Research Article

Effect of Biofortification of Zinc on Growth, Yield, Zinc Uptake and Economics of Pearl Millet

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Abstract

A field experiment was conducted during *kharif* 2019 at College Farm, College of Agriculture, Rajendranagar, Hyderabad, PJTSAU to evaluate the effect of agronomic zinc biofortification in pearl millet. Results revealed that basal application of RDF (60:30:20 kg ha^{-1} N, P_2O_5 and K_2O) + enriched vermicompost $ZnSO_4$ @ 25 kg ha^{-1}+ Foliar spray of 0.5% $ZnSO_4$ at tillering, heading and milking stages (T_{14}) registered significantly higher leaf area, tillers, dry matter production, effective tillers m^{-2}, number of grains, grain and stover yield over RDF alone and rest of the treatments but, T_{14} was on par with T_{12} -RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage, T_{13}-RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$, T_7- RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ - and T_5- RDF + 25 kg ha^{-1} $ZnSO_4$. Highest zinc uptake by grain (221.3 g ha^{-1}) was also registered by T_{14}-RDF (60:30:20 kg ha^{-1} N, P_2O_5 and K_2O) + enriched vermicompost $ZnSO_4$ @ 25 kg ha^{-1}+ Foliar spray of 0.5% $ZnSO_4$ at tillering, heading and milking stages over rest of the treatments.

Highest monetary returns (net returns ₹46,468 ha^{-1} and B:C ratio 3.16) were accrued with the application of T_{12}-RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray of 0.5% ZnSO4 at tillering, heading and milking stages but it was on par with T_5- RDF + 25 kg ha^{-1} $ZnSO_4$ (₹42773 ha^{-1} and 3.11), T_4-RDF + 12.5 kg ha^{-1} $ZnSO_4$ (₹40,003 $ha^{-1}$and 3.02) and T_{11}- RDF + 12.5 kg ha^{-1} $ZnSO_4$ + 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stages (₹41,880 ha^{-1} and 2.99).

Keywords: Pearl millet, Zinc biofortification, Growth, Yield, Zinc uptake, economics

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Introduction

Pearl millet is one of the world's hardiest warm season crops among the cereals and well adapted to drought-prone areas, low soil fertility and high temperature situations [1]. It is the fourth most important cereal in India in terms of area cultivated after rice, wheat and sorghum [2]. It is cultivated in 6.93 m ha producing 8.61 m tonnes with a productivity of 1243 kg ha^{-1} [3]. Grain is nutritious and contains 60-78% carbohydrates, 11-19% protein, 3.0-4.6% fat and also has good amount of phosphorous and iron along with rich source of Ca, K, Mg, Zn, Mn, riboflavin, thiamine, niacin, lysine and tryptophan [4]. Zinc is one of the essential micronutrients required relatively in small concentrations (5-100 mg kg^{-1}) for healthy growth and reproduction of plants apart from imparting protection against heat stress and certain pathogens [5]. It is also an essential nutrient for human health and vital for many biological functions apart from strong influence on fertility and growth of hair and nails. Low availability of nutrients in grain particularly micronutrients lead to increased malnutrition. Zinc deficiency, especially in infants and young children under five years of age, has received global attention. Zinc deficiency is the fifth leading cause of death and disease in the developing world. According to the World Health Organization (WHO), about 8,00,000 people die annually due to zinc deficiency, of which 4,50,000 are children under the age of five [6]. Globally, around 2 billion people are affected by zinc deficiency [7]. The solubility of zinc is highly dependent on soil p^H and moisture and hence, arid and semi-arid areas of Indian agro-ecosystems are often deficit in zinc. There are several approaches adopted to eliminate micronutrient malnutrition. Ferti-fortification/Bio-fortification is a process of increasing the density of vitamins and minerals in crops through plant breeding, transgenic techniques, or agronomic practices. Agronomic bio-fortification is a promising and cost - effective measure to increase Zinc concentration in cereal grains to address Zn malnutrition [8].

Agronomic bio-fortification is often considered as a short-term solution to increase micronutrient availability and mainly to complement genetic bio-fortification through breeding. Among different inorganic sources of Zinc, Zinc sulphate ($ZnSO_4$) is the most widely used due to its high solubility and lower cost. Foliar application of micronutrients is more beneficial than soil application as the application rates is lower than soil application coupled with the immediate nutrient supply to the plants for correcting deficiencies in standing crops. Moreover, soil pollution would be a major concern through soil application of micronutrients [9]. Crop roots are unable to absorb some important nutrients such as zinc, because of the soil properties, such as high soil p^H, lime or heavy texture, delete, and under this situations, foliar spraying is 6 to 20 times more effective over soil application.

Apart from direct application of micronutrients, application of enriched manures is also one of the viable options which directly supplies and also solubilizes the native reserves of micronutrient elements and renders them available to plants. Further, the beneficial effect of these materials on soil structure, nutrient retention capacity and their bio-regulatory roles in soil and productivity, quality and nutrient uptake. Integrated use of micronutrients in combination with organic manures serves as a better option due to high chelation and slow availability which prevents micronutrient losses through precipitation, fixation, oxidation and leaching. Organics may serve as a source of micronutrients and complexing agent. Zinc enriched organics provide beneficial effect on plant growth enriched nutrients for a longer time [10]. Keeping these points in view an experiment was carried out to find out the effect of zinc biofortification in pearl millet.

Materials and Methods

The field investigation was carried during *Kharif 2019* on sandy loam soils at College Farm of PJTSAU, College of Agriculture, Rajendranagar, Hyderabad, PJTSAU, Telangana state. Farm is geographically located at 17º 32' N latitude, 78º 41’ E longitude at an altitude of 541.6 m above mean sea level. The soil of the experimental field was sandy loam in texture, neutral (p^H 7.11) in soil reaction with normal electrical conductivity (0.31 dSm^{-1}), low in organic carbon (0.47%), low in available nitrogen (150.5 kg ha^{-1}), high in available phosphorus (82.3 kg ha^{-1}), high in available potassium (351.3 kg ha^{-1}) and low in available DTPA extractable zinc (0.52 ppm). The experiment was laid out in Randomized block design with 14 treatments (Table.2 ~~not 1)~~ and replicated thrice. Uniform dose of recommended dose of fertiliser (60:30:20 kg N, P_2O_5 and K_2O ha^{-1}) was applied to all treatments. N (Urea) was applied in 2 equal splits (50 % as basal dose and remaining 50% at tillering stage). Entire P_2O_5 through Single super phosphate and K_2O through Muriate of potash were applied at the time of sowing (basal). The required quantity of well decomposed farm yard manure @ 5 t ha^{-1} was applied as per the treatments (T_2 and T_9) 15 days prior to sowing of the crop and thoroughly incorporated in the soil and required quantity of well-prepared vermicompost @ 2 t ha^{-1} was applied as per the treatments (T_3 and T_{10}) as basal and thoroughly incorporated in the soil. Vermicompost @ 2 t ha^{-1} was incubated and left for enrichment with 21% $ZnSO_4$ @ 12.5 kg ha^{-1} (T_6 and T_{13}) and 25 kg ha^{-1} (T_7 and T_{14}) at room temperature for 15 days by proper moistening and later it was applied as per the treatments as basal one day before sowing and incorporated in the soil. The required quantity of 21% $ZnSO_4$ (Zinc sulphate heptahydrate - $ZnSO_4.7H_2O$) @ 12.5 kg ha^{-1} and 25 kg ha^{-1} was applied as per the treatments (T_6, T_7, T_{13} and T_{14}) as basal one day after SSP application. For foliar application 21% $ZnSO_4$ at 0.5% concentration was sprayed as per treatments. The pearl millet crop (PHB-3) was sown on 22nd July, 2019 adopting a spacing of 45 cm × 15 cm. The weather conditions during the crop growth period were conducive for normal growth and development and no serious incidence of pest and disease was noticed. Initial soil physico-chemical properties and nutrient content of the manures were analysed (**Table 1**) duly following standard procedures.

Table 1 Nutrient content (%) of organic manures

S. No.	Organic manure	Nutrient content			
		N (%)	P (%)	K (%)	Zn (ppm)
1	Farmyard manure	0.56	0.28	0.52	24.2
2	Vermicompost	1.28	0.56	0.62	46.8
3	Enriched vermicompost @12.5 kg ha^{-1}	1.64	0.68	0.76	54.5
4	Enriched vermicompost @ 25 kg ha^{-1}	1.68	0.69	0.82	57.8

Observations on growth, yield attributes, grain and stover yield were recorded duly following standard procedures for biometric sampling. Monetary returns (net returns and benefit: cost ratio) were calculated on the basis of prevailing market price of different input and output. Data were statistically analyzed as suggested by [11].

Results and Discussion

Perusal of data (**Table 2** and **3**) revealed that different zinc bio-fortification significantly influenced the growth parameters, yield attributes, yield, Zinc uptake and monetary returns of pearl millet.

Leaf area (cm^{-2} plant^{-1})

An overview of data on leaf area at heading stage (Table 2), indicated that there was profound influence of Zinc application through various sources and doses over sole application of RDF. Among the treatments, T_{14} - RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (Basal) + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage recorded significantly higher leaf area (1897.5 cm^2 plant^{-1}) over rest of the treatments but, it was on par with T_{12} -RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (1875.0 cm^2 plant^{-1}), T_7 – RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (1845.5 cm^2 plant^{-1}), T_{13} -RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (1841.1 cm^2 plant^{-1}), T_5 – RDF + 25 kg ha^{-1} $ZnSO_4$ (1818.0 cm^2 plant^{-1}) and T_{11} -RDF + 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (1817.8 cm^2 plant^{-1}). These treatments were followed by T_6, T_{10}, T_4, T_9 and T_3 which were in turn comparable with each other in terms of leaf area. While, the lowest leaf area (1588.1 cm^2 plant^{-1}) was recorded with T_1- RDF alone (60- 30- 20 N, P2O5 and K2O kg ha^{-1}), T_2- RDF+ 5 t FYM ha^{-1} (16.21.3 cm^2 plant^{-1}) and T_8-RDF + Foliar spray @ 0.5% $ZnSO_4$ at Tillering + Heading + Milking stage (1642.7 cm^2 plant^{-1}).

Improved leaf area in T_{14} and other comparable treatments could be ascribed to the enhanced cell division and elongation due to efficient utilization and prolonged availability of nutrients due to chelation of zinc with the organic ligands during enrichment process with vermicompost in conjunction with RDF and direct application of $ZnSO_4$ coupled with foliar spray of $ZnSO_4$ @ 0.5% at tillering, heading, milking coinciding with the peak nutrient requirement over application of RDF alone. These results are in line with the findings of [12] and [13].

Table 2 Growth and yield attributes ~~Yield and economic~~s of pearl millet as influenced by agronomic Zinc biofortification

Treatment	Leaf area (cm^{-2} plant^{-1})	Tillers (m^{-2})	Dry matter production (kg ha^{-1})	Effective tillers m^{-2}	Grains ear head^{-1}
T_1 - RDF (60:30:20 kg ha^{-1} N: P_2O_5:K_2O) alone	1588.1	45.3	3620	14.2	2116
T_2 - RDF + FYM @ 5 t ha^{-1}	1621.3	46.2	3687	14.5	2158
T_3 - RDF + Vermicompost @ 2 t ha^{-1}	1687.2	48.1	3771	15.1	2223
T_4 - RDF + 12.5 kg ha^{-1} $ZnSO_4$ (Basal)	1742.1	49.6	3866	15.5	2291
T_5 - RDF + 25 kg ha^{-1} $ZnSO_4$ (Basal)	1818.0	51.8	4083	16.2	2432
T_6 -RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ (Basal)	1770.8	50.4	3985	15.8 b	2352
T_7 - RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (Basal)	1845.5	52.6	4136	16.5	2466
T_8 - RDF + Foliar spray @ 0.5% $ZnSO_4$ at Tillering + Heading + Milking stage	1642.7	46.8	3752	14.7	2194
T_9 - RDF + FYM @ 5 t ha^{-1} + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage	1692.4	48.2	3849	15.1	2264
T_{10} - RDF + Vermicompost @ 2 t ha^{-1} + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage	1755.3	50.0	3985	15.7	2357
T_{11} - RDF + 12.5 kg ha^{-1} $ZnSO_4$ (Basal)+ Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage	1817.8	51.8	4105	16.2	2429
T_{12} - RDF + 25 kg ha^{-1} $ZnSO_4$ (Basal) + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage	1875.0	53.4	4288	16.7	2524
T_{13} - RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ (Basal)+ Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage	1841.1	52.5	4179	16.4	2467
T_{14} - RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (Basal) + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage	1897.5	54.1	4311	16.9	2554
SEm $\pm$	39.7	1.1	98	0.3	64
CD (p=0.05)	115.9	3.3	287	1.0	187

Number of tillers (m^{-2})

Similar to the dry matter production the treatment T_{14} - RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$+ Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage maintained its superiority by recording highest tillers (54.1 m^{-2}) as compared to RDF alone and rest of the treatments, but T_{14} was equally superior T_{12} -RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (53.4 m^{-2}), T_7 – RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (52.6 m^{-2}), T_{13} -RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (52.5 m^{-2}), T_{11} -RDF + 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (51.8 m^{-2}) and T_5 – RDF + 25 kg ha^{-1} $ZnSO_4$ (51.8 m^{-2}). These were followed by treatments T_5, T_6, T_{10}, T_4 and T_3 which were on par with each other and the lowest number of tillers were recorded with T_1- RDF alone (45.3 m^{-2}) and T_8-RDF + Foliar spray @ 0.5% $ZnSO_4$ at Tillering + Heading + Milking stage (48.2) and T_2- RDF+ 5 t FYM ha^{-1} (46.2 m^{-2}). Application of Zinc enriched vermicompost along with Zn foliar spray might have favorably altered the Zn dynamics in soil and plant to prolong its availability for better growth (higher assimilatory surface and dry matter production) that reflected in improved tillering. Positive role of Zinc on improved tillering was also earlier documented by [14] and [15].

Dry matter production (kg ha^{-1})

Perusal of data (Table. 2) highlighted that crop supplied with T_{14}-RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage) recorded significantly higher dry matter production (4310.7 kg ha^{-1}) over rest of the treatments but T_{14} was comparable with T_{12} -RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (4288.5 kg ha^{-1}), T_{13} -RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (4179.2 kg ha^{-1}), T_7 – RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (4135.6 kg ha^{-1}), T_{11} -RDF + 12.5 kg ha^{-1} $ZnSO_4$ (Basal) + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (4105.4 kg ha^{-1}) and T_5 - RDF + 25 kg ha^{-1} $ZnSO_4$ (4082.8 kg ha^{-1}) and the lowest dry matter production was observed with T_1- RDF alone (60- 30- 20 N, P_2O_5 and K_2O kg ha^{-1} (3619.6 kg ha^{-1}). Adequate and sustained availability of zinc through enriched vermicompost (Table.1) and direct application of ZnSO4 coupled with foliar spray coinciding with critical stages in T_{14} and other treatments enhanced the activity of meristematic cells and reflected in better vegetative growth (photosynthetic area and number of tillers) and eventually contributed to the increased dry matter production [16] and [17].

Effective tillers (m^{-2})

Similar to the growth parameters, the treatment T_{14} recorded maximum number of effective tillers (16.9 m^{-2}) over rest of the treatments, but it was on par with T_{12} -RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (16.7 m^{-2}), T_7 – RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (16.5 m^{-2}), T_{13} -RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (16.4 m^{-2}), T_{11} (RDF + 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (16.2 m^{-2}) and T_5 – RDF + 25 kg ha^{-1} $ZnSO_4$ (16.2 m^{-2}). While, least number of effective tillers m^{-2} were registered with T_1- RDF alone (14.2 m^{-2}).Higher number of effective tillers associated with crop applied with T_{14} was probably due to combined use of RDF and zinc enriched vermicompost in conjoint with foliar zinc sprays at growth stages that might have released growth-promoting enzymes, vitamins, and nutrients, which play an important role in the metabolic process of the plant, increasing nutrient uptake and thus enhancing effective tillers. These results corroborate with those of [18].

Grains ear head^{-1}

Highest number of grains ear head^{-1} (2554)were recorded by the crop fertilized with T_{14} but, it was on par with T_{12} - RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (2524), T_{13} -RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (2467), T_7 – RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (2466), T_5 – RDF + 25 kg ha^{-1} $ZnSO_4$ (2432) and T_{11} -RDF + 12.5 kg ha^{-1} $ZnSO_4$+ Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (2429). While, the treatment T_1- RDF alone registered the lowest number of grains ear head^{-1} (2116). The zinc enriched vermicompost might have created favorable physical environment for increased mineralization and mobility of nutrients through enrichment technique and chelation process of zinc to organics, that might have improved available N, resulting in higher nutrient uptake and crop growth, thus leading to higher ear head length and accommodated more grains ear head^{-1} [19].

Grain Yield (kg ha^{-1})

Crop supplied with T_{14}-RDF and zinc enriched vermicompost @ 25 kg ha^{-1} in conjunction with 0.5% foliar spray of $ZnSO_4$ at tillering, heading and milking stages recorded significantly higher grain yield (3193 kg ha^{-1}) over rest of the treatments (**Table 3**) but, T_{14}- was on par with T_{12} -RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (3135 kg ha^{-1}), T_{13-} RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (2981 kg ha^{-1}) and T_7 – RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (2928 kg ha^{-1}) and lowest grain yield was registered with T_1- RDF alone (2477 kg ha^{-1}). Improved grain yield in T_{14} treatment was probably due to favorable effect of enriched vermicompost on physico-chemical and biological properties that enhanced the availability of nutrients through mineralization kinetics and enhance the plant nutrient uptake pattern for prolonged period that improved the growth parameters and sustained supply of zinc, through enrichment technique which subsequently reflected positively on grain yield. These results corroborate with the findings of [20].

Table 3 Yield, Zinc uptake and economics of pearl millet as influenced by agronomic Zinc biofortification

Treatment	**Grain yield (kg ha^{-1})**	**Straw yield (kg ha^{-1})**	**Zinc uptake by grain (g ha^{-1})**	**Net returns (₹ ha^{-1})**	**B:C ratio**
T_1 - RDF (60:30:20 kg ha^{-1} N: P_2O_5:K_2O) alone	2477	4678	129.2	34868	2.80
T_{2-} RDF + FYM @ 5 t ha^{-1}	2570	4724	139.1	31767	2.30
T_{3-} RDF + Vermicompost @ 2 t ha^{-1}	2667	4832	150.2	22815	1.65
T_{4-} RDF + 12.5 kg ha^{-1} $ZnSO_4$ (Basal)	2746	4908	168.1	40003	3.02
T_{5-} RDF + 25 kg ha^{-1} $ZnSO_4$ (Basal)	2897	5140	186.7	42773	3.11
T_{6-}RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ (Basal)	2821	5020	175.8	25622	1.72
T_{7-} RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (Basal)	2928	5192	193.7	27452	1.76
T_{8-} RDF + Foliar spray @ 0.5% $ZnSO_4$ at Tillering + Heading + Milking stage	2601	4812	138.9	36239	2.76
T_{9-} RDF + FYM @ 5 t ha^{-1} + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage	2720	4928	156.2	33735	2.32
T_{10-} RDF + Vermicompost @ 2 t ha^{-1} + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage	2853	5009	168.9	25542	1.70
T_{11-} RDF + 12.5 kg ha^{-1} $ZnSO_4$ (Basal)+ Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage	2890	5148	185.2	41880	2.99
T_{12-} RDF + 25 kg ha^{-1} $ZnSO_4$ (Basal) + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage	3135	5318	211.5	46468	3.16
T_{13-} RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ (Basal)+ Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage	2981	5189	194.0	27727	1.75
T_{14-} RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (Basal) + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage	3193	5335	221.3	31645	1.84
SEm $\pm$	91	107	172.8	1885	0.08
CD (p=0.05)	265	311	3.2	5478	0.23

Straw yield (kg ha^{-1})

Among the treatments, significantly higher stover yield of 5335 kg ha^{-1} was recorded in T_{14} -RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage and it was significantly superior over rest of the treatments (Table.3). However, it was on par with T_{12} -RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (5318 kg ha^{-1}), T_7 – RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (5192 kg ha^{-1}), T_{13} -RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (5189 kg ha^{-1}), T_{11} -RDF + 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (5148 kg ha^{-1}), T_5 – RDF + 25 kg ha^{-1} $ZnSO_4$ (5140 kg ha^{-1}), T_{10} (5089 kg ha^{-1}), T_6 (5020 kg ha^{-1}), T_9 (4928 kg ha^{-1}) and T_4 (4908 kg ha^{-1}). Lowest stover yield of 4678 kg ha^{-1} was registered with T_1- RDF alone. Increased stover yield associated with the treatment T_{14} might be due to prolonged availability and uptake of primary nutrients coupled with addition of zinc that improved assimilatory surface that contributed to higher photosynthate, protein synthesis and growth hormone production that enhanced internode elongation and subsequent luxurious growth which eventually contributed to the increased dry matter production. [21] and [22].

Zinc uptake by grain (g ha^{-1})

Among the various Zinc biofortification treatments highest zinc uptake (221.3 g ha^{-1}) was recorded with the by (T_{14}) - RDF (60:30:20 kg ha^{-1} N, P_2O_5 and K_2O) + enriched vermicompost $ZnSO_4$ @25 kg ha^{-1}+ Foliar spray of 0.5% $ZnSO_4$ at tillering, heading and milking stages) over rest of all treatments. It was followed by T_{12} - RDF + 25 kg ha^{-1} $ZnSO_4$ (Basal) + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (211.5 g ha^{-1}). While the lowest uptake was recorded with application of RDF alone (129.2 g ha^{-1}). Improved Zinc uptake associated with T_{14} treatment could be attributed to the improved availability of Zinc on account of higher Zinc content coupled with the foliar spray at critical stages and beneficial effects of vermicompost in mobilizing the native nutrients besides chelation [10].

Net returns (₹ ha^{-1})

Among the different treatments, T_{12}- RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage recorded highest net returns (₹ 46,468 ha^{-1}) over rest of the treatments but, it was on par with T_5 – RDF + 25 kg ha^{-1} $ZnSO_4$ (₹ 42,773 ha^{-1}) and T_{11} (RDF + 12.5 kg ha^{-1} $ZnSO_4$ (Basal) + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (₹ 41,880 ha^{-1}) followed by T_4 – RDF + 12.5 kg ha^{-1} $ZnSO_4$ (₹ 40,003 ha^{-1}). While, the lowest net returns were recorded from the treatment T_3 – RDF + Vermicompost @ 2 t ha^{-1} (₹ 22,815 ha^{-1}). The results are in conformity with [23].

B: C ratio

Highest B: C ratio was fetched with T_{12} -RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (3.16) over rest of the treatments but it was found on par with T_5 – RDF + 25 kg ha^{-1} $ZnSO_4$ (Basal) (3.11), T_4 – RDF + 12.5 kg ha^{-1} $ZnSO_4$ (Basal) (3.02) and T_{11} -RDF + 12.5 kg ha^{-1} $ZnSO_4$ (Basal) + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (2.99) followed by T_1 – RDF alone (2.80), T_8 (2.76) T_9 (2.32) and T_2 (2.30). While, the lowest B: C ratio was recorded with T_3 – RDF + Vermicompost @ 2 t ha^{-1} (1.65). Lower net returns associated with vermicompost treatments was due to the high cost incurred on vermicompost in comparison to rest of the inorganics. The results are in conformity with [24] and [25].

Conclusion

From the present experiment it could be concluded that among different doses and methods of zinc biofortification tested in pearl millet, basal application of RDF along with vermicompost enriched with $ZnSO_4$ @ 25 kg ha^{-1} + foliar spray of $ZnSO_4$ @ 0.5% at tillering, heading and milking stages was superior in terms of growth, yield attributes and zinc uptake by grain. Although the B:C ratio accrued with RDF and inorganic source of $ZnSO_4$ were higher, in the present situations of declining cattle population in order to sustain the yield, profitability and soil health in long run, biofortification involving Zinc enrichment technique using vermicompost prepared at farm level using crop residues and other farm wastes would be a sound and viable option on long run as compared to the sole application of inorganic off-farm resources.

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