunflower with increasing levels of Zn (Table 1). Among various sources, RDF $+ZnSO_4.H_2O$ @ 20 kg ha^{-1} recorded significantly highest seed yield as compared to control. Seed yield was lowest at control (1,122 kg ha^{-1}) and highest at T_7 (1,680 kg ha^{-1}) which received $ZnSO_4.H_2O$ @ 20 kg ha^{-1} along with recommended dose of N, P, K in sunflower. On an average, the percent increase in seed yield was 49% in the treatment T_7 over the control T_1. Seed yield is the function of several growth parameters (plant height, leaf area index and dry matter accumulation) yield attributing characters viz., head diameter, number of filled seeds, test weight and yield plant^{-1}. Among different levels and sources (namely $ZnSO_4.H_2O$, $ZnSO_4.7H_2O$ and Zn-EDTA), the $ZnSO_4.H_2O$ @ 20 kg ha^{-1} has shown better influence on seed yield.

Greater head diameter, higher number of filled seeds head^{-1} and test weight due to adequate supply of recommended dose of fertilizers along with Zn application had positively reflected in higher seed yield. Head diameter is the most important attributing character, which improves the seed yield by providing maximum number of florets for higher seed set. The cumulative effect of all these growth and yield components were reflected on seed yield. Mirzapour and Khoshgoftar [6] found increase in seed yield of sunflower with the application of 10 and 20 kg ha^{-1} Zn. Zinc deficiency known to reduce net photosynthesis, internodal length of stem, increasing chlorosis and necrotic spots in the leaves and severely reduce seed yield [7].

It was revealed that Zn-treated plants exhibited a significant increase in yield components compared to control. It is evident that this element plays important role in plants. The increase in yield induced by Zn treatments will markedly affect plant growth and development. The increased in yield attributes and yield of sunflower due to Zn may be attributed basically to the reason that Zn shows beneficial effect on chlorophyll content and so it indirectly affect the photosynthesis and reproduction.

A significant increase in seed and shoot yield of mustard up to 5.0 kg Zn ha^{-1} application was reported the increase in yield might be due to role of Zn in biosynthesis of indole acetic acid and especially due to its role in initiation of primordia for reproductive parts and partitioning of photosynthates towards them, which resulted in better flowering and fruiting. Earlier researches support the findings of present investigation. In the present study, higher seed yield recorded in $ZnSO_4$. H_2O could be due to the better utilization of bioavailable Zn from this source compared to the other source.

N uptake

At 60 DAS, the results indicated significant differences among the different sources and levels of Zn (Table 2). The highest N uptake (51. 22 kg ha^{-1}) of shoot was recorded under the treatment T_7 (RDF + $ZnSO_4.H_2O$ @ 20 kg ha^{-1}) which were on par with treatment T_4 (RDF+$ZnSO_4$. $7H_2O$ @ 20 kg ha^{-1}) and T_6 (RDF+$ZnSO_4$. H_2O @ 15 kg ha^{-1}) and lowest (28. 4 kg ha^{-1}) was recorded under T_1 (control). On an average, the percentage increase in N uptake by shoot was 80% in the treatment (T_7) over control (T_1).

At 90 DAS, the results indicated significant differences among the different sources and levels of Zn in shoot. The highest N uptake (65. 4 kg ha^{-1}) was recorded under the treatment T_7 (RDF + $ZnSO_4.H_2O$ @ 20 kg ha^{-1}) which were at par with treatment T_4 (RDF + $ZnSO_4.7H_2O$ @ 20 kg ha^{-1}) and T_6 (RDF + $ZnSO_4$. H_2O @ 15 kg ha^{-1}) and lowest (19.0 kg ha^{-1}) was recorded under T_1 (control). At harvest, application of Zn (RDF+$ZnSO_4.H_2O$ @ 20 kg ha^{-1}) resulted higher N uptake (50.4 kg ha^{-1}) in seed and the lowest N uptake (27.2 kg ha^{-1}) at control (Table 2).

Synergistic N uptake by shoot and seed could be attributed to the synergistic effect of Zn with N. Similar trend was noticed in N uptake of shoot at 90 DAS. There was an increase in uptake of N in shoot and seed with increased levels of Zn the bioavailability of Zn from $ZnSO_4$. H_2O and the crop may be easily available compared to the other sources.

The results obtained in the present study are in agreement with those of earlier findings [4]. Significant effect of Zn and boron (B) micronutrients on the plant nutrient uptake were observed by them. The soil incorporation of 15 kg Zn ha^{-1} and 1.5 kg B ha^{-1} or higher doses recorded maximum N uptake (52.25 kg

Table 3. Nitrogen, phosphorus, potassium, sulfur and zinc nutrient uptake by sunflower (hybrid DRSH-1) seed.

	Treatments	Nutrient uptake by seed N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	S (kg ha^{-1})	Zn (kg ha^{-1})
T_1	Control (RDF - 90-60-30 kg ha^{-1})	27.21	3.45	9.6	1.5	39.5
T_2	RDF + $ZnSO_4.7H_2O$ @ 10 kg ha^{-1}	34.94	7.03	11.8	2.1	67.4
T_3	RDF + $ZnSO_4.7H_2O$ @ 15 kg ha^{-1}	39.06	6.56	12.2	2.3	71.4
T_4	RDF + $ZnSO_4.7H_2O$ @ 20 kg ha^{-1}	39.41	6.02	12.5	2.4	76.9
T_5	RDF + $ZnSO_4.H_2O$ @ 10 kg ha^{-1}	40.53	7.25	12.4	2.6	80.7
T_6	RDF + $ZnSO_4.H_2O$ @ 15 kg ha^{-1}	41.24	5.90	13.5	2.8	88.8
T_7	RDF + $ZnSO_4.H_2O$ @ 20 kg ha^{-1}	50.4	5.50	17.6	3.6	104.3
T_8	RDF + Zn-EDTA @ 10 kg ha^{-1}	29.37	5.26	10.3	1.6	51.6
T_9	RDF + Zn-EDTA @ 15 kg ha^{-1}	33.01	4.70	10.6	1.8	58.9
T_{10}	RDF + Zn-EDTA @ 20 kg ha^{-1}	35.94	3.91	11.4	2.0	64.1
	SEm ±	1.4	0.244	0.3	0.2	2.27
	CD (p = 0.05)	4.2	0.73	1.0	0.5	6.8

ha^{-1}) in sunflower.

P uptake

Data pertaining to P uptake of shoot at 60 DAS and 90 DAS as influenced by different sources and levels of Zn are presented in Table 2.

The results indicated significant differences among the different sources and levels of Zn in shoot at 60 DAS. The highest P uptake (4.75 kg ha^{-1}) was recorded in the treatment T_5 (RDF + $ZnSO_4$. H_2O @ 10 kg ha^{-1}) which was on par with treatment (T_2, T_3, T_5, T_6, T_7, T_8) and lowest (2.5 kg ha^{-1}) was recorded in T_1 (control). On an average the percentage increase in P uptake was 90% in the treatment (T_5) over control.

The results indicated significant differences among the different sources and levels of Zn at 90 DAS. The highest P uptake (4.49 kg ha^{-1}) was recorded in the treatment T_5 (RDF + $ZnSO_4.H_2O$ @ 10 kg ha^{-1}) which were on par with treatment (T_2, T_3, T_4, T_5, T_6, T_7) and lowest (1.9 kg ha^{-1}) was recorded under T_1 (control). At harvest, application of Zn (RDF +$ZnSO_4.H_2O$ @ 10 kg ha^{-1}) resulted higher P uptake (7.25 kg ha^{-1}) in seed and the lowest (3.45 kg ha^{-1}) was recorded in control (Table 3).

Phosphorus uptake by sunflower decreased significantly with the application of 10 kg Zn ha^{-1} over their lowest doses. The decrease in P uptake with higher dose of Zn might be due to antagonistic effect between P and Zn. From the table it could be observed that the P uptake in 60 and 90 DAS stages of crop (shoot and seed) decreased with increasing levels of Zn application, irrespective of sources.

These results are in agreement with earlier findings in which [4] significant effect of Zn and B micronutrients on the sunflower nutrient uptake was observed. The soil incorporation of 15 kg Zn ha^{-1} and 1.5 kg B ha^{-1} or higher doses recorded maximum P uptake (16.72 kg ha^{-1}) in sunflower.

K uptake

At 60 DAS, the results indicated significant differences in shoot uptake among the different sources and levels of Zn applied (Table 2). The highest K uptake (70.4 kg ha^{-1}) was recorded under the treatment T_7 (RDF + $ZnSO_4$. H_2O @ 20 kg ha^{-1}) which were on par with treatment T_4 (RDF + $ZnSO_4$. $7H_2O$ @ 20 kg ha^{-1}) and lowest (28.4 kg ha^{-1}) was recorded under T_1 (control). On an average the percentage increase in K uptake was 147% in the treatment (T_7) over control treatment (T_1).

At 90 DAS, the results indicated significant differences among the different sources and levels of Zn. The highest K uptake of shoot (142.0 kg ha^{-1}) was recorded under the treatment T_7 (RDF + $ZnSO_4.H_2O$

@ 15 kg ha^{-1}) and lowest (19.0 kg ha^{-1}) was recorded under T_1.

At harvest, application of Zn (RDF + $ZnSO_4.H_2O$ @ 20 kg ha^{-1}) resulted significantly higher K uptake (17.6 kg ha^{-1}) in seed and the lower uptake (9.6 kg ha^{-1}) was recorded in control (Table 3). These results are in agreement with earlier finding [4]. Significant effect of Zn and B micronutrients on the K uptake was reported by them. The soil incorporation of 15 kg Zn ha^{-1} and 1.5 kg B ha^{-1} or higher doses recorded maximum K uptake (78.94 kg ha^{-1}) and Zn uptake (294.60 g ha^{-1}) in sunflower.

Jat and Mehra [8] showed that the magnitude of significant increase in K uptake of mustard from 5.0 kg Zn ha^{-1} was 24.0 and 9.1% and 24.7 and 10.2% in seed and 22.1, 7.8, 22.5% and 8.9% in shoot over control and 2.5 kg Zn ha^{-1} application in 2001-02 and 2002-03, respectively.

Singh et al. [9] showed that total nutrient uptake (N, P and K) was significantly affected by the Zn application. On pooled basis, total uptake of K increased with the application of 6.0 kg Zn ha^{-1} to the tune of 52 and 15%, 43 and 12% and 54 and 15%, respectively over control and 3.0 kg Zn ha^{-1}. The response of mustard crop to applied Zn in present study may be attributed to the increase in cation exchange capacity of roots associated with improved Zn sulfate application. Further, the beneficial role of Zn might have accrued from chlorophyll formation, regulation of auxin concentration and stimulatory effect on most of physiological and metabolic processes. This might have helped the plants in increased absorption of nutrients from soil.

S uptake

At 60 DAS, the results indicated significant differences in shoot S uptake among the different sources and levels of Zn (Table 2). The highest S uptake (9.9 kg ha^{-1}) was recorded under the treatment T_7 (RDF + $ZnSO_4$. H_2O @ 20 kg ha^{-1}) and lowest (5 kg ha^{-1}) was recorded under T_1 (control). On an average the percentage increase in S uptake was 98% in the treatment (T_7) over control (T_1).

At 90 DAS, the results indicated significant differences among the different sources and levels of Zn in shoot S uptake. The highest S uptake (12.5 kg ha^{-1}) was recorded in the treatment T_7 (RDF + $ZnSO_4.H_2O$ @ 20 kg ha^{-1}) which were on par with treatment T_4 (RDF + $ZnSO_4$. $7H_2O$ @ 20 kg ha^{-1}) and T_6 (RDF + $ZnSO_4$. H_2O @ 15 kg ha^{-1}) and lowest (4.9 kg ha^{-1}) was recorded in control.

At harvest, application of Zn (RDF + $ZnSO_4.H_2O$ @ 20 kg ha^{-1}) resulted significantly higher S uptake (3.6 kg ha^{-1}) in seed and the lower uptake (1.5 kg ha^{-1}) was recorded in control (Table 3).

Singh et al. [9] showed that total uptake of S increased with the application of 6.0 kg Zn ha^{-1} up to the 53% and 13% on pooled basis, respectively over control and 3.0 kg Zn ha^{-1}. Jat and Mehra [8] showed similarly. Total uptake of S by mustard at flowering stage also increased with application of increasing levels of Zn and sulfur due to increase in dry weight and increase in S content because of S application. The highest total uptake of S was found with the combination of S and Zn. Results of these studies collaborates those findings.

Zn putake

Data pertaining to Zn uptake at 60 DAS and 90 DAS as influences by different sources and levels of Zn are presented in Table 2.

At 60 DAS, the results indicated significant differences in shoot Zn uptake among the different sources and levels of Zn applied. The highest Zn uptake (120.7 kg ha^{-1}) was recorded in the treatment T_7 (RDF + $ZnSO_4$. H_2O @ 20 kg ha^{-1}) and lowest (35.1 kg ha^{-1}) was recorded in T_1 (control).

At 90 DAS, the results indicated significant differences in shoot among the different sources and levels of Zn. The highest Zn uptake (105 kg ha^{-1}) was recorded under the treatment T_7 (RDF + $ZnSO_4.H_2O$ @ 20 kg ha^{-1}) which were on par with treatment T_6 (RDF + $ZnSO_4$. H_2O @ 15 kg ha^{-1}) and lowest (31.9 kg ha^{-1}) was recorded under T_1 (control).

At harvest, application of Zn (RDF + $ZnSO_4.H_2O$

@ 20 kg ha^{-1}) resulted significantly higher Zn uptake (104.3 kg ha^{-1}) in seed and the lowest Zn uptake (39.5 kg ha^{-1}) was recorded in control (Table 3). On an average, the percentage increase in Zn uptake was 164% in the treatment (T_7) over control (T_1).

Among the different Zn sources tried, the bioavailability of Zn to the crop seems to be easier in case of $ZnSO_4.H_2O$ over the other sources. This could be a reason why there was a better Zn uptake by the shoot and seed of sunflower.

Present studies are in agreement with earlier finding [4]. Significant effect of Zn and B micronutrients on the plant nutrient uptake was reported by them. The soil incorporation of 15 kg Zn ha^{-1} and 1.5 kg B ha^{-1} or higher doses recorded maximum Zn uptake (294.60 g ha^{-1}) showed that the micronutrient treatments had significant effects on nutrient uptake. Also reported that addition of these essential micronutrients, which led to increase in growth and micronutrient uptake in sunflower.

Singh et al. [9] concluded that Zn uptake was found to increase with increase in the levels of Zn from 0 to 9 kg Zn ha^{-1} but significant increase was only up to application of 6.0 kg Zn ha^{-1}. Increased in Zn content and yield of mustard resulted in a significant increase in Zn uptake by mustard. Jat and Mehra [8] have observed similar results.

Conclusion

Based on results it is concluded that the seed and shoot yield and nutrient uptake were maximum with Zn sulfate monohydrate followed by Zn sulfate heptahydrate and Zn-EDTA. The yields and nutrient uptake were more at higher levels of Zn application viz., 20 kg ha^{-1} than 15 and 10 kg ha^{-1}. Among all treatments, Zn sulfate monohydrate @ 20 kg ha^{-1} shown 49% increase in seed yield and 72% increase in shoot yield over control. Zn was highly influential in increasing the uptake of N, K, S and Zn with $ZnSO_4.H_2O$ @ 20 kg ha^{-1} among all treatements.

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