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Response of Rainfed Castor to Soil and Foliar Application of Zinc and Iron Micronutrients

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Abstract

A field investigation was carried out to study the influence of zinc and iron micronutrients on the performance of rainfed castor, in Professor Jayashankar Telangana State Agricultural University, Telangana state, India for three consecutive years during *kharif* 2011-12, 2012-13 and 2013-14. There were nine treatments *viz.,* Control (no micronutrient application); soil application of $FeSO_4$ @ 15 kg ha^{-1}; soil application of $FeSO_4$ @ 25 kg ha^{-1}; soil application of $ZnSO_4$ @ 15 kg ha^{-1}; soil application of $ZnSO_4$ @ 25 kg ha^{-1}; foliar application of 0.5% $FeSO_4$ at 50 DAS; foliar application of 0.5% $FeSO_4$ at 50 and 90 DAS; foliar application of 0.5% $ZnSO_4$ at 50 DAS; foliar application of 0.5% $ZnSO_4$ at 50 and 90 DAS and tested in randomized block design with three replications. The foliar application of $ZnSO_4$ (0.5%) twice at 50 and 90 DAS resulted in significantly higher seed yield (1698 kg ha^{-1}), higher gross returns (Rs. 54344 ha^{-1}), net returns (Rs. 33501 ha^{-1}) and B:C ratio (2.60) over rest of the treatments. The seed yield improvement was to the tune of 54% over no micronutrient application. The uptake of major and micronutrients was greater when the crop received two sprays of $ZnSO_4$ as compared to one spray of $ZnSO_4$, two sprays of $FeSO_4$ and soil application of either of the micronutrients. The castor bean crop responded to Zn better than Fe by producing 10.2% to 12.2% higher seed yield. Foliar spray was found superior to soil application in case of both the micronutrients.

Keywords: Castor, economics, foliar spray, iron, micronutrients, rainfed, zinc

1. Introduction

Castor bean (*Ricinus communis* L.) is an important non-edible oilseed crop having multiple uses in industrial, Agriculture and medical sectors. The moisture stress affects uptake of major and micronutrients in castor though it is drought tolerant (Tadayyon et al., 2018). It is widely grown for its oil in India, China, Brazil and Mozambique. Of late, it has been recognized as a useful plant for biofuel production (Carrino et al., 2020) and phytoremediation of arsenic contaminated soils and hyper accumulation of nickel (Malarkodi et al., 2008). In general, crops need micro nutrients besides macro and secondary nutrients for proper growth, development and achieving better yields. A decline in the availability of such nutrients due to either non-application, moisture

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stress or soil inherent problems, reduces yield drastically. In India, the castor bean is cultivated under rainfed and irrigated conditions due to the availability of high yielding, pest and disease resistant hybrids in both public and private domain. India has exported castor oil worth more than USD 59.89 million during 2020 (Anonymous, 2021), thus, the crop has high export potential. However, this oilseed plant is often grown on marginal soils having many constraints (Rego et al., 2007). Continuous cultivation of castor bean crop on less fertile Alfisols especially under rainfed conditions led to the emergence of micronutrient deficiencies resulting in inferior productivity levels of 500-600 kg ha^{-1}. A castor crop yielding 2.3 t ha^{-1} of seed removed 105 kg N ha^{-1} from soil (Ramanjaneyulu et al., 2013). Further, a crop with 1.37 t ha^{-1} yield potential has removed 86.6 g Zn ha^{-1} on Alfisols (Suresh et al., 2013). Among micronutrients, Zn and Fe gained macro importance, hence, their adequate supply is essential for better growth and yield. Their bioavailability is very important for nutritional security of the vegetarian community (Ganeshmurthy et al., 2017). In semiarid regions of India where deficiency of S, B and Zn are widespread, their supply improved the seed yield of rainfed castor from 757 to 1043 kg ha^{-1} with a 38% yield advantage, which is more than that obtained with the addition of N and P (15%) (Sahrawat, 2010). Agricultural soils in India are deficient in Zn and deficient to sufficient in Fe. Further, Zn deficiency may aggravate in the coming years from 42% (1975) to 63% (2025) following the adoption of intensive cropping systems without supplementation with organic manures and micronutrients and excessive application of phosphatic fertilizers. Similarly, 12-15% soils are deficient in iron (Singh, 2008). Zinc (Zn) plays a pivotal role in the proper functioning of various enzymes in carbohydrate and protein metabolism, photosynthesis, growth regulation, sugar to starch conversion and resistance to certain disease causing pathogens (Alloway, 2008), affects chloroplasts, thylakoids and amyloplasts (Junior et al., 2012). Further, it is needed for proper flowering, pollen formation and fruit or seed development. Hence, its deficiency leads to stunted growth, 'rosette' formation and reduces crop productivity. Iron (Fe) is basically required for chlorophyll formation and maintenance of chloroplast structure and function. Its deficiency is common in rainfed upland crops especially on calcareous or alkaline soils of arid region. It's deficiency leads to interveinal chlorosis of young leaves and stunted growth leading to poor yield and quality. It becomes deficit under low moisture stress thus less available to the plant. While, under excess moisture, its availability is increased and becomes toxic. Thus, iron stress is considered as a serious problem as it is limiting yields of many crops across the globe (Prasad and Shivay, 2021). Balanced nutrition with the inclusion of micronutrients in crop nutrient management is gaining importance across crops and agro-climatic zones in order to improve or sustain crop productivity and ensure an adequate supply of food, feed and fiber for the growing population (Malavolta et al., 2006; Taylor and Townsend, 2010). However, such studies are very less in castor bean. Hence, an attempt was made to quantify the impact of zinc and iron nutrition on the performance of rainfed castor crop grown on Alfisols.

2. Materials and Methods

2.1. Study site and year of experimentation

The three year field study was executed during *kharif* (July to January) season of 2011-12 to 2013-14 in Professor Jayashankar Telangana State Agricultural University (PJTSAU), Telangana, India to quantify the impact of micronutrient application on the performance of rainfed castor. The study site was located at 16°35' N latitude and 78°1' E longitude and an altitude of 642 above mean sea level (MSL) in Southern Telangana Zone (STZ). The experimental soil was near neutral with a pH of 6.3, low in organic carbon (0.3%) and available N (220 kg ha^{-1}), high in available P (75.1 kg P_2O_5 ha^{-1}) and K (425.6 kg K_2O ha^{-1}), deficient in DTPA extractable Zn (0.25 ppm) and sufficient in DTPA extractable Fe (4.40 ppm).

2.2. Details of treatments and agronomic operations

The trial comprised of nine treatments *viz.*, T_1**:** Control (no micronutrient application); T_2**:** Soil application of $FeSO_4$ @ 15 kg ha^{-1} (2.93 kg Fe ha^{-1}); T_3: Soil application of $FeSO_4$ @ 25 kg ha^{-1} (4.88 kg Fe ha^{-1}); T_4: Soil application of $ZnSO_4$ @ 15 kg ha^{-1} (3.15 kg Zn ha^{-1}); T_5**:** Soil application of $ZnSO_4$ @ 25 kg ha^{-1} (5.25 kg Zn ha^{-1}); T_6: Foliar application of 0.5% $FeSO_4$ at 50 DAS (0.488 kg Fe ha^{-1}); T_7: Foliar application of 0.5% $FeSO_4$ at 50 and 90 DAS (0.975 kg Fe ha^{-1}); T_8: Foliar application of 0.5% $ZnSO_4$ at 50DAS (0.525 kg Zn ha^{-1}); T_9: Foliar application of 0.5% $ZnSO_4$ at 50 and 90 DAS (1.05 kg Zn ha^{-1}), each replicated thrice and was conducted in a randomized block design (RBD).

The trial was taken up with a double bloom, fusarium wilt resistant and high yielding hybrid PCH-111 and was sown on 13-07-11, 15-07-12 and 11-07-2013 at a spacing of 90×60 cm^2. Each treatment had a gross plot size of 5.4×6.0 m^2 (6 rows*10 plants) and a net plot size of 3.6×4.8 m^2 (4 rows*8 plants). A gap of two meters was left among treatments and replications to avoid lateral flow of rain water and nutrients. A uniform nutrient dose of 80-40-30 kg N, P_2O_5 and K_2O ha^{-1} was followed in the form of urea (46% N), single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O), respectively by pocketing method for all nine treatments. Half the dose of nitrogen, total dose of phosphorus and potash were applied as basal, while, remaining half nitrogen dose in three equal splits at 30, 60 and 90 DAS (days after sowing). The Zn and Fe were applied as basal through $ZnSO_4.7H_2O$ (21% Zn) and $FeSO_4.7H_2O$ (19.5% Fe), respectively in T_2 to T_5 treatments, while they are sprayed on to the crop foliage at the rate of 0.5% in T_6 to T_9 treatments. An amount of 361.2, 534.0 and 841.0 mm rainfall was received over 31, 37 and 31 rainy days during crop growth period in 2011, 2012 and 2013 indicating 36.1% and 5.5% deficit rainfall in the first two years, but, 57.5% excess rainfall in the last year of trial. The sucking pest jassid (*Empoasca flavescens* Fab.) was controlled by spraying

Acephate (1.5 g l^{-1}), semi looper (*Achaea janata* Linn.) and tobacco caterpillar (*Spodopetra litura*) by spraying Novoluron (1 ml l^{-1}) twice. The weeds were controlled through pre-emergence application of Pendimethalin 30 EC (1.0 kg a.i. ha^{-1}) a day after sowing, two inter cultivations at 30 and 45 DAS and one hand weeding at 60 DAS.

2.3. Data collection and chemical analysis

The data on ancillary traits were recorded on five tagged plants in the net plot area. Plant height and number of nodes $plant^{-1}$ were recorded up to the base of primary raceme. A total of three pickings were taken at monthly intervals starting from October second fortnight up to the first fortnight of January during all the years of experimentation. The racemes with 75% matured capsules were harvested using secature, sun dried for a week and then threshed by beating with wooden mallets to get seed from capsules. The seed yield from all the pickings was summed up to report the final seed yield.

The seed samples collected at primary raceme (90 DAS), secondary raceme (120 DAS) and remaining racemes maturity stage (150 DAS) were mixed and made into powder with the help of Willey mill. A similar procedure was followed for plant samples which were oven dried using a hot air oven (105°C) before grinding. The samples were used for estimating N, P and K content following the procedures suggested by Piper (1966) and Fe and Zn concentration using atomic absorption spectrophotometer (Sims and Johnson, 1991). The pre sowing and post harvest soil samples were collected for analyzing pH, EC and available K (Jackson, 1973), available N (Subbaiah and Asija, 1956) and P (Olsen et al., 1954).

Use efficiency of nitrogen, zinc and iron were computed by dividing the castor seed yield by N, Zn or Fe dose applied as per the treatment and expressed in kg kg^{-1}.

The cost of cultivation (COC), gross returns (GRs), net returns (NRs) and B:C ratio were computed by the formulas furnished below.

COC (₹ ha^{-1})	:	Input cost+labour cost
GRs (₹ ha^{-1})	:	Seed yield * Market price
NRs (₹ ha^{-1})	:	GRs-COC
B:C ratio	:	GRs/COC

The data were subjected to RBD analysis. Further, the standard error of means (SEm±) and least significant difference at 5% probability (p=0.05) were used to compare the treatments and draw valid conclusions as per the procedure by given Panse and Sukhatme (1985).

3. Results and Discussion

3.1. Changes in growth and yield traits due to micronutrient application

The plant population and number of nodes $plant^{-1}$ did not differ significantly in all the nine treatments under test. Though the plant height and number of nodes $plant^{-1}$ improved with micronutrient application, it did not differ significantly from that of control (no micronutrients) (Table 1). Previously, Leles et al. (2010) reported that, addition of Zn failed to show a significant effect on plant growth or production in a semi arid climate.

The pooled data of three years revealed that T_9 recorded significantly more number of branches $plant^{-1}$ than rest of the treatments barring T_8, T_7 (two times foliar spray of $FeSO_4$ @ 0.5%), T_5 (soil application of $ZnSO_4$ @ 25 kg ha^{-1}) and T_3 (soil application of $FeSO_4$ @ 25 kg ha^{-1}). Quantitative enhancement

Table 1: Effect of micronutrient application on growth parameters of castor bean crop (Pooled data of *Kharif*, 2011-11, 2012-13 and 2013-14)

Treatments	Plant population (ha^{-1})	Plant height upto primary raceme (cm)	No. of branches $plant^{-1}$	No. of nodes $plant^{-1}$	Total no.of racemes $plant^{-1}$	No.of effective racemes $plant^{-1}$	Total raceme length (cm)	Effective raceme length (cm)	100 seed weight (g)
T_1	16461	44.6	3.3	10.7	4.5	3.0	41.4	33.1	27.1
T_2	16770	45.2	3.5	10.1	4.7	3.4	44.4	36.2	27.4
T_3	16872	47.8	3.9	10.3	5.2	3.6	46.4	39.9	27.5
T_4	16461	46.3	3.6	10.6	5.4	3.8	44.4	39.7	26.3
T_5	16838	49.2	3.8	10.5	5.3	3.5	44.9	40.4	27.5
T_6	16495	43.6	3.5	10.4	5.1	4.3	42.5	37.4	26.9
T_7	16804	49.1	3.9	10.9	5.4	4.1	44.7	42.2	27.3
T_8	16771	46.9	3.8	10.2	5.5	5.1	44.0	40.3	27.0
T_9	16632	50.2	4.5	10.9	6.5	5.4	47.4	45.3	27.6
SEm±	274	1.9	0.2	0.3	0.3	0.3	1.7	1.5	0.4
CD (p=0.05)	NS	NS	0.7	NS	1.0	0.8	NS	4.3	NS

in the vegetative growth of the plant is positively correlated to the optimum application of micronutrients in castor as suggested by Rastogi et al. (2014).

The relation between increase in number of total and effective racemes plant^{-1} and micronutrient application has been linear (Table 1). Significantly more number was recorded with the application of 0.5% $ZnSO_4$ at 50 DAS and 90 DAS (T_9) or 50 DAS alone (T_8).

Significantly longer effective racemes were recorded with foliar application of 0.5% $ZnSO_4$ at 50 and 90 DAS (T_9). Further, micronutrient application except soil application of $FeSO_4$ @ 15 kg ha^{-1} greatly improved the effective raceme length over control (Table 1). The foliar spray method was found effective than soil application. Within soil, 25 kg ha^{-1} fared better than 15 kg ha^{-1}. In the case of foliar spray, application at two crop stages was found better than one stage. This implies that micronutrients play a major role in enzymatic activities which in turn improved productive traits. The results of data pooled over three years revealed that the addition of micronutrients did not bring out any significant change in 100 seed weight (Table 1).

3.2. Changes in seed yield of castor due to micronutrient application

The trend in seed yield of castor bean crop was similar regardless of year of trial (Table 2). The differential yield in three years was due to variations in rainfall. The yield levels were comparatively higher during the second year (2012-13) due to receipt of normal rainfall, while it was low during the first year (2011–12) due to 36.1% deficit rainfall and 57.5% excess rainfall during the third year. The low rainfall conditions have created a dry spell which affected the growth and yield during the first year. On the other hand, higher rainfall during the third year led to the incidence of *Botryotinia* gray mold on castor racemes. The data pooled over three years indicated that control treatment which excludes micronutrient application resulted in significantly lower seed yield (1100 kg ha^{-1}). The seed yield improved linearly with the application of Fe or Zn either through soil application or foliar spray. Application of $FeSO_4$ or $ZnSO_4$ resulted in significantly higher seed yield over soil application of respective micronutrients. One time foliar spray of $FeSO_4$ was found at par with its soil application @ 25 kg ha^{-1}, but, significantly superior to 15 kg ha^{-1}. Further, two times foliar spray of $FeSO_4$ being at par with one time foliar spray of $FeSO_4$ and soil application of 25 kg $FeSO_4$ ha^{-1}, but, significantly superior to soil application of 15 kg $FeSO_4$ ha^{-1}. Though, the seed yield obtained due to two foliar sprays of $ZnSO_4$ at par with one spray, but, significantly greater to its soil application either at 15 and 25 kg ha^{-1}. Application of 15 and 25 kg ha^{-1} resulted in similar seed yields in both the micronutrients. Similarly, one and two foliar sprays did not differ significantly with regard to seed yield of castor bean. Of all the nine treatments evaluated, foliar application of $ZnSO_4$ @ 0.5% twice at 50 and 90 DAS (T_9: 1698 kg ha^{-1}) being at par with foliar application of $ZnSO_4$ @ 0.5% once at 50 DAS (1589 kg ha^{-1}) was found to be significantly superior to the rest of the treatments (Table 2). The seed yield improvement was to the tune of 7% (109 kg ha^{-1}) to 54% (598 kg ha^{-1}), the highest being over no micronutrient application. Significantly more number of branches plant^{-1}, total and effective number

Table 2: Effect of micronutrient application on seed yield, nutrient use efficiency and economics of castor bean crop (*Kharif* 2011-11, 2012-13 and 2013-14)

Treatments	Seed yield (kg ha^{-1})				YID	% YID	FeUE (kg kg^{-1})	ZnUE (kg kg^{-1})	NUE (kg kg^{-1})	GR	NR	ARD	% ID	B:C ratio
	2011-12	2012-13	2013-14	Pooled										
T_1	869	1404	1026	1100					13.8	35286	15036	18465	123	1.73
T_2	995	1736	1078	1270	598	54	-	-	15.9	40554	19190	14311	75	1.89
T_3	1075	1824	1162	1354	428	34	433	-	16.9	43261	21423	12078	56	1.97
T_4	1234	1800	1212	1415	344	25	277	-	17.7	45294	23869	9632	40	2.11
T_5	1394	1878	1313	1528	283	20	-	449	19.1	48965	27023	6478	24	2.24
T_6	1225	1966	1208	1466	170	11	-	291	18.3	46815	26289	7212	27	2.28
T_7	1331	1916	1305	1517	232	16	3004	-	19.0	48583	27780	5721	21	2.33
T_8	1344	2105	1317	1589	181	12	1556	-	19.9	50755	30214	3287	11	2.47
T_9	1419	2213	1463	1698	109	7	-	3027	21.2	54334	33501	-	-	2.60
SEm±	99	107	60	59	-	-	-	1617	0.8			-		
CD (p=0.05)	298	317	183	167					2.4					

YID: Yield increase due to T_9 (kg ha^{-1}); % YID: % yield increase due to T_9; GR: Gross returns (₹ ha^{-1}); NR: Net returns (₹ ha^{-1}); ARD: Additional net returns due to T_9 Over other treatments (₹ ha^{-1}); % ID: % increase due to T_9 over others of racemes plant^{-1} and effective raceme length might have contributed to higher seed yield in T_9. Furthermore, foliar spray might have supplied the nutrients readily to the plant and thereby transformation from store parts to sink parts regardless of soil moisture, which, otherwise it is difficult for the plant to absorb the same from soil in the absence of optimum soil moisture. Earlier, Rastogi et al. (2014) reported a positive correlation between Zn supply and seed yield. Further, the synergistic effect of inorganic nutrients and Zinc sulphate could have positively improved growth and yield attributes. Though such studies are meager in castor, but, it is understood that two times foliar spray of micronutrients at flowering and podding stage in soybean had significant effect on stamens and pollens which inturn increased number of pods per plant and seed yield (Nadergholi et al., 2011). The response of castor bean to foliar spray was better than soil application irrespective of Zn or Fe. According to Murthy and Muralidharudu (2003) and Mathukia and Khanpara (2008), application of Zinc @ 5 kg ha^{-1} was found optimum for achieving higher dry matter production, 11.5% higher seed yield and zinc use efficiency in rainfed castor. Further, the response was higher when micronutrients were applied in integration with macronutrients. Application of 50 kg ha^{-1} $ZnSO_4$ resulted in better growth and yield attributes and 11.0% and 18.4% yield improvement over no Zn application on medium black calcareous soils in Western India (Polara et al., 2010).

In the current experiment, the yield improvement was high (54%) due to low zinc content at the experimental site. Crops and varieties vary in their response to micronutrient application depending on the soil type and condition, moisture availability, method of application, type of crop, concentration of the nutrient in the soil and spray fluid. Sakal (2001) and Gupta et al. (2007) reported the superiority of foliar spray to soil application. In the present experiment also, castor bean which was grown rainfed, responded better to foliar spray as compared to that of soil application. The primary reason for this could be low or excessive soil moisture stress. Such results were published earlier by Salamatbakhsh et al. (2012) who observed no significant difference in number of leaves, seeds and racemes plant^{-1}, but, reported significantly more number of fertile capsules plant^{-1} and 100 seed weight and 50% improvement in castor seed yield, when foliar feeding of micronutrients was done twice i.e. flowering stage of primary raceme and secondary racemes control. The results of several field experiments have shown that micronutrients improved crop yield and quality significantly. In fact, photosynthesis and the regulation of transpiration are the primary tasks of foliage. The advantage of nutrient uptake through foliage is that nutrient absorption is quick and directly to the leaf cells and will be utilized for further growth and development and improve dry matter transformation from source to sink. Our research further highlighted the importance of balanced fertilization involving micro and macronutrients for the significant increase in yield. The castor bean crop performed better when sprayed twice than once, which might be to meet the growing nutritional demand from primary, secondary and tertiary racemes. Further, the use efficiency of Zn or Fe was higher when they are applied through foliar spray than soil. Application of micronutrients improved the nitrogen use efficiency (NUE) significantly (15.9 to 21.2 kg kg^{-1}) over control (13.8 kg kg^{-1}) (Table 3).

3.3. Economics

Foliar spray of $ZnSO_4$ twice at 50 and 90 DAS resulted in higher gross returns (₹ 54344 ha^{-1}), net returns (₹ 33501 ha^{-1}) and B:C ratio (2.60) (Table 2). It gave 11-123% higher additional net returns (₹ 3287 to 18465 ha^{-1}) over other treatments and the highest being over no micronutrient application.

Table 3: Effect of micronutrient application on N, P, K, Fe and Zn concentration in castor bean crop (Pooled data of 2011-12 to 2013-14)

Treat-ments	N (%)			P_2O_5 (%)			K_2O (%)			Fe (ppm)			Zn (ppm)		
	Stalk	Seed	Total	Stalk	Seed	Total	Stalk	Seed	Total	Stalk	Seed	Total	Stalk	Seed	Total
T_1	1.69	1.85	3.54	0.37	0.35	0.72	0.94	1.70	2.64	70.5	84.7	155.2	22.5	22.2	44.8
T_2	1.59	1.70	3.30	0.33	0.35	0.68	0.93	1.59	2.51	61.3	94.7	156.0	21.0	22.0	43.0
T_3	1.52	1.72	3.24	0.34	0.35	0.69	0.95	1.52	2.47	62.1	95.3	157.5	20.8	22.4	43.2
T_4	1.50	1.82	3.31	0.34	0.36	0.70	0.97	1.55	2.52	64.7	87.6	152.3	19.3	23.7	43.1
T_5	1.56	1.80	3.35	0.36	0.33	0.70	0.94	1.49	2.43	64.5	87.2	151.7	22.9	25.0	47.8
T_6	1.49	1.93	3.42	0.33	0.38	0.71	0.92	1.55	2.47	68.9	95.9	164.8	24.4	23.4	47.8
T_7	1.45	1.79	3.24	0.36	0.34	0.70	0.94	1.66	2.60	68.8	85.5	154.3	25.0	23.1	48.1
T_8	1.52	1.68	3.20	0.33	0.36	0.69	0.84	1.62	2.47	67.5	89.1	156.5	24.7	24.8	49.5
T_9	1.56	1.87	3.43	0.34	0.38	0.72	0.97	1.66	2.63	63.7	88.5	152.3	26.2	23.7	49.8
SEm±	0.10	0.14	0.18	0.03	0.03	0.03	0.03	0.08	0.09	0.62	1.3	1.3	0.5	0.4	0.7
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	1.9	3.9	3.8	1.6	1.2	2.1

Foliar spray of either Zn or Fe was found better than soil application due to higher net returns following higher yield. Further, foliar spray was economical due to less dose (2.5 kg ha^{-1}) than soil application (15 or 25 kg ha^{-1}). Moreover, the micronutrients can be also applied by tank mixing with plant protection chemicals thus avoids double cost. Nevertheless, the absorption and use efficiency of micronutrients were higher when sprayed on to foliage than soil application as the latter one needs optimum soil moisture for solubility, nutrient uptake by roots and transportation to shoots and reproductive parts (Garg, 2003). Lack of optimum moisture in the soil during the first year might have impaired nutrient uptake and excess soil moisture during the third year of the trial might have drained away the nutrients making them unavailable to the plant. Hence, foliar spray has given better results than soil application.

3.4. Nutrient concentration and uptake

Micronutrient application did not change significantly the concentration of N, P and K in castor stalk and seed (Table 3). It is similar in the case of total concentration too. In case of micronutrients, significantly higher Fe concentration in stalk was observed in the control plot (T_1), while, higher seed and total Fe was recorded in T6 (one time foliar spray of $FeSO_4$ at 50 DAS). Further, Zn in castor stalk was highest when the crop received foliar spray of $ZnSO_4$ twice at 50 and 90 DAS (T_9), but, it was par with that of two sprays of $FeSO_4$ (T_8) and one spray of $ZnSO_4$ (T_7). While, Zn in castor seed was higher due to soil application of $ZnSO_4$ @ 25 kg ha^{-1} as basal (T_5) and one time foliar spray of $FeSO_4$ at 50 DAS (T_8). The total Zn content was significantly greater due to two sprays of $ZnSO_4$ than the rest of the treatments barring one time $ZnSO_4$ spray, one or two sprays of $FeSO_4$ and soil application of $ZnSO_4$ @ 25 kg ha^{-1}.

The castor bean crop accumulated significantly less amount of nutrients *viz.,* N, P, K, Fe and Zn, when it was not supplied with micronutrients (Table 4). However, the relation between micronutrient application (either soil or foliar) and nutrient uptake was found to be linear.

Significantly greater amount of N, P, K, Fe and Zn were accumulated by the castor bean plant when the crop received foliar spray of $ZnSO_4$ at two stages (T_9). This was mainly due to the realization of significantly higher seed and stalk yield. However, T_9 was at par with that of T_8, T_7, T_6 and T_5 for total N and P, stalk and total Fe uptake; T_8 and T_7 for seed and total K; T_8 and T_6 for P and Fe uptake by seed and only T_8 for stalk, seed and total Zn uptake. Further, higher seed and stalk yield and greater nutrient removal in T_9 treatment might be due to synergistic effect between the applied macronutrients and zinc (Kumar and Kanjana, 2009). The earlier researchers Junior et al. (2012) reported higher concentration and removal of Zn in castor bean plants with increased micronutrient availability, under green house conditions.

Table 4: Effect of micronutrient application on N, P, K, Fe and Zn uptake by castor bean crop (Pooled data of 2011-12 to 2013-14)

Treat-ments	N uptake (kg ha^{-1})			P uptake (kg ha^{-1})			K uptake (kg ha^{-1})			Fe uptake (g ha^{-1})			Zn uptake (g ha^{-1})		
	Stalk	Seed	Total	Stalk	Seed	Total	Stalk	Seed	Total	Stalk	Seed	Total	Stalk	Seed	Total
T_1	27.9	20.4	48.3	6.1	3.8	10.0	15.5	18.7	34.2	116.2	93.1	209.3	37.1	24.4	61.6
T_2	30.4	21.5	51.9	6.3	4.4	10.7	17.6	20.2	37.8	116.6	120.0	236.6	39.9	27.9	67.8
T_3	30.9	23.3	54.2	6.9	4.7	11.5	19.4	20.4	39.8	126.0	128.9	254.9	42.2	30.3	72.6
T_4	31.8	25.6	57.4	7.3	5.1	12.3	20.7	21.9	42.5	137.1	123.8	260.9	41.0	33.6	74.6
T_5	35.4	27.3	62.7	8.4	5.0	13.4	21.6	22.8	44.4	147.6	133.0	280.7	52.4	38.1	90.4
T_6	32.9	28.2	61.1	7.3	5.6	12.9	20.3	22.8	43.0	151.4	140.3	291.7	53.6	34.3	87.9
T_7	33.0	27.1	60.1	8.2	5.2	13.4	21.4	25.1	46.5	156.5	129.6	286.1	57.0	35.0	92.0
T_8	36.2	27.0	63.1	8.0	5.7	13.6	20.2	25.8	46.0	161.0	141.5	302.5	59.0	39.4	98.4
T_9	39.8	32.0	71.8	8.7	6.4	15.1	24.8	28.2	53.0	162.1	150.2	312.3	66.6	40.1	106.6
SEm±	2.4	2.4	4.1	0.8	0.4	0.7	1.3	1.4	2.5	6.8	6.0	12.6	2.8	1.6	4.2
CD (p=0.05)	NS	NS	12.5	NS	1.1	2.3	4.0	4.3	7.4	20.1	18.1	35.2	8.4	4.7	12.8

4. Conclusion

Foliar spray of $ZnSO_4$ (0.5%) twice at 50 and 90 DAS could be recommended for rainfed castor due to realisation of higher productivity (1698 kg ha^{-1}) and net returns (₹ 33501 ha^{-1}) and returns per rupee invested (2.60). Further, foliar spray was proved better than soil application in improving castor seed yield by 12.6% and use efficiency of applied nutrients by six times. The castor bean yield improved by 10.2-12.2% when nourished with $ZnSO_4$ than $FeSO_4$. Thus, this study emphasized the role of balanced nutrition involving major and minor nutrients in accruing macro benefits in rainfed castor.

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