Effect of different sourcesand application methods of zinc on content and uptake of micronutrients in basmati rice crop in sandy loam soil.

Abstract

Zinc (Zn) is an essential trace element for plants, animals and humans' health. Zn deficiency is widely spread in paddy soils of India and has negative impact on national rice production. Field experiment on rice crop was conducted in sandy loam soil at crop research center chirodi of SVBP University of Agriculture and Technology, Meerut., during kharif season of 2011 and 2012 toevaluate the "Effect of different sources and application methods of zinc on content and uptake of micronutrients in basmati rice crop in sandy loam soil" The experiment was laid out in randomized block design with three replications. The experiment comprised of twelve treatments *viz.;* T_1 (control), T_2 (recommended NPK @120:60:60 kg ha^{-1}) T_3 (5 kg Zn through ZnSO4.7H_2O+RDF),T_4(5 kg Zn through mono ZnSO4.7H_2O).T_5(0.1% Zn spray through ZnSO4.7H_2O+RDF),T_6 (0.1% Zn spray through ZnSO4.7H_2O + RDF),T_7 (0.012% Zn spray through chelated Zn at tillering + RDF),T_8 (0.05% Zn spray through ZnSO4.7H_2O at tillering +0.05% at panicle initiation+ RDF), T_9 (0.05% Zn spray through mono ZnSO4.7H_2O at tillering + 0.05% at panicle initiation +RDF),T_{10} (0.006% Zn spray through chelated Zn at tillering + 0.006% at panicle initiation+ RDF), T_{11} (micronutrient mixture@ 25kg ha^{-1} + RDF), T_{12} (vermicompost @ 3tha^{-1}+ RDF).The experimental soil was low in organic carbon and available nitrogen and medium in phosphorus and higher in potassium with slightly alkaline in pH. The status of DTPA extractable Zn 1.23 mg Kg^{-1},Fe 14.85 mg Kg^{-1} Cu 2.43 mg Kg^{-1} Mn 10.91 mg Kg^{-1} in the surface soil..Nutrient assimilation at different stages by the rice crop varied significantly due to application of different treatments in the study. Maximum zinc content 85.78 and 93.57 ppm and uptake 288.60 and 341.85 gm/ha at 30 DAT during 2011 and 2012 found in T12 which was significantly higher than the rest of the treatments while minimum zinc content recorded in T_1 was significantly lower than the rest of the treatments during both the years. Similar trends were also recorded at 60 DAT, grain and straw growth stages of rice plant. The zinc content of plant sample in T_{11} and T_3 was also higher and statistically at par to the level of zinc content recorded in T_{12}. The Cu, Fe, and Mn content and uptake at different growth stages of rice plant sample in T_{11} and T_3 was also higher and like the level in T_{12}. Among the method of Zn application, soil application resulted in higher biomass, micronutrient content and uptake in the grain and straw. Foliar application caused greater effect on zinc content and uptake and as well as content and uptake of Cu, Fe and Mn in rice plant at different growth stages during both the years. Among the sources of Zinc ,ZnSO4.7H2O proved to be the most efficient source of Zn for rice production.

Key Word: Rice, zinc sulphate, Content, uptake, micronutrients, soil application.

Introduction

Rice (Oryza sativa L.) is one of the most predominant cereal food crops in about 40 countries in the world. In India, it is grown in an area of 45.07 m ha with a total production of 122.27 m t and a productivity of 2713 kg ha^{-1}.Milled production in India in 2022-23 is 136.00 million tones and 2023-24 is 134.00 million tones. As per the ministry of Agriculture, Vanakalam (kharif) paddy acreage as on 08th September 2023 has increased by 2.69 % to 403.40 lakh hectares (996.84 lakh acres) as compared to 392.81 lakh hectares (970.6 lakh acres) during the same period of last year. Higher acreage was covered in Uttar Pradesh 59.01 lakh ha (145.83 lakh acres). Green revolution, introduction the high yielding varieties, extension of irrigated areas and use of high analysis micro-nutrient free NPK fertilizers which increasingly catalyze the depletion of finite reserves of soil micronutrients leading to the occurrence of widespread multi-micronutrient deficiencies. Significance of these nutrients has been realized during past decades when their widespread deficiencies, especially Zn, Fe and B were observed in most of the soils in India **(Katyal, 2018)**. Enhancing the availability of micronutrients along with macronutrients in rice cultivation could improve the quality and yield and thus micronutrients are more important for sustainable rice production **(Chauhan et al. 2017).** Indian soils are becoming poorer in respect of organic matter content. The depletion of primary, secondary and micronutrients like Zn, Cu, Mn, B and Fe has also become more conspicuous in decreasing the productivity of crops which can be alleviated either by external application of organic matter or any other application of suitable sources to sustain productivity and quality of produce besides soil health and fertilizer use efficiency. High-yielding varieties and greater fertilizer application were the strategies to vigor the crop yield potential and feed increasing population. Increased application of fertilizers was not sufficient to compensate over-use of cultivated land. Highyielding varieties rapidly depleted soil micronutrients, therefore recent literature witnessed Zn deficiency, along with Iron (Fe), vitamin A, and Iodine (I) deficiency. **(Rana and Kashif, 2014).**Among the essential nutrients, zinc plays a vital role in various plant physiological processes, including nutrient metabolism, enzyme activation, and stress tolerance. Zinc is a cofactor for numerous enzymes involved in carbohydrate and protein metabolism, growth regulation, and defense mechanisms. Adequate zinc nutrition is crucial for maintaining optimal plant growth, development, and overall productivity **(Yadav et al., 2020)**. Zn influences the activity, structural integrity, and folding of numerous proteins as a fundamental or catalytic enzyme **(Castillo-González et al., 2018) and (Zaheer et al., 2020).** In addition to its role as a key factor for the structural integrity of ribosomes, Zn plays a number of other important bio-physicochemical roles in plants, including gene regulation and activation, protein synthesis, involvement in carbohydrate metabolisms, and morphological and anatomical participation in bio-membranes **(Hafeez et al., 2013;)** . Application of zinc salts e.g., zinc sulphate is a common practice to correct Zn deficiency. Moreover, Zn chelates, such as Zinc ethylene diamine tetra acetic acid (Zn-EDTA), which supply significant amount of Zn to the plant without interacting with soil components. In Zn-EDTA Zn ion (Zn^2+) is surrounded by chelated ligands. Efficient uptake and transport of micronutrients to the grains can be increased by foliar application of micronutrient containing fertilizers. Therefore, like other micronutrients, foliar application of Zn is considered as potential method to ameliorate Zn deficiency in cereal grains **(Cakmak, 2008: Fang et al., 2008)** This study was aimed to investigate the effects of different sources of zinc applied through soil or foliar method on rice yield dynamics and nutrients status in paddy grains and straw. Results of this study will help to mitigate zinc deficiency in rice and improve zinc, Copper, Iron and Manganese use efficiency in the rice crop.**Nayan and Fouzi (2023)**to evaluate the the application of Zn and Fe in the form of sulfate salt showed a lower toxicity effect in terms of growth and dry matter of plants than Fe and Zn in the form of ethylene di amine tetra acetic acid (EDTA). In terms of Zn uptake, it was found that there was a significant difference observed compared to the control, especially when 3 kg/ha Zn was applied, regardless of whether it was in the form of sulfate or EDTA. Furthermore, there was an increase in Fe uptake observed with increased Zn application.**Mrudhula et al,(2023)** exhibited that in brown rice significantly received highest zinc content (22.4) with soil application of ZnSo4 @ 50kg ha-1+ foliar application of zinc at grain filling stage @ 1% over control and it was on par with all other treatments. At 60 days, 120 days and 180 days after harvest of the crop data revealed that soil application of ZnSO4 @ 50 kg ha-1 + foliar application of zinc at grain filling stage @ 0.5% recorded significantly the highest zinc content in single polished and double polished rice followed by soil application of ZnSO4 @ 50 kg ha-1 + foliar application of zinc at grain filling stage @ 1%.**Sathiyamurthi et al.(2019)**The results of the study indicated that soil application of Zn significantly increased the seed index and lint index and micro- nutrient uptake of cotton.The maximum Zn uptake by straw and total Zn uptake by rice was observed with Zn EDTA followed by ZnO, ZnSO4.7H2O, Zn3(PO4)2 and $ZnCl_2$ but these sources were found nonsignificant. These findings are well corroborated with **Verma et al., (2015) and Islam et al., (2016).**This study was aimed to investigate the effects of different sources of zinc applied through soil or foliar methods on micronutrient content and uptake at different growth stages of rice. Results of this study will help to mitigate micronutrient deficiency in rice and improve the nutrient use efficiency in the rice paddies.

Materials and Methods

The experiment was conducted at the Crop Research Center, Chirodi of Sardar Vallabhbhai Patel University of Agriculture & Technology (SVPUAT), Meerut (U.P.) during *kharif* 2011 and 2012. The area receives 862 mm of rain annually on an average, of which 90% is confined to rainy season (July - September). The soil of experimental site was sandy loam in texture having 53.54, 27.6, and 18.86 % sand , silt and clay, respectively; pH 8.35, Electrical conductivity (EC) 0.189 dSm^{-1}, Organic Carbon 0.42% (4.2 g Kg^{-1}) low, alkaline $KMnO_4$ N 206.30 Kg ha^{-1}, Olson –P 18.60 Kg ha^{-1} ammonium acetate extractable K 278.70 Kg ha^{-1} and DTPA extractable Zn 1.23 mg Kg^{-1},Fe 14.85 mg Kg^{-1} Cu 2.43 mg Kg^{-1} Mn 10.91 mg Kg^{-1}. The treatments comprised of 4 sources of Zn (zinc sulphate heptahydrate), mono zinc sulphate, chelated zinc and micronutrient mixture) and vermicompost with the combination of RDF (NPK @ 120:60:60) in different mode of application (soil application and foliar spray). There were 12 treatments combinations replicated thrice in a randomized block design. The vermicompost @ 3 t ha^{-1} were applied before transplanting with the combination of RDF during 2011 and 2012. While the graded level of Zn was applied at the time of transplanting, tillering and panicle initiation. A uniform dose of Urea, Diammonium Phosphate (DAP) , Muriate of Potash (MOP) , Zinc Sulphate , Mono Zinc suphate, Chelated Zinc, micronutrient mixture and Vermicompost were used to provide N, P, K, Zn, Cu, Fe, Mn as per treatments in T_2-T_{12} Whereas in T_1 no fertilizers were used. A basal dose of 60 Kg N, 30 Kg P and 30 Kg K ha^{-1} and 5 Kg Zn ha^{-1} and full dose of vermicompost was applied at the time of transplanting while remaining half dose of N were applied at the time of tillering and panicle initiation. Growth observations were recorded at 30 and 60 day after transplanting (DAT) and at harvesting of the crop. Yield attributes were recorded at harvest and grain and straw yield was recorded plot wise after threshing of produce. After cleaning and drying the to 14 per cent moisture. The yield of net plot, thus converted to q ha^{-1}. Dry weight of straw collected from net plot was recorded after sun grains; the grain yield was recorded in kg per plot. Total uptake of N, P, K, Zn, Cu, Fe and Mn by rice was calculated from dry matter obtained at respective interval and after harvesting (grain and straw). Plant sample were analyzed for total N, P, K, Zn, Cu, Fe and Mn The total N content was estimated through Automatic N analyzer using 0.2 gm grounded samples. For P and K analysis, plant samples were wet digested in di-acid mixture. P was determined by Vanadomolybidos phosphoric yellow color method (Jackson, 1973), K by Flame Photometer (*Jackson*,1973), Zn, Cu, Fe and Mn by atomic absorption spectrophotometer.The entire data was analyzed statistically by using ANOVA. Chemical analysis for plant and soil was done by using standard methods in the Department of Soil Science, College of Agriculture, SVPUAT, Meerut (U.P.), India.

Result and Discussion

Zinc content (mg kg^{-1}) and uptake (gha^{-1})of rice at different stages of rice plant.

The two years data presented in table 1. Indicates that the Zinc content of rice plant at 30 DAT ranges from 46.37 to 85.78 and 50.24 to 93.59 ppm and uptake ranges from 80.86 to 288.04 and 99.62 to 341.41gha^{-1} was recorded in different treatments during 2011 and 2012, respectively. Maximum zinc content 87.78 and 93.57 ppm and uptake 288.04 and 341.41 gha^{-1} during 2011 and 2012 recorded in T12 significantly higher than the rest of the treatments while minimum zinc content(0.75 and 0.89 ppm) and uptake (13.08 and 17.65g ha^{-1})was observed in T_1which was significantly lower than the rest of the treatments during both the years. Generally, the zinc content of plant sample at all the growth stage was higher in those treatments where zinc through either source was applied basal than foliar. The zinc content of plant sample in T_{11} and T_3 was also higher and statistically at par to the level of zinc content recorded in T_{12}. Among the treated plots minimum plant zinc content was recorded in T_2 having no zinc application followed by T_{10} and T_9 received lower concentration of zinc in foliar mode. Zinc content of rice plant at 60 DAT ranges from 26.19 to 74.35 and 31.93 to 79.35 ppm and uptake 87.55 to 459.03 and 126.03 to 523.86 g ha^{-1}during 2011 and 2012, respectively. Maximum zinc content 74.35 and 79.35 and uptake 459.03 and 523.86 g ha^{-1} during 2011 and 2012 found in T12 was significantly higher than the rest of the treatments while minimum zinc content (0.60 and 0.74ppm) and uptake (20.05 and 29.20 g ha^{-1})recorded in T_1 was significantly lower than the rest of the treatments during both the years. In general the zinc content at 60DAT of plant sample was found superior in those treatments where zinc through either source was applied basal than foliar. The zinc content and uptake of plant sample in $T_{11}$and $T_3$was also higher because of Micronutrient mixture @25kgha^{-1}and $ZnSO_4.7H_2O$ @25Kg ha^{-1} was applied with RDF respectively but not to the level of zinc was recorded in $T_{12}$where Vermicompost @3tons ha^{-1} + RDF was used. Among the zinc treated plots minimum zinc content and uptake at this growth stage was recorded in T_{10}followed by T_9 receiving lower concentration of zinc in foliar mode and significantly superior with T_2 where no zinc was applied.Zinc content of rice grain ranges from 41.46 to 81.54 and 47.63 to 88.46 ppm and uptake ranges from 100.87 to 301.69 and 127.64 to 384.80gha^{-1} was recorded during 2011 and 2012, respectively. Maximum zinc content 81.44 and 88.46 ppm and uptake 301.69 and 384.80 gha^{-1} during 2011 and 2012 found in T_{12} was significantly higher than the rest of the treatments while minimum zinc content and uptake recorded in T_1 was significantly lower than the rest of the treatments during both the years. In general, the zinc content of rice grain was found to be superior in those treatments where zinc through either source was applied basal than foliar. The zinc content of rice grain in T_3 and T_{11} was also higher but not to the level of zinc recorded in T_{12}. Among the zinc treated plots minimum zinc content was recorded in T_{10} followed by T_9 receiving lower concentration of zinc in foliar mode and significantly superior with T_2 where the zinc was notapplied.Zinc content of rice straw ranges from 4.58 to 17.65 and 5.82 to 19.52 ppm and uptake18.68 to 100.65 and 23.85 to 117.68 gha^{-1}during 2011 and 2012, respectively. Maximum zinc content 17.65 and 19.52 ppm and uptake 100.65 and 117.68 gha^{-1} during 2011 and 2012 found in T_{12} was significantly higher than the rest of the treatments while minimum zinc content recorded in T_1control where any fertilizerwasnot applied. The zinc content of rice straw was found superior in those treatments where zinc through either source was applied in basal and foliar. The zinc content of rice straw in T_{11} and T_3 was also higher and statistically at par to the level of zinc content recorded in T_{12}. Among the zinc treated plots minimum zinc content was recorded in T_{10} followed by T9.Treatments where zinc is applied in foliar mode receiving lower zinc content and uptake but significantly superior to T_2 where zinc was not applied.Higher zinc uptake at 30 and 60 DAT and by rice grain and straw at harvesting in T_{12} may be described with higher biomass production at respectively growth stages and higher zinc content. Higher zinc content in plant sample under these treatments may be due to inclusion of vermicompost and organic matter had been reported to improve zinc availability in soil. Similar result were also recordedby**Kumar et al. (2023)**The experimental results also showed that micronutrient (Zn, Fe and Mn) concentration and uptake significantly increased as compared to control with micronutrient application (Zn, Fe and Mn).**Kumar and Kumar (2009)** studied that there was a significant increase in the yield and yield attributes of rice up to 45 kg ZnSO4/ha. The content and uptake of Zn also increased significantly with increasing levels of zinc sulfate. Soil applied Zn was superior compared to its foliar application. Similarly, the maximum Zn uptake by straw and total Zn uptake by rice was observed with Zn EDTA followed by ZnO, ZnSO4.7H2O, Zn3(PO4)2 and ZnCl2 but these sources were found nonsignificant. These findings are well corroborated with **Verma et al., (2015) [27] and Islam et al., (2016). Ghatak *et.al* (2005)** reported that application of 30 kg ZnSO4/ha recorded the highest values of yield attributes, yield, uptake of Zn, N and K by plant. Similar result also observed by **Kailiang Mi, (2023)** and **Rana and Kashif, 2014**

4.3.5 Copper content (mg kg^{-1}) and uptake (gha^{-1}) of rice at different stages

The two years data are presented in table 2. indicated that the copper content and uptake of rice biomass at 30 and 60 DAT and rice grain and straw was significantly affected by different treatments during both the years. Copper content of rice plant at 30 DAT ranged from 16.69 to 34.68 and 20.35 to 38.83 ppm and uptake 29.11 to 116.56 and 40.38 to 141.72 gha^{-1}in different treatments during 2011 and 2012, respectively. Maximum Copper content 87.78 and 93.57 ppm and uptake 116.56 and 141.72 gha^{-1}during 2011 and 2012 found in T_{12} was significantly higher than the rest of the treatments while minimum copper content was recorded in $T_1$was significantly lower than the rest of the treatments during both the years. Generally, the Copper content of plant sample at this stage was higher in those treatments where zinc through either source was applied as basal than foliar. The copper content of plant sample in $T_{11}$where micronutrient mixture @25 Kgha^{-1}and $T_3$where $ZnSO_4.7H_2O$@ 25 Kgha^{-1} was applied with RDF respectively was also higher but not to the level of copper was recorded in T_{12}. Among the zinc treated plots minimum plant Copper content was recorded in T_{10} and T_9 where lower concentration of zinc was applied in foliar mode and those treatments slightly higher with T_2 receiving no zinc. Similar trends in content and uptake was also recorded in rice plants at stage of 60 DAT. Copper content in rice grain ranged from 14.46 to 30.58 and 16.65 to 33.86 ppm and uptake 34.89 to 113.35 and 44.75 to 147.28 gha^{-1} during 2011 and 2012, respectively. Maximum Copper content 30.58 and 33.87 ppm and uptake 113.35 and 147.28 gha^{-1} during 2011 and 2012 found in T_{12} was significantly higher than the rest of the treatments while minimum Copper content and uptake was recorded in $T_1$was significantly lower than the rest of the treatments during both the years. Generally, the Copper content and uptake of plant sample at this stage was higher in those treatments where zinc through either source was applied basal than foliar. The

Copper content of plant sample in T_{11} and T_3 was also higher and statistically at par with T_{12} during 2011 while during 2012.The treatments received micronutrient mixture and zinc sulphat heptahydrate with RDF respectivelyinT_{11} and T_3 was also higher but not to the level of copper recorded in T_{12}. The effect of foliar application with lower concentration of zinc was non-significant and it was found statistically at par with T_2 receiving no zinc during 2011 but during 2012 those treatments significantly varied to T_2.Copper content in rice straw ranged from 5.49 to 17.25 and 7.86 to 19.62 ppm and uptake 21.83 to 94.07 and 31.95 to 129.93 gha^{-1} during 2011 and 2012, respectively. Maximum Copper content 17.25 and 19.62 ppm and uptake 94.07 and 129.93 gha^{-1} during 2011 and 2012 found in $T_{12}$where vermicompost @3 ton $ha^{-1}$was applied with RDF significantly higher than the rest of the treatments while minimum Copper content and uptake was recorded in T_1which was significantly lower than the rest of the treatments during both the years. Generally, the Copper content and uptake of rice straw was higher in those treatments where zinc through either source was applied basal than foliar application. The Copper content of plant sample in T_{11} and T_3 was also higher and while T_{11} is statistically at par with T_{12} during 2011 while during 2012 those treatments were also higher but not to the level of copper was recorded in T_{12}. Except for T_5 and T_6 the effect of foliar application with higher to lower concentration of zinc was non-significant and it was found statistically at par with T_2 receiving no zinc during both the years.The higher uptake of copper by rice plant, grain, and straw in T_{12} at 30, 60 DAT and harvesting is well expected since the biomass yield as well as copper content was higher in T_{12} at these stages.**Gurmani*et al.* (2003)** observed that Application of NPK + Zn + Cu + Fe + Mn resulted in the highest Zn concentration, whereas application of NPK + Cu resulted in the highest Cu concentration in the leaves. Fe and Mn concentrations in the leaves were highest with the application of NPK Cu + Mn and NPK + Zn + Cu + Fe + Mn, respectively.

4.3.6 Iron content (ppm) of rice at different stages

The two years data presented in table 3. Indicated that the Iron content of rice biomass at 30 and 60 DAT and rice grain and straw was significantly affected by different treatments during both the years. Iron content of rice plant at 30 DAT ranged from 312.65 to 366.93 and 320.46 to 374.59 ppm and uptake from 545.83 to 1233.14 and 6635.25 to 1366.11gha^{-1} during 2011 and 2012, respectively. Maximum iron content 366.93 and 374.59 ppm and uptake 1233.14 and 1366.11gha^{-1} during 2011 and 2012 found in T_{12} was significantly higher than the rest of the treatments while minimum iron content and uptake recorded in T_1 (control) was significantly lower than the rest of the treatments during both the years. In general, the iron content and uptake of plant sample at this stage was higher in those treatments where zinc through either source was applied basal than foliar. The content of iron in plant sample in T_{11} and T_3 was also higher and statistically at par to the level of iron content recorded in T_{12}. Similar trends in content and uptake were also observed at the 60 DAT stage of rice plant.The iron content of grain ranged from 56.58 to 92.85 and 62.25 to 98.78 ppm and uptake from 134.64 to 343.36 and 167.57 to 429.86 gha^{-1} during 2011 and 2012, respectively. Maximum iron content 92.85 and 98.78 ppm and uptake 343.36 and 429.86 gha^{-1} during 2011 and 2012 found in T_{12} was significantly higher than the rest of the treatments while minimum iron content and uptake recorded in T_1 which was significantly lower than the rest of the treatments during both the years. In general, the iron content of grain was lower in those treatments where zinc through either source was applied in foliar than basal. The iron content of grain in T_{11}, $T_3$and T_4 was also higher and statistically at par with the level of iron content recorded in T_{12}. But in the of uptake ironuptake of grain sample in T_{11} and T_3 was also higher and statistically at par to T_{12} during 2011 but during 2012 these treatments were found significantly inferior to T_{12} in respect of iron uptake. Iron content of rice straw ranged from 148.89 to 212.59 and 162.35 to 218.35 ppm and uptake from 610.03 to 1212.06 and 667.64 to 1445.22 gha^{-1} during 2011 and 2012, respectively. Maximum iron content 212.59 and 218.35 ppm and uptake 1212.06 and 1445.22 gha^{-1} during 2011 and 2012 found in T_{12} was superiorto the rest of the treatments while minimum iron content and uptake recorded in T_1 was significantly lower than the rest of the treatments during both the years. Generally, the iron content and uptake of rice straw was higher in those treatments where zinc is applied basal than foliar. The iron content and uptake of rice straw in T_{11} and T_3 was also higher and statistically at par to the level of iron content recorded in T_{12}. Among the treated plots receiving lower concentration of zinc in foliar mode did not show any effect and straw iron content and uptake was minimum and statistically at par to T_2 during both the years. The maximum iron uptake during 2011and 2012 found in T_{12} at different stages may be supposed due to higher dry matter accumulation and iron content. Higher iron content in plant in T_{12} may be supposed due to the application of vermicompost, which is a rich source of nutrients and enhances the availability of micronutrients in the soil, is responsible for the rise in micronutrient concentrations. The more iron availability in soil owing to more reductive condition than the rest of the treatments. Decomposition of vermicompost will utilize the soil oxygen and therefore more reduction will take place which is very conductive for iron availability. Similar result was also recorded by **Gurmani *et al. (*2003)** that Application of NPK + Zn + Cu + Fe + Mn resulted in the highest Zn concentration, whereas application of NPK + Cu resulted in the highest Cu concentration in the leaves. Fe and Mn concentrations in the leaves were highest with the application of NPK Cu + Mn and NPK + Zn + Cu + Fe + Mn, respectively. **Kumar et al. (2023**) The application of 125% RDF + Vermicompost at 6 t ha-1 + 2% Zinc Solubilizing bacteria (T8) produced the highest values for Fe, Mn, Zn, and Cu content in grain and straw among the various treatments.**Dhaliwal and Walia (2008)**reported that incorporation of manures increased the availability of micronutrients like Zn, Cu, Fe and Mn.

4.3.7 Manganese content (ppm) and uptake ($gmha^{-1}$) of rice at different stages

The data regarding application effect of various sources of zinc in different mode and vermicompost along with RDF on manganese content during 2011 and 2012, respectively are shown in Table 4. The Mn content of rice biomass at 30, 60 DAT and rice grain and straw was significantly affected by different treatments during both the years. The Mn content of rice plant at 30 DAT ranged from 125.76 to 187.87and 133.75 to 195.78 ppm and uptake from 218.58 to 630.67 and 265.25 to 664.92 gha^{-1} during 2011and 2012, respectively. Maximum Mn content 187.85 and 195.78 ppm and uptake 630.67 and 664.92 gha^{-1} during 2011 and 2012 found in T_{12} was significantly higher than the rest of the treatments while minimum Mn content recorded in T_1 was significantly lower than the rest of the treatments during both the years. The Mn content and uptake of plant sample in T_{11} was higher and statistically at par to the T_{12} and the treatment T_3 was also higher but not to the level of Mn content and uptake recorded in T_{12}. Among the treated plots minimum Mn content was recorded in T_2 where no zinc is used followed by T_{10} and T_9 receiving lower concentration of zinc in foliar mode. Similar trends in Mn content and uptake was also observed at 60 DAT stage of rice plant.Mn content of rice grain ranged from 25.65 to64.58 and 32.53 to 68.85 ppm and uptake from 62.09 to 238.94 and 87.36 to 299.64 gha^{-1}during 2011and 2012, respectively. Maximum Mn content 160.55 and 165.86 ppm and uptake 238.94 and 299.64 gha^{-1} during 2011 and 2012 respectively found in T_{12} was significantly higher than the rest of the treatments while minimum Mn content recorded in T_1 was significantly lower than the rest of the treatments during both the years. In general Mn content and uptake of plant sample at this stage was higher in those treatments where zinc through either source was applied as basal than foliar. The Mn content of grain in T_{11} and T_3 was also higher but not to the level of Mn content recorded in T_{12}. Among the zinc treated plots minimum Mn content and uptake was recorded in T_{10} and it was found statistically at par with T_2 and followed by T_9 during both the years. Mn content of rice straw ranges from 45.56 to 107.86 and 49.76 to m112.73 ppm and uptake 186.15 to 615.19 and 201.59 to 745.81 gha^{-1}during 2011and 2012, respectively. Maximum Mn content 107.86 and 112.73 ppm and uptake 615.19 and 745.81gha^{-1}during 2011 and 2012 found in T_{12} was significantly higher than the rest of the treatments while minimum Mn content recorded in T_1 was significantly lower than the rest of the treatments during both the years. In general Mn content of rice straw was higher in those treatments where zinc through either source was applied basal than foliar. The Mn contentof rice straw in T_{11} and T_3 during 2011was also higher but not to the level of Mn content recorded in T_{12} but during 2012 were found statistically at par to the T_{12}. Among the zinc treated plots minimum Mn content in straw during 2011 was recorded in T_{10} and T_9 and these treatments were significantly higher to the T_2 where no zinc is used but during 2012 these treatments were found statistically at par to T_2.But in the case of manganese uptake of rice straw in T_{11} was also higher and statistically at par with T_{12} while T_3 was significantly varied to T_{12} but during 2012 these treatments were significantly inferior to T_{12}. The effect of foliar application of zinc in lower concentration on manganese uptake was non-significant and it was also found statistically at par with T_2 during both the years.The maximum manganese uptake during 2011and 2012 found in T_{12} at different stages may be supposed due to higher dry matter accumulation and manganese content. Higher manganese content in plant in T_{12} may be supposed due to the more Mn availability in soil owing to the more reductive condition than the rest of the treatments. Decomposition of vermicompost will utilize the soil oxygen and therefore more reduction will took place which is very conductive for Mn availability. Similar result was also recorded by **Gurmani *et al. (*2003)** that Application of NPK + Zn + Cu + Fe + Mn resulted in the highest Zn concentration, whereas application of NPK + Cu resulted in the highest Cu concentration in the leaves. Fe and Mn concentrations in the leaves were highest with the application of NPK Cu + Mn and NPK + Zn + Cu + Fe + Mn, respectively.**Walia et al. (2008)** reported similar results pertaining to uptake of Zn, Cu, Fe and Mn in rice-wheat system. This result is supported by **Saddika (2013),** who observed that application of Zn markedly increased their respective concentration and uptake by the rice crops.**(Doreet.al., 2018).** Observed that the increase in Zn uptake might be due to theapplication of zinc sulphate that might have increasedthe availability and uptake of other essential nutrients.

Conclusion

The present study has shown that application of zinc improved the biomass, grain and straw yield and uptake of micronutrients in basmati rice crop. The application of Vermicompost @ 3 t ha^{-1}+RDF in the treatment T_{12} recorded higher values ofmicronutrients content and uptake over the other treatments. But the content and uptake of micronutrients in treatments (T_{11}) T_3 where micronutrient mixture@ 25 kg ha^{-1} and$ZnSO_4$ @ 25kg ha^{-1}were applied respectively with RDF was also higher and equally good like the treatment $T_{12.}$

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Table1. Effect of zinc sources and application methods on content (ppm) and uptake (g ha^{-1})of zinc in rice at different stages

Treatments	Content(ppm)								Uptake (g ha^{-1})							
	30DAT		60DAT		Grain		Straw		30DAT		60DAT		Grain		Straw	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
T_1	46.37	50.24	26.19	31.93	41.46	47.63	4.58	5.82	80.86	99.62	87.57	125.94	100.87	128.12	18.68	23.85
T_2	51.48	54.83	30.45	36.52	47.39	53.22	6.53	7.79	100.45	121.17	116.75	161.33	151.65	176.85	33.71	41.93
T_3	78.73	83.38	52.48	57.86	72.59	78.89	14.91	16.19	223.98	261.72	277.59	339.59	262.55	311.76	81.66	93.59
T_4	72.75	76.58	48.53	54.54	67.25	73.52	12.25	14.42	182.92	221.38	252.30	315.49	237.50	274.22	67.04	82.82
T_5	68.92	72.35	44.38	49.82	64.68	68.84	11.69	13.56	168.44	194.54	220.87	276.94	224.24	254.22	63.59	77.86
T_6	64.93	69.38	41.87	47.92	59.49	65.45	10.60	11.83	154.96	183.58	199.15	255.86	204.22	236.73	57.10	67.38
T_7	61.95	65.59	38.54	44.46	57.36	63.75	9.85	11.19	140.63	164.01	193.68	231.56	195.02	228.55	52.35	63.53
T_8	58.39	62.34	35.69	41.95	54.65	60.45	8.35	10.23	129.62	151.81	159.75	211.83	180.34	213.98	44.22	57.81
T_9	55.83	59.37	34.73	40.36	53.83	58.53	7.45	9.94	119.65	139.59	148.15	197.63	177.64	204.86	39.41	54.03
T_{10}	54.38	57.86	33.85	38.59	51.75	57.60	7.21	9.24	111.60	129.83	148.22	172.67	170.77	200.06	37.34	49.94
T_{11}	80.43	87.48	59.85	65.54	77.24	83.45	15.56	17.74	247.29	295.74	132.15	411.63	282.97	335.22	87.18	102.89
T_{12}	85.78	93.59	74.35	79.35	81.54	88.46	17.65	19.52	288.60	341.85	338.45	523.71	301.69	385.11	100.65	117.68
SE (m).	***3.53***	***2.99***	***.68***	***.67***	***1.69***	***2.81***	***1.31***	***.17***	***11.35***	***8.53***	***4.93***	***4.49***	***12.81***	***15.02***	***2.01***	***6.55***
CD(p=0.05)	***10.43***	***8.83***	***2.00***	***1.98***	***4.98***	***8.29***	***3.85***	***.49***	***33.51***	***25.19***	***3.99***	***13.26***	***37.83***	***44.33***	***5.95***	***19.33***

Table 2. Effect of zinc sources and application methods on content (ppm) and uptake (g ha^{-1}) of copper in rice at different stages

Treatments	Content (ppm)								Uptake (g ha^{-1})							
	30DAT		60DAT		Grain		Straw		30DAT		60DAT		Grain		Straw	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
T_1	16.69	20.35	10.26	13.96	14.46	16.65	5.49	7.86	29.11	40.38	34.23	54.98	34.89	44.75	21.83	31.95
T_2	20.38	24.38	12.56	15.68	17.39	19.95	7.95	9.68	40.02	53.95	48.05	69.31	57.25	70.02	43.35	55.21
T_3	31.78	35.84	20.75	24.59	26.56	28.63	13.49	16.06	90.53	112.45	109.76	144.47	96.12	113.48	71.64	92.59
T_4	29.45	33.69	18.73	22.48	24.64	26.43	11.83	13.37	73.76	97.62	97.28	129.99	87.25	98.64	66.04	77.22
T_5	28.69	32.45	17.85	20.54	23.39	25.87	10.49	12.95	70.01	87.35	88.95	114.26	78.97	91.65	59.92	75.75
T_6	28.25	30.79	16.38	19.82	22.56	24.64	9.48	12.84	67.30	85.15	78.02	105.80	78.46	91.09	50.24	72.52
T_7	26.25	28.53	15.85	19.55	22.24	24.43	9.30	11.35	59.06	77.17	73.24	101.96	74.93	88.02	48.16	61.57
T_8	24.46	26.65	15.36	18.65	21.75	23.58	8.74	11.35	56.15	69.61	68.58	94.29	71.16	85.38	47.41	64.61
T_9	23.36	26.65	13.95	17.45	20.39	22.95	8.45	10.78	50.15	62.60	59.57	85.47	69.22	82.14	43.40	58.69
T_{10}	22.63	25.49	13.45	17.32	19.85	21.59	8.32	10.65	61.88	56.95	52.48	77.56	65.44	74.59	45.66	60.97
T_{11}	32.59	36.79	23.83	27.49	28.79	30.85	16.05	17.98	100.16	124.37	134.73	172.54	105.47	123.93	84.96	103.33
T_{12}	34.68	38.83	26.58	30.65	30.58	33.87	17.25	19.62	116.56	141.72	164.03	202.25	113.35	147.28	94.07	129.93
SE (m).	*3.89*	*0.45*	*0.70*	*0.48*	*1.77*	*0.40*	*0.62*	*0.56*	*5.36*	*1.76*	*3.34*	*2.981*	*4.72*	*3.95*	*4.11*	*4.68*
CD(p= 0.05)	*N.S.*	*1.33*	*2.06*	*1.43*	*5.22*	*1.18*	*1.83*	*1.65*	*15.83*	*5.20*	*9.88*	*8.79*	*13.95*	*11.66*	*12.14*	*13.82*

Table 3.Effect of zinc sources and application mode on content (ppm) and uptake (g ha^{-1})ofiron in rice at different stages

Treat ments	Content (ppm)								Uptake (g ha^{-1})							
	30DAT		60DAT		Grain		Straw		30DAT		60DAT		Grain		Straw	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
T_1	312.65	320.46	170.21	176.61	56.58	62.25	148.89	162.35	545.83	635.25	569.81	696.42	134.64	167.57	610.03	667.64
T_2	326.85	334.58	174.43	180.71	61.45	66.53	162.86	169.59	640.99	739.38	667.96	797.36	196.33	221.97	840.67	914.82
T_3	357.26	365.64	203.96	208.94	85.76	90.24	198.75	206.85	1017.14	1146.31	1078.07	1225.80	308.60	358.59	1088.36	1196.50
T_4	353.37	361.37	199.08	204.66	82.67	87.85	193.95	200.69	885.58	1079.41	1032.75	1184.64	293.33	327.04	1061.43	1152.86
T_5	350.45	358.46	195.71	201.36	77.65	83.46	186.87	193.38	857.37	964.84	974.01	1119.52	270.95	310.44	1016.34	1107.57
T_6	346.76	354.44	191.83	196.94	75.88	81.48	183.55	190.47	828.85	935.54	912.18	1052.14	261.41	295.15	988.27	1092.70
T_7	340.74	348.68	188.58	194.44	72.64	78.56	180.86	187.68	766.31	874.18	872.89	1013.61	246.10	293.33	961.41	1068.56
T_8	335.84	343.38	184.91	191.73	70.63	75.18	176.87	183.48	746.10	836.89	828.32	968.34	239.72	266.36	937.04	1043.23
T_9	33.970	341.49	182.13	188.83	67.85	73.78	172.66	179.36	716.63	801.14	777.36	923.47	224.96	258.15	913.54	1013.96
T_{10}	329.56	337.65	179.73	186.67	65.97	71.96	169.44	176.88	678.71	755.05	701.68	835.35	217.28	248.70	877.65	960.51
T_{11}	364.85	372.89	208.18	214.76	87.59	92.37	206.96	214.82	1122.18	1260.06	1176.60	1349.65	320.97	371.10	1159.61	1255.15
T_{12}	366.93	374.59	212.22	218.46	92.85	98.78	212.59	218.35	1233.14	1366.11	1310.06	1442.76	343.36	429.86	1212.06	1445.22
SE (m).	***4.79***	***3.81***	***3.49***	***3.82***	***4.24***	***3.91***	***2.17***	***4.65***	***29.28***	***18.30***	***22.71***	***27.84***	***19.44***	***19.00***	***47.99***	***46.50***
CD(p= 0.05)	***14.14***	***11.25***	***10.32***	***11.28***	***12.53***	***11.53***	***6.39***	***13.74***	***86.43***	***54.03***	***67.06***	***82.18***	***57.37***	***56.09***	***141.65***	***137.26***

Table 4. Effect of zinc sources and application mode on content (ppm) and uptake (g ha^{-1})ofmanganese in rice at different stages

Treatments	Content (ppm)								Uptake (g ha^{-1})							
	30DAT		60DAT		Grain		Straw		30DAT		60DAT		Grain		Straw	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
T_1	125.76	133.75	82.09	86.12	25.65	32.53	45.560	49.76	218.58	265.25	274.85	339.44	62.09	87.36	186.15	201.59
T_2	137.95	145.79	86.68	90.71	31.49	36.86	54.39	58.38	270.74	321.77	331.61	400.61	104.03	122.90	295.72	327.51
T_3	170.85	179.38	111.26	116.12	51.76	55.45	94.25	98.55	484.96	562.42	588.81	683.06	187.16	219.58	516.31	569.70
T_4	165.45	173.64	108.48	111.48	47.68	51.86	87.48	92.73	414.66	502.74	565.34	645.10	168.57	193.36	487.35	532.53
T_5	161.85	169.78	104.58	108.66	44.70	48.65	81.85	85.78	396.32	456.70	520.86	604.35	152.19	172.49	445.04	493.74
T_6	157.56	165.85	101.88	105.43	42.89	45.95	79.51	83.45	377.18	437.92	485.38	562.83	148.90	169.72	442.05	479.66
T_7	153.97	161.39	100.47	103.94	40.68	43.75	75.65	79.36	345.77	437.87	465.05	542.10	130.21	156.62	412.75	451.54
T_8	150.65	158.76	96.63	100.35	37.85	40.55	68.95	73.69	334.34	386.95	431.76	508.53	130.12	146.87	371.80	416.04
T_9	147.36	154.39	96.42	97.46	35.69	37.86	65.85	69.38	297.06	362.41	411.95	476.43	121.47	135.47	348.39	395.03
T_{10}	144.57	151.85	91.26	94.94	33.65	35.65	62.54	65.25	283.15	339.62	356.77	424.96	110.98	123.26	324.04	355.53
T_{11}	179.56	187.65	116.82	120.42	58.78	61.94	100.68	104.85	552.18	600.61	660.19	757.03	215.59	248.78	564.14	613.00
T_{12}	187.85	195.78	120.41	124.39	64.58	68.85	107.86	112.73	630.67	664.92	743.70	795.36	238.94	299.64	615.19	745.81
SE (m).	***4.91***	***4.58***	***3.46***	***3.71***	***0.73***	***0.68***	***0.94***	***4.92***	***15.11***	***15.64***	***20.64***	***25.96***	***8.56***	***7.76***	***23.16***	***31.02***
CD(p=0.05)	***14.49***	***13.52***	***10.23***	***10.95***	***2.15***	***2.01***	***2.79***	***14.52***	***44.59***	***46.16***	***60.94***	***76.65***	***25.27***	***22.90***	***68.39***	***91.57***