International Journal of Research in Agronomy 2025; SP-7(10): 797-802

E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2025; SP-7(10): 797-802
Received: 28-08-2024
Accepted: 29-09-2024

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Response of zinc nutrition on growth and yield of direct seeded rice (*Oryza sativa* L.)

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DOI: https://doi.org/10.33545/2618060X.2024.v7.i10Sk.2325

Abstract
The investigation on "Response of direct seeded rice (*Oryza sativa* L.) to zinc nutrition in sub-montane zone of Maharashtra during kharif 2021. The field experiment was laid out in randomized block design with three replications and eleven treatments replicated thrice. The result revealed that application of $ZnSO_4$ through soil + foliar spray of 0.2% EDTA Zn along with RDF and Vermicompost was significantly superior and at par with soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ foliar application of 0.1% EDTA Zn with RDF and Vermicompost [T_{10}] and soil application of $ZnSO_4$ @ 10 kg ha^{-1} + foliar application of 0.2% EDTA Zn with RDF and Vermicompost [T_9] in respect of yield attributing characters *viz*., number of panicles m^{-2}, panicle length $plant^{-1}$ (cm), panicle weight $plant^{-1}$ (g), number of spikelets and filled grains $panicle^{-1}$ and grain weight $plant^{-1}$ (g). Whereas, (RDF + Vermicompost) + soil application of $ZnSO_4$ @ 10 kg ha^{-1} + foliar application of 0.1% EDTA Zn [T_8] was also found at par with it might be due to combined method of zinc application except in terms of length and weight of panicles because of low level of zinc nutrition. However, 1000- grains weight (g) and harvest index failed to reach the level of significance. Grain yield (60.53 q ha^{-1}), straw yield (69.71 q ha^{-1}) and biological yield (130.24 q ha^{-1}) were significantly maximum when $ZnSO_4$ at rate 20 kg ha^{-1} was applied through soil + 0.2% EDTA Zn through foliar spray with RDF and Vermicompost [T_{11}], which was at par with soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ foliar application of 0.1% EDTA Zn with RDF and Vermicompost [T_{10}] (59.94 q ha^{-1}, 69.11 q ha^{-1}) and (129.05 q ha^{-1}), respectively. The combined method of Zn application i.e. soil + foliar with high level of zinc nutrition effective method to maintain zinc level in zinc deficient soil and increase the yield of DSR.

Keywords: Zinc, plant height, grain yield, straw yield, harvest index, direct seeded rice

Introduction
Rice (*Oryza sativa* L.) is a staple food for more than one third of the world population. India will have the most acreage planted with rice and the second-highest output of rice in the world in 2020–21, after China (Anonymous, 2021ᵃ) [1]. In 2020–21, rice production will reach a record 122 million metric tonnes, up from 118.9 million metric tonnes the year before (Anonymous, 2021ᵇ) [2]. Transplanting method requires at least 25 ha-cm of water for puddling. However, transplanting method became difficult due to water scarcity and shortage of labour. Manual transplanting takes about 250-300 man hours ha^{-1} which is about 25 per cent of the total labour requirement of the crop (Dongarwar *et al*., 2015) [5]. For this instance, the present study is taken into consideration. The direct seeding is time and labour saving method, constitutes both wet and dry seeding. The upland rice grown in India is about 13 per cent of area under cultivation; it helps in feeding numbers of poor farmer from its limited resources in India.
Fertilizer is the key input in maximizing agricultural production and productivity. Injudicious application of only chemical fertilizers to crops as resulted in soil, plant as well as human health problem. Nowadays, it is necessary to use of organic sources such as vermicompost, farm yard manures, biocompost and various biofertilizers to get maximum quality production without adhering the soil health. Application of vermicompost is considered good to safe supply of all micronutrients for the crop production. It is rich in all nutrients, enzymes and contains 'plant growth hormones'. It is scientifically proved as 'miracle growth promoter' and plant protector from diseases and pests of crops.
Micronutrients are crucial for the growth and development of plants as well as for boosting crop

productivity. Since zinc is the micronutrient that is most deficient in soils across the world, zinc insufficiency is one of the primary agricultural issues that threatens regional and global food security. In the world more than 30 per cent of the cultivated soils are zinc deficient and about 50 per cent of the soils used for cereal crop production are low in available zinc. Nearly half of the world population suffers from zinc deficiency (Cakmak, 2008) [3]. In India, about 26 per cent populations and about 54 per cent childrens are suffering from Zn deficiency (Verma *et al*., 2015) [17].

The most economic way to alleviate zinc deficiency in the rice is application of zinc fertilizers and improves productivity and zinc concentration in grains. In addition to specific zinc fertilizers, organic manures are good source of zinc and other nutrients. Therefore, adopting direct seeded rice in zinc-deficient soil and performing well under adequate zinc nutrient supplies coupled with vermicompost become equally significant to farmers. As a result, this study may be helpful to evaluate the nutritional value of zinc and the effectiveness of its use in rice grain and straw when various zinc sources are combined with RDF. Keeping all this points in view the experiment titled to study "Response of Direct Seeded Rice (*Oryza sativa* L.) to Zinc Nutrition In Sub-Montone Zone of Maharashtra" was planned and conducted.

Materials and Methods

The experiment was conducted at the Post Graduate Research Farm, Agronomy Section of Rajarshee Chhatrapati Shahu Maharaj College of Agriculture, Kolhapur (M.S), India, during *kharif*, 2021.The field experiment was laid out in randomized block design with three replications and eleven treatments replicated thrice. The treatment comprises of T_1: Absolute control, T_2: RDF (100:50:50 kg NPK kg ha^{-1})., T_3: RDF (100:50:50 kg NPK kg ha^{-1} + Vermicompost @ 2.5 t ha^{-1})., T_4: RDF (100:50:50 kg NPK kg ha^{-1} + Vermicompost @ 2.5 t ha^{-1}) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1}., T_5: RDF (100:50:50 kg NPK kg ha^{-1} + Vermicompost @ 2.5 t ha^{-1}) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}., T_6: RDF (100:50:50 kg NPK kg ha^{-1} + Vermicompost @ 2.5 t ha^{-1}) + Foliar application of 0.1% EDTA Zn., T_7: RDF (100:50:50 kg NPK kg ha^{-1} + Vermicompost @ 2.5 t ha^{-1}) + Foliar application of 0.2% EDTA Zn., T_8: RDF (100:50:50 kg NPK kg ha^{-1} + Vermicompost @ 2.5 t ha^{-1}) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1} + Foliar application of 0.1% EDTA Zn., T_9: RDF (100:50:50 kg NPK kg ha^{-1}+ Vermicompost @ 2.5 t ha^{-1}) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1} + Foliar application of 0.2% EDTA Zn., T_{10}: RDF (100:50:50 kg NPK kg ha^{-1}+ Vermicompost @ 2.5 t ha^{-1}) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Foliar application of 0.1% EDTA Zn., T_{11}: RDF (100:50:50 kg NPK kg ha^{-1} +Vermicompost @ 2.5 t ha^{-1}) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Foliar application of 0.2% EDTA Zn. The variety used for the experiment is Indrayani (IET-12897) (Amb-157× IR-8).

Fertilizers were applied at the time of paddy sowing as a basal dose. Basal dose comprises 40 per cent of nitrogen, and full dose of P_2O_5 and K_2O. The remaining 60 per cent nitrogen was applied in two split doses; 40 per cent at maximum tillering stage i.e. 30 DAS and 20 per cent at initial panicle initiation stage i.e. 60 DAS. Nitrogen was applied through urea, P_2O_5 through single super phosphate, K_2O through muriate of potash. Soil application of $ZnSO_4$ @ 10 and 20 kg ha^{-1} was done by mixing with sandy soil at the time of sowing as per treatment and foliar spray of chelated Zn-EDTA @ 0.1% and 0.2% at initial panicle initiation stage and late growth stage i.e., one week after flowering as per treatment wise.

The experimental soil was sandy clay loam soil. The pH and electrical conductivity values were 7.80 (slightly alkaline in reaction) and 0.45 dSm^{-1} (normal-low saline), respectively. The status of soil organic carbon content (0.51%) was medium. The plot was low in available N (168.27 kg ha^{-1}), relatively very high in available P_2O_5 (30.02 kg ha^{-1}), medium in available K_2O (339.88 kg ha^{-1}) and deficient in available Zn (0.25 ppm). The five representative plants were selected randomly from each net plot for studying the effects of various treatments on plant character of rice. The periodical biometric observations were recorded at an interval of 14 DAS up to harvest.

Result and Discussion

1. Plant count (m^{-2})

The data shows that the initial as well as final plant count of direct seeded rice did not show remarkable influence due to various zinc nutrition treatments (Table 1). The findings indicated that zinc had no any significant effect on initial plant count at crop commencement and the final plant count at harvest. The mean initial plant of direct seeded rice (DSR) was 40.43 plants m^{-2} at 15 DAS; however, mean final plant stand at harvest stage was 37.18 plants m^{-2}.

Table 1: Initial and final plant count (m^{-2}) of DSR as influenced by various treatments

Treatments	Plant count m^{-2}	
	14 DAS	**At harvest**
T_1 – Absolute control	39.26	35.11
T_2 – RDF (100:50:50 kg NPK ha^{-1})	40.12	36.29
T_3 – RDF + Vermicompost @ 2.5 t ha^{-1}	40.32	36.41
T_4 – (RDF + Vermicompost*) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1}	40.48	37.12
T_5 – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}	40.52	37.76
T_6 - (RDF + Vermicompost) + Foliar application of 0.1% EDTA Zn	40.46	36.53
T_7 - (RDF + Vermicompost) + Foliar application of 0.2% EDTA Zn	40.51	36.84
T_8 - (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1} + Foliar application of 0.1% EDTA Zn	40.61	37.93
T_9 – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1} + Foliar application of 0.2% EDTA Zn	40.67	38.02
T_{10} – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Foliar application of 0.1% EDTA Zn	40.82	38.21
T_{11} – (RDF +Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Foliar application of 0.2% EDTA Zn	40.93	38.63
S.Em±	0.09	0.23
C. D. at 5%	NS	NS
General mean	40.43	37.18

(RDF 100:50:50 kg NPK ha^{-1}) and (Vermicompost* @ 2.5 t ha^{-1} for T_4 to T_{11})

2. Growth studies

Plant height (cm)

From the data it was revealed that plant height of DSR was increased progressively during growth period of the crop and reached maximum at harvest stage. The mean plant height at 28, 42, 56, 70, 84, 98 DAS and at harvest stage was 26.90, 37.80, 46.86, 61.13, 74.02, 78.57 and 81.77 cm, respectively.

All stages of crop growth, with the exception of 28 DAS, observed significant effect of zinc application on height of plant. The treatment with soil application of $ZnSO_4$ @ 20 kg ha^{-1} + foliar application of 0.2% EDTA Zn along with RDF (100:50:50 NPK kg ha^{-1}) and Vermicompost @ 2.5 t ha^{-1} [T_{11}] recorded significantly highest plant height from 42 DAS to till harvest. However, it was found at par with soil application of $ZnSO_4$ @ 20 kg ha^{-1} + foliar spray of 0.1% EDTA Zn along with RDF (100:50:50 NPK kg ha^{-1}) and Vermicompost @ 2.5 t ha^{-1} [T_{10}]. At 70 DAS onwards, treatments T_8 and T_9 with soil application of $ZnSO_4$ @ 10 kg ha^{-1} + foliar application of 0.1% EDTA Zn along with RDF and Vermicompost and soil application of $ZnSO_4$ @ 10 kg ha^{-1} + foliar application of 0.2% EDTA Zn along with RDF and Vermicompost found at par with treatment T_{11} might be due to foliar application of zinc. It was found significantly superior over rest of treatments except T_8, T_9 and T_{10}. At various phases of crop growth, the absolute control [T_1] treatment recorded the lowest plant height value among the other treatments. Significant influence on plant height of DSR on zinc application might be attributed to the cell division and caused more stem elongation, increased enzymatic activity lead auxin metabolism in plants.

Similar results were obtained by Saha *et al*. (2015) [11], Shivay *et al*. (2015) [13], Sudhagar Rao *et al*. (2019) [15] and Dev Narayan (2020) [4].

Numbers of tillers m^{-2}

The soil application of ZnSO4 @ 20 kg ha^{-1} + foliar spray of EDTA Zn 0.2% along with RDF (100:50:50 NPK kg ha^{-1}) and vermicompost @ 2.5 t ha^{-1} [T_{11}] recorded maximum number of tillers (Table 3.) among all treatment combinations. However, it was remained at par with soil application of ZnSO4 @ 20 kg ha^{-1} + foliar spray of 0.1% EDTA Zn [T_{10}], and it was found significantly superior over rest of treatments except treatment T9 and T_{10}. Higher tillers were found under zinc supplied treatments might be due to zinc nutrition accelerate photosynthetic rate and auxin metabolism in plants, as auxins are involved in root formation and cell division and which control plant growth, resulted in increasing number of tillers. Due to a lack of appropriate nutrition's, the absolute control treatment [T_1] only produced the minimum number of tillers per square meter.

Table 3: Number of tillers m^{-2} of DSR as influenced periodically by various treatments

Treatments	Days after sowing						
	28	42	56	70	84	98	At harvest
T_1 – Absolute control	86.17	214.23	254.51	260.92	272.48	272.32	272.32
T_2 – RDF (100:50:50 kg NPK ha^{-1})	102.76	275.51	323.85	327.60	333.36	334.12	334.12
T_3 – RDF + Vermicompost @ 2.5 t ha^{-1}	106.07	279.73	327.63	331.88	336.6	337.05	337.05
T_4 – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1}	112.89	288.88	337.8	344.48	350.83	351.09	351.09
T_5 – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}	117.99	294.73	345.26	350.04	358.77	359.83	359.83
T_6 - (RDF + Vermicompost) + Foliar application of 0.1% EDTA Zn	109.32	282.76	332.55	334.32	346.05	346.37	346.37
T_7 - (RDF + Vermicompost) + Foliar application of 0.2% EDTA Zn	111.64	289.17	338.79	338.92	351.05	351.86	351.86
T_8 - (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1} + Foliar application of 0.1% EDTA Zn	119.14	296.32	347.18	353.16	362.89	364.07	364.07
T_9 – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1} + Foliar application of 0.2% EDTA Zn	121.72	301.16	351.53	355.68	366.65	367.11	367.11
T_{10} – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Foliar application of 0.1% EDTA Zn	127.92	307.48	356.36	361.76	375.26	376.19	376.19
T_{11} – (RDF +Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Foliar application of 0.2% EDTA Zn	130.63	313.39	360.29	368.57	379.72	380.64	380.64
S.Em±	2.96	3.91	4.33	5.11	5.43	4.45	4.45
C. D. at 5%	NS	12.75	13.02	15.29	16.18	13.36	13.36
General mean	113.29	285.76	334.21	338.97	348.61	349.15	349.15

Leaf area $plant^{-1}$ (dm^2)

Among all treatment combinations of zinc nutrition, T_{11}-soil application of $ZnSO_4$ @ 20 kg ha^{-1} + foliar application of 0.2% EDTA Zn recorded maximum leaf area $plant^{-1}$ (dm^2) during all growth stages. However, it was at par with soil application of $ZnSO_4$ @ 20 kg ha^{-1} + foliar spray of 0.1% EDTA Zn [T_{10}]. At 70 DAS, treatment T_9 was remained at par with T_{11} might be due to foliar application of zinc responsible for cell division and cell enlargement and increases the leaf area. Also at 84 DAS, combined method of zinc application (Soil + foliar) i.e., Soil application of $ZnS0_4$ @ 10 kg ha^{-1} + foliar spray of 0.1% EDTA Zn [T_8] and soil application of $ZnSO_4$ @ 10 kg ha^{-1} + foliar spray of 0.2% EDTA Zn [T_9] was found at par with treatment T_{11}. Among the all treatment combinations T_{11} was found significantly superior over rest of the treatments except soil + foliar application of zinc nutrition. The results indicating that zinc had a play important role in synthesis of tryptophan and IAA which are responsible for increase in leaf area. Leaf area is an indicator of total photosynthetic surface area, available to crop for photosynthates production and zinc responsible for increase in photosynthetic process, which might be the reason for increase in growth and leaf area. Lower leaf area was recorded in absolute control [T_1] during all stages of crop growth due to unavailability of nutrients to the plant. Similar results were noted by Mandal *et al*. (2009) [10] and Kumari *et al*. (2019) [9].

Table 4: Mean number of leaf area plant^{-1} (dm^2) of DSR as influenced by various treatments

Treatments	Days after sowing				
	28	42	56	70	84
T_1 – Absolute control	0.42	2.13	3.16	5.13	5.86
T_2 – RDF (100:50:50 kg NPK ha^{-1})	1.21	3.62	5.84	6.98	8.03
T_3 – RDF + Vermicompost @ 2.5 t ha^{-1}	1.32	3.74	5.91	7.19	7.84
T_4 – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @10 kg ha^{-1}	1.83	3.91	6.29	8.11	9.42
T_5 - (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}	1.97	4.03	6.73	8.45	9.63
T_6 - (RDF + Vermicompost) + Foliar application of 0.1% EDTA Zn	1.38	3.79	6.14	8.09	9.25
T_7 - (RDF + Vermicompost) + Foliar application of 0.2% EDTA Zn	1.42	3.83	6.23	8.36	9.51
T_8 - (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1} + Foliar application of 0.1% EDTA Zn	1.87	3.97	6.65	8.69	9.85
T_9 – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1} + Foliar application of 0.2% EDTA Zn	1.92	4.05	6.68	8.76	9.96
T_{10} – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Foliar application of 0.1% EDTA Zn	2.35	4.25	7.89	9.08	10.03
T_{11} – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Foliar application of 0.2% EDTA Zn	2.49	4.47	8.54	9.42	10.16
S.Em±	0.04	0.13	0.23	0.24	0.16
C. D. at 5%	NS	0.38	0.67	0.71	0.47
General mean	1.65	3.80	6.37	8.02	9.05

Dry matter production plant^{-1} (g)

The mean dry matter production per plant of DSR was influenced significantly by various zinc nutrition at all development stages of crop except, at initial stage i.e., 28 DAS. The significantly highest amount of dry matter production plant^{-1} was recorded with soil application of $ZnSO_4$ @ 20 kg ha^{-1} + foliar application of 0.2% EDTA Zn along with RDF (100:50 50 NPK kg ha^{-1}) and Vermicompost @ 2.5 t ha^{-1} [T_{11}] during all growth stages and it was statistically at par with soil application of $ZnSO_4$ @ 20 kg ha^{-1} + foliar spray of 0.1% EDTA Zn along with RDF and Vermicompost. Dry weight of DSR was influenced significantly with application of zinc (soil + foliar). It could be because applying zinc together with RDF makes other nutrients more readily available, increases chlorophyll content as a consequence of zinc foliar spraying, and produces the most photosynthates, which results in accelerated development of plant parts and an increase in dry matter. Under absolute control [T_1], the lowest dry matter production was noted. These results support the findings of Tharakan and Gite (2018) [16], Saha *et al*. (2020) [12] and Singh *et al*. (2020) [14].

Table 5: Mean dry matter production plant^{-1} (g) of DSR as influenced periodically by various treatments

Treatments	Days after sowing						
	28	42	56	70	84	98	At harvest
T_1 – Absolute control	0.73	1.12	2.93	7.13	10.50	13.62	14.73
T_2 – RDF (100:50:50 kg NPK ha^{-1})	1.17	7.13	8.36	12.49	16.56	20.43	21.52
T_3 – RDF + Vermicompost @ 2.5 t ha^{-1}	1.23	7.27	8.68	12.89	16.83	20.75	21.82
T_4 – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1}	1.41	8.94	9.85	14.10	18.34	23.05	24.80
T_5 – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}	1.48	9.24	10.22	15.32	19.94	24.53	25.65
T_6 - (RDF + Vermicompost) + Foliar application of 0.1% EDTA Zn	1.27	7.58	8.77	13.25	17.37	22.43	23.53
T_7 - (RDF + Vermicompost) + Foliar application of 0.2% EDTA Zn	1.29	7.96	9.41	13.87	18.09	23.81	24.83
T_8 - (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1} + Foliar application of 0.1% EDTA Zn	1.46	9.21	10.15	15.94	21.38	25.89	26.98
T_9 – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1} + Foliar application of 0.2% EDTA Zn	1.47	9.26	10.13	16.36	21.77	26.15	27.29
T_{10} – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Foliar application of 0.1% EDTA Zn	1.54	9.96	11.37	16.88	22.47	27.81	28.92
T_{11} – (RDF +Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Foliar application of 0.2% EDTA Zn	1.56	10.13	12.09	17.06	22.66	28.62	29.72
S.Em±	0.02	0.24	0.47	0.56	0.64	0.77	0.80
C. D. at 5%	NS	0.70	1.38	1.64	1.89	2.27	2.36
General mean	1.33	7.98	9.27	14.12	18.72	23.37	24.52

Yield attributing characters of DSR

Data regarding yield attributing characters of direct seeded rice as affected by various treatments of zinc application are recorded and tabulated in Table 6.

Table 6: Yield attributing characters of DSR as influenced by various treatments at harvest

Treatments	Number of panicles m^{-2}	Panicle length $plant^{-1}$ (cm)	Panicle weight $plant^{-1}$ (g)	Number of spikelets $panicle^{-1}$	Number of filled grains $panicle^{-1}$	Grain weight $plant^{-1}$ (g)	1000 grains weight (g)
T_1 – Absolute control	253.08	14.44	6.21	121.35	113.27	14.47	16.92
T_2 – RDF (100:50:50 kg NPK ha^{-1})	321.93	17.32	8.26	168.94	163.23	17.92	19.34
T_3 – RDF + Vermicompost @ 2.5 t ha^{-1}	328.49	17.67	9.45	169.89	165.37	18.13	19.59
T_4 – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1}	346.69	18.65	10.57	176.05	169.27	18.73	19.94
T_5 – (RDF +Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}	354.87	20.34	10.97	177.94	172.70	19.37	20.47
T_6 - (RDF +Vermicompost) + Foliar application of 0.1% EDTA Zn	339.33	18.10	10.14	176.47	168.10	18.60	19.81
T_7 - (RDF +Vermicompost) + Foliar application of 0.2% EDTA Zn	344.08	19.23	10.61	177.70	172.23	18.94	20.04
T_8 - (RDF+ Vermicompost) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1} + Foliar application of 0.1% EDTA Zn	358.73	21.06	11.31	182.39	177.47	19.50	20.65
T_9 – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1} + Foliar application of 0.2% EDTA Zn	364.52	21.75	11.79	183.11	179.13	19.74	20.92
T_{10} – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Foliar application of 0.1% EDTA Zn	371.20	22.65	12.22	187.54	182.33	20.42	21.34
T_{11} – (RDF +Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Foliar application of 0.2% EDTA Zn	375.31	23.40	12.78	188.66	184.60	20.71	21.83
S.Em±	6.51	0.77	0.35	5.07	4.83	0.69	0.93
C. D. at 5%	19.51	2.27	1.04	15.13	14.45	2.06	NS
General mean	341.66	19.51	10.39	173.64	167.97	18.78	20.08

Significantly higher number of panicles m^{-2} (375.31), mean panicle length $plant^{-1}$ at harvest 23.40 cm, mean panicle weight $plant^{-1}$ (12.78) g at harvest, number of spikelets per panicle (188.66), number of grains (filled) $panicle^{-1}$ (184.60), number of grains (filled) $panicle^{-1}$ (184.60), weight of grains $plant^{-1}$ (20.71) and test weight 21.83 g was recorded under the treatment of soil application of $ZnSO_4$ @ 20 kg ha^{-1} + foliar application of 0.2% EDTA Zn along with RDF (100:50:50 NPK kg ha^{-1}) and Vermicompost @ 2.5 t ha^{-1} [T_{11}]. However, it was found at par with soil application of $ZnSO_4$ @ 20 kg ha^{-1} + foliar application of 0.1% EDTA Zn [T_{10}] and soil application of $ZnSO_4$ @ 10 kg ha^{-1} and foliar spray of 0.2% EDTA Zn [T_9]. Among these all treatments T_1 (Absolute control) recorded lowest panicle per plant (14.44 cm), panicle weight $plant^{-1}$ (6.21) g, number of spikelets per panicle (121.35), number of filled grains $panicle^{-1}$ (113.27), grain weight $plant^{-1}$ (14.47 g), test weight (16.92 g). The increase in number of spikelets $panicle^{-1}$ might be ascribed to adequate supply of zinc had positive effect on enhancing photosynthesis, translocation and uptake of nutrients which ultimately increased the number of spikelets $panicles^{-1}$. Similar results reported by Khan *et al.* (2007) [8] and Kumari *et al.* (2019) [9]. Soil as well as foliar zinc application recorded more number of filled grains, zinc is responsible for pollen formation, seed production and foliar application of Zn has been reported to increase the pollen grains viability. Gomaa *et al.* (2015) [7], Shivay *et al.* (2015) [13], Sudhagar Rao *et al.* (2019) [15] reported the similar result.

3. Yield studies

Mean grain yield, straw yield, biological yield and harvest index ha^{-1} as influenced by various treatments is presented in Table 7. Grain, straw, biological yield (q ha^{-1}) and harvest index of DSR as influenced by various treatments. Among various zinc nutrition treatments (Table 7) soil application of ZnSO4 @ 20 kg ha-1+ foliar application of 0.2% EDTA Zn along with RDF (100:50:50 NPK kg ha-1) and Vermicompost @ 2.5 t ha-1 [T_{11}] recorded significantly the highest grain yield (48.97 q ha^{-1}), maximum straw yield (69.71 q ha^{-1}), highest biological yield (130.24 q ha^{-1}), biological yield (46.42 q ha^{-1}) and harvest index (46.51) which was at par with the treatment of soil application of $ZnSO_4$ @ 20 kg ha^{-1} + foliar application of 0.1% EDTA zinc along with RDF (100:50:50 NPK kg ha^{-1}) and Vermicompost @ 2.5 t ha^{-1} [T_{10}]. The harvest index is reproductive efficiency of the plant. The mean value of harvest index was 46.48 per cent. The numerical value of highest harvest index (46.51) was noticed under [T_{11}] soil application of ZnSO4 @ 20 kg ha^{-1} + foliar application of 0.2% EDTA Zn and [T_5] soil application of ZnSO4 @ 20 kg ha^{-1}. However, [T_1] absolute control treatment was recorded lowest harvest index value of 46.42 per cent of direct seeded rice. Ghasal *et al.* (2015) [6] and Shivay *et al.* (2015) [13] reported similar results on harvest index. It might be due to combined method of application of zinc had favourable effect on root proliferation and there by plant nutrient uptake increasing from soil to aerial plant parts and ultimately enhancing vegetative plant growth parameters and yield attributing characters which finally makeup the yield.

Table 7: Grain, straw, biological yield (q ha^{-1}) and harvest index of DSR as influenced by various treatments

Treatments	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Biological yield (q ha^{-1})	Harvest Index
T_1 – Absolute control	21.55	24.87	46.42	46.42
T_2 – RDF (100:50:50 kg NPK ha^{-1})	34.70	39.96	74.66	46.48
T_3 – RDF + Vermicompost @ 2.5 t ha^{-1}	39.50	45.46	84.96	46.49
T_4 – (RDF + Vermicompost)+ Soil application of $ZnSO_4$ @ 10 kg ha^{-1}	51.42	59.16	110.58	46.50
T_5 – (RDF + Vermicompost)+ Soil application of $ZnSO_4$ @ 20 kg ha^{-1}	53.94	62.02	115.96	46.51
T_6 - (RDF + Vermicompost) + Foliar application of 0.1% EDTA Zn	50.31	57.89	108.20	46.50
T_7 - (RDF + Vermicompost) + Foliar application of 0.2% EDTA Zn	52.48	60.37	112.85	46.50
T_8 - (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1} + Foliar application of 0.1% EDTA Zn	56.61	65.29	121.90	46.44
T_9 – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 10 kg ha^{-1} + Foliar application of 0.2% EDTA Zn	57.64	66.39	124.03	46.47
T_{10} – (RDF + Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Foliar application of 0.1% EDTA Zn	59.94	69.11	129.05	46.47
T_{11} – (RDF +Vermicompost) + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Foliar application of 0.2% EDTA Zn	60.53	69.71	130.24	46.51
S.Em±	0.353	0.409	0.878	1.56
C. D. at 5%	1.043	1.208	2.593	NS
General mean	48.97	56.39	105.36	46.48

Conclusion

Application of $ZnSO_4$ through soil + foliar spray of 0.2% EDTA Zn along with RDF and Vermicompost was significantly superior and at par with soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ foliar application of 0.1% EDTA Zn with RDF and Vermicompost [T_{10}] and soil application of $ZnSO_4$ @ 10 kg ha^{-1} + foliar application of 0.2% EDTA Zn with RDF and Vermicompost [T_9] in respect of yield attributing characters *viz*., number of panicles m^{-2}, panicle length $plant^{-1}$ (cm), panicle weight $plant^{-1}$ (g), number of spikelets and filled grains $panicle^{-1}$ and grain weight $plant^{-1}$ (g). Whereas, (RDF + Vermicompost) + soil application of $ZnSO_4$ @ 10 kg ha^{-1} + foliar application of 0.1% EDTA Zn [T_8] was also found at par with it. might be due to combined method of zinc application except in terms of length and weight of panicles because of low level of zinc nutrition. However, 1000- grains weight (g) and harvest index failed to reach the level of significance. Grain yield (60.53 q ha^{-1}), straw yield (69.71 q ha^{-1}) and biological yield (130.24 q ha^{-1}) were significantly maximum when $ZnSO_4$ at rate 20 kg ha^{-1} was applied through soil + 0.2% EDTA Zn through foliar spray with RDF and Vermicompost [T_{11}], which was at par with soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ foliar application of 0.1% EDTA Zn with RDF and Vermicompost [T_{10}] (59.94 q ha^{-1}, 69.11 q ha^{-1}) and (129.05 q ha^{-1}), respectively. The combined method of Zn application i.e. soil +foliar with high level of zinc nutrition effective method to maintain zinc level in zinc deficient soil and increase the yield of DSR.

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