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Agronomic fortification in finger millet (*Eleusine coracana*) for yield and quality improvement in red sandy loam soils

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ABSTRACT

A field experiment was conducted during *kharif* 2015–18 to study the yield responses of finger millet [*Eleusine coracana* (L.) Gaertn.] to graded doses of macronutrient fertilizers (100% and 150% RDF) in combination with soil and foliar application of Zn and Fe, which are important for early establishment of finger millet. The experimental results indicated that significantly higher grain and straw yields of finger millet were recorded with 150% RDF+$ZnSO_4$ 0.5% foliar spray+$FeSO_4$ 0.2% foliar spray compared to 100% RDF. Soil available N, P_2O_5, K_2O and plant macronutrient uptake were also found highest in the same treatment. Whereas the highest available Zn in the soil was recorded in the treatment 150% RDF+$ZnSO_4$ soil application+$FeSO_4$ 0.2% foliar spray, and the highest available Fe was evidenced in the treatment 150% RDF+$FeSO_4$ 0.2% foliar spray. The grain zinc content was found highest with the treatment 150% RDF+$ZnSO_4$ 0.5% foliar spray, iron content in the grain was found highest with the treatment 150% RDF+$ZnSO_4$ 0.5 % foliar spray + $FeSO_4$ 0.2% foliar spray. The uptake of Zn and Fe were found highest with the treatment 150% RDF+$ZnSO_4$ 0.5 % foliar spray+$FeSO_4$ 0.2 % foliar spray. Hence, the treatment with 150% RDF+$ZnSO_4$ 0.5% foliar spray + $FeSO_4$ 0.2% foliar spray was considered to be the best treatment which was at par with 150% RDF+$ZnSO_4$ @50 kg/ha soil application+$FeSO_4$ 0.2% foliar spray.

Keywords: Finger millet, Ferti-Fortification, Iron, Nutrient Management, Soil available nutrients, Zinc

Finger millet, [*Eleusine coracana* (L.) Gaertn.] commonly known as "Nutritious millet", besides being a staple food especially in some parts of South India, is superior to many cereals in providing proteins, minerals, calcium and vitamins. Malnutrition and under nourishment are the major problems of Indian population due to which millets are becoming a popular alternative source of food. Among different micronutrients, zinc and iron deficiency is a well-documented problem in food crops due to which crop yield and nutritional quality decreases. Agronomic biofortification is a short-term approach and offers the easiest and the quickest way for biofortification. Further, ferti-fortification is a promising and cost effective method to increase the micronutrient concentration in cereal grains to combat malnutrition (Kumar *et al.* 2017).

Though finger millet is valued as a low fertilizer input crop, when grown in marginal lands with poor soil fertility, it gives low yield (Rurinda *et al.* 2014). Less use of mineral fertilizer, poor recycling of crop residues and low rates of organic matter application are the major reasons which limit the yield potential of finger millet crop. High yielding varieties of finger millet require comparatively large quantities of both macronutrients and micronutrients like zinc in the soil which reaches plant roots through diffusion, and this process is severely impaired when organic matter declines (Rengel 2015). Experimental evidences indicate that application of micronutrients in combination with macronutrients have cumulative positive effect on increase in grain yield over NPK (Cakmak *et al.* 2010). Moreover, Cakmak (2008) showed that foliar or combined soil and foliar application of zinc fertilizer under field conditions is highly effective and very practical way to maximize uptake and accumulation of zinc in whole wheat grain.

Keeping this in view, finger millet, widely grown and commonly consumed in India, was explored as a vehicle for fortification with zinc and iron. Hence, the present study was carried out with an objective to assess the requirement of macronutrients and impact of agronomic biofortification of Zn and Fe on yield, soil health and nutritional quality of finger millet crop.

MATERIALS AND METHODS

The field experiment was conducted during *kharif* 2015–18 at Agricultural Research Station, Vizianagaram which has a typical tropical climate. The soil was sandy loam in texture, low in organic carbon, available nitrogen, high in available phosphorus and medium in available potassium.

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The experiment was laid down in Randomized Block Design with 12 treatments replicated thrice. The treatments were T_1(100% RDF), T_2(150% RDF), T_3 (T_1+$ZnSO_4$ @50 kg/ha as soil application), T_4 (T_1+$ZnSO_4$ 0.5% foliar spray), T_5 (T_1+$FeSO_4$ 0.2% foliar spray), T_6 (T_1 +$ZnSO_4$ soil application @50 kg/ha +$FeSO_4$ 0.2% foliar spray), T_7 (T_1+$ZnSO_4$ 0.5% foliar spray+$FeSO_4$ 0.2% foliar spray), T_8 (T_2+$ZnSO_4$ @50 kg/ha as soil application), T_9 (T_2+$ZnSO_4$ 0.5% foliar spray), T_{10} (T_2+ $FeSO_4$ 0.2% foliar spray), T_{11} (T_2+$ZnSO_4$ soil application @50 kg/ha+$FeSO_4$ 0.2% foliar spray) and T_{12} (T_2+$ZnSO_4$ 0.5% foliar spray+$FeSO_4$ 0.2% foliar spray).

The recommended dose of nutrients (RDF) was 60-40-30 kg N-P_2O_5-K_2O/ha which was applied in the form of urea, DAP and muriate of potash. Foliar spray of nutrients, viz. zinc sulphate (0.5%) and ferrous sulphate (0.2%) was done twice at the time of flowering and 15 days after flowering, while soil application of zinc sulphate @50 kg/ha was done as per the treatments at the time of transplanting.

The growth and yield parameters were recorded at the time of harvest. The initial and final soil samples were analysed for available N, P_2O_5, K_2O and micronutrients, viz. Zn and Fe as per the standard procedures. The plant samples of both the grain and straw of finger millet was analysed for both macronutrient and micronutrient uptake. The three years experimental pooled mean data were subjected to statistical analysis as per procedure described by Gomez and Gomez (1984). Differences among the means and treatments were compared by the least significant difference (LSD) at $P \leq 0.05$.

RESULTS AND DISCUSSION

Growth and yield attributes: The growth characters and yield attributes (Table 1) were significantly influenced by different nutrient management practices. The plant height was found highest with the treatment 150% RDF+$ZnSO_4$ 0.5% foliar spray+$FeSO_4$ 0.2% foliar spray (122.6 cm) which was at par with 150% RDF+$ZnSO_4$ soil application @50kg/ha+$FeSO_4$ 0.2% foliar spray (120.9 cm), these were significantly better compared to all the other treatments. The lowest plant height was recorded with the treatment 100% RDF (111.7 cm). Increase in plant height with increasing levels of nitrogen was probably due to enhanced availability of nitrogen that expands the leaf area and is an integral part of the pyroll ring in chlorophyll, which is a primary absorber of light energy needed for photosynthesis resulting in higher photoassimilates, and thereby more dry matter accumulation (Havlin *et al.* 2011).

Significantly higher number of productive tillers/plants, ear head length and fingers/ear (3.8, 10.1 cm and 9.8, respectively) were recorded with 150% RDF+$ZnSO_4$ 0.5% foliar spray+$FeSO_4$ 0.2% foliar spray compared to application of 100% RDF (2.7, 8.2 cm and 8.1, respectively) which was at par with 150% RDF+$ZnSO_4$ soil application @50kg/ha+$FeSO_4$ 0.2% foliar spray (3.4, 9.9 cm and 9.3, respectively). Nitrogen which plays a vital role in cell division is probably the reason for more number of productive tillers/plant. Similar results were recorded by Sankar *et al.* (2011), in which the highest number of effective tillers was obtained with 120 kg N/ha. Moreover, foliar application of zinc augments the yield attributes as it is an essential catalyst in auxin biosynthesis in the active sinks which leads to higher transport of photosynthates.

Grain yield, Straw yield and Economics: Results of nutrient management in finger millet showed that 150% RDF (3250 kg/ha) recorded 28.5% increase in grain yield

Table 1 Growth, yield attributes, yield, grain quality and nutrient uptake of finger millet as influenced by nutrient management practices

Treatment	Plant height (cm)	Productive tillers/ plant	Ear head length (cm)	Fingers/ ear	Straw yield (kg/ha)	Grain yield (kg/ha)	B:C ratio	Protein content (%)	Zn content (ppm)	Fe content (ppm)	N uptake (kg/ha)	P uptake (kg/ha)	K uptake (kg/ha)	Zn uptake (g/ha)	Fe uptake (g/ha)
T_1	111.7	2.7	8.2	8.1	5212	2530	2.25	7.32	18.1	66.4	58.5	12.8	44.0	110.6	669.5
T_2	119.5	3.2	8.7	8.6	6465	3250	2.47	8.14	19.2	73.2	81.5	21.2	61.7	158.2	899.9
T_3	112.5	2.8	8.6	8.3	5606	2750	2.30	6.62	20.6	69.3	62.5	12.0	46.8	160.3	755.4
T_4	114.6	2.9	8.8	8.4	5612	2850	2.23	6.33	21.2	76.9	62.7	14.1	45.5	191.2	802.5
T_5	115.7	2.8	8.5	8.5	5714	2860	2.26	6.30	18.5	77.1	66.2	15.6	54.3	106.8	1150.7
T_6	115.4	3.0	9.0	8.6	5863	2805	2.30	6.04	21.8	83.8	66.1	11.0	50.8	164.3	1195.3
T_7	115.6	3.0	9.1	8.7	5944	2810	2.29	7.20	22.9	85.3	73.1	17.3	59.9	198.9	1167.6
T_8	117.6	3.1	9.5	8.8	6642	3170	2.33	6.24	22.1	77.4	73.8	19.8	58.1	199.9	907.5
T_9	118.9	3.2	9.8	8.9	6545	3140	2.26	7.03	24.6	78.7	76.9	19.1	64.3	252.1	956.1
T_{10}	119.4	3.1	9.4	8.9	7044	3365	2.42	6.45	18.7	91.1	83.7	21.9	72.1	134.5	1544.2
T_{11}	120.9	3.4	9.9	9.3	7000	3310	2.28	7.61	23.3	89.9	86.1	24.2	73.9	195.9	1301.7
T_{12}	122.6	3.8	10.1	9.8	7510	3490	2.63	8.72	24.2	94.1	95.6	25.8	81.9	280.7	1648.4
SEm±	1.988	0.142	0.158	0.18	222.8	102.5		0.563	1.50	5.57	2.82	1.527	4.036	8.69	57.6
CD (P=0.05)	5.83	0.42	0.46	0.52	653.2	301.4		NS	4.41	16.36	8.28	4.48	11.84	26.08	172.8

over 100% RDF (2530 kg/ha) (Table 1). Among different treatments, highest grain yield was recorded with application of 150% RDF+$ZnSO_4$ 0.5% foliar spray+$FeSO_4$ 0.2% foliar spray (3490 kg/ha), it showed 37.9% yield increase over 100% RDF and 7.6% yield increase over 150% RDF. With respect to the method of application of $ZnSO_4$, foliar application was found to be superior at both 100% and 150% RDF over soil application. Similar results were also observed for straw yield (Table 1) which recorded 47.6% higher yield with 150% RDF+$ZnSO_4$ 0.5% foliar spray+$FeSO_4$ 0.2% (7510 kg/ha) when compared 100% RDF (5212 kg/ha). Nitrogen fertilization in combination with Zinc fertilization increased the yield as well as zinc content in pearl millet (Prasad *et al.*2014) and maize crop (Kanwal *et al.* 2010). This might be due to the influence of nitrogen and zinc on photosynthesis which induces more starch and sugar production under balanced fertilizer application. Phosphorus, being primary essential nutrient is involved in almost all biochemical pathways as a component of ATP and ADP. Thus, increase in the rate of phosphorus fertilization makes this nutrient available to the plants and results in increased grain yields. Cost economics (Table 1) of different nutrient management treatments was worked out and higher B:C ratio was observed with 150% RDF+$ZnSO_4$ 0.5% foliar spray+$FeSO_4$ 0.2% foliar spray (2.63) compared to T_2+$ZnSO_4$ soil application+$FeSO_4$ 0.2% foliar spray (2.28), 100% RDF (2.25) and 150% RDF (2.47).

Grain quality: The grain protein content (Table 1) showed no significant influence with the application of different nutrient management practices. Whereas, significant difference of grain zinc and iron contents was observed between different treatments. The highest zinc content was observed with the treatment 150% RDF+$ZnSO_4$ 0.5% foliar spray (24.6 ppm) which was 35.9% higher than 100% RDF (18.1 ppm). Increased Zn supply through fertilization translates into increased Zn concentration in the plant under the condition of non-deficient Zn status in the soil, as the effect of fertilization would be seen in the Zn tissue concentrations. Phattarakul *et al.* (2012) demonstrated that foliar Zn application or a combination of soil and foliar Zn is highly effective to increase grain Zn content. Iron content in the grain was found highest with the treatment 150% RDF+$ZnSO_4$ 0.5% foliar spray+$FeSO_4$ 0.2% foliar spray (89.9 ppm) which was 48.5% higher than 100% RDF (66.4 ppm). These results are in agreement with Zhou *et al.* (2012) who recorded 84% increase in grain zinc content through foliar application. Kumar *et al.* (2016) reported that the grain concentrations of Zn and Fe can be enhanced by increasing the nitrogen supply in crops like wheat and rice. This is probably because nitrogen appears to be a critical component for effective biofortification of food crops with Zn and Fe due to several physiological and molecular mechanisms which are under the influence of N nutritional status (Cakmak *et al.* 2010). Nitrogen fertilization caused an increase in plant growth and also altered the *p*H around the root zone which had a positive effect on the grain Zn concentration (Shafea and Saffari 2011). The increase in iron content in grain could also be due to the P impact on root development that resulted in higher uptake of iron.

Plant nutrient uptake: The plant uptake of N, P and K (Table 1) was found highest in the treatment 150% RDF+$ZnSO_4$ 0.5% foliar spray+$FeSO_4$ 0.2% foliar spray (95.6 kg/ha, 25.8 kg/ha and 81.9 kg/ha, respectively) which was found at par with 150% RDF+$ZnSO_4$ soil application+$FeSO_4$ 0.2% foliar spray (86.1 kg/ha, 24.2 kg/ha and 73.9 kg/ha, respectively), 150% RDF+$FeSO_4$ 0.2% foliar spray (83.7 kg/ha, 21.9 kg/ha and 72.1 kg/ha, respectively) and 150% RDF (81.5 kg/ha, 21.2 kg/ha and 61.7 kg/ha, respectively). The plant nutrient uptake increased significantly with the increasing rates of fertilization, which was attributed to luxuriant crop growth, high dry matter production, yield and yield attributes, that resulted in increased uptake of nutrients (Shubhashree *et al.* 2011).

Zn and Fe uptake (Table 1) was found highest with the treatment 150% RDF+$ZnSO_4$ 0.5% foliar spray+$FeSO_4$ 0.2% foliar spray (280.7 g/ha and 1648.4 g/ha, respectively) while the lowest was recorded with 100% RDF (110.6 g/ha and 669.5 g/ha, respectively). Similar results were reported by Ramachandrappa *et al.* (2014). Similarly, Cakmak *et al.* (2010) recorded that increasing soil N application significantly enhanced shoot and grain iron uptake in wheat crop under both field and greenhouse conditions. Erenoglu *et al.* (2011) demonstrated that increased nitrogen supply almost quadrupled the Zn uptake rate.

Soil available nutrients: The physicochemical properties (*p*H and EC) and organic carbon (Table 2) showed no significant influence with the application of different nutrient management practices. The soil available nitrogen, phosphorus and potassium (Table 2) were significantly influenced by different nutrient management practices. The maximum soil available nitrogen, phosphorus and potassium after harvest of the crop was recorded with 150% RDF+$ZnSO_4$ 0.5% foliar spray+$FeSO_4$ 0.2% foliar spray (270.2 kg/ha, 75.6 kg/ha and 272.7 kg/ha, respectively) which was at par with 150% RDF+$ZnSO_4$ @50kg/ha as soil application+$FeSO_4$ 0.2% foliar spray (263.3 kg/ha, 72.2 kg/ha and 270.2 kg/ha). These results are in agreement with Rurinda *et al.* (2014) who reported increased grain yield and nitrogen availability with increased doses of fertilizer application. Phosphorus, being a primary essential nutrient that has prime importance in crop nutrition, is involved in almost all biochemical pathways as a component of energy carrier compounds. Thus, increased dose of phosphorus fertilizer application makes this nutrient available to crop plants and results in better growth and development. These results were in agreement with Hemalatha and Chellamuthu (2013).

Soil available Zn and Fe nutrients (Table 2) were also significantly influenced by various treatments of nutrient management. The soil available zinc was found highest with 150%RDF+$ZnSO_4$ @50 kg/ha as soil application+$FeSO_4$ 0.2% foliar spray (3.20 ppm) followed by 100% RDF+$ZnSO_4$ @50 kg/ha as soil application+$FeSO_4$ 0.2% foliar spray (2.56 ppm) which were at par with each other

Table 2 Physicochemical properties, OC, available macro and micronutrients as influenced by nutrient management practices

Treatment	*p*H	EC	OC (%)	Available N (kg/ha)	Available P_2O_5 (kg/ha)	Available K_2O (kg/ha)	Available Zn (ppm)	Available Fe (ppm)
T_1	7.06	0.17	0.44	201.7	58.2	220.8	1.18	12.39
T_2	7.05	0.17	0.44	219.5	71.1	230.5	1.11	12.49
T_3	7.14	0.17	0.46	184.6	63.1	216.7	2.01	13.97
T_4	7.03	0.18	0.45	188.8	64.2	219.8	1.61	14.93
T_5	7.03	0.18	0.43	204.1	60.7	215.1	1.38	14.15
T_6	7.02	0.17	0.47	204.1	61.2	215.4	2.56	13.84
T_7	7.13	0.17	0.48	219.5	64.5	233.1	1.98	15.36
T_8	7.08	0.17	0.46	235.2	67.1	222.8	2.28	14.76
T_9	7.05	0.16	0.47	242.5	68.1	230.9	1.95	14.77
T_{10}	7.03	0.17	0.49	265.0	66.8	252.3	1.68	17.84
T_{11}	7.10	0.18	0.47	263.3	72.2	270.2	3.20	15.58
T_{12}	7.11	0.16	0.48	270.2	75.6	272.7	2.14	17.77
SEm±	0.038	0.006	0.019	10.64	2.083	7.061	0.103	0.861
CD (P=0.05)	NS	NS	NS	31.20	6.11	20.71	0.30	2.53
Initial values	7.16	0.18	0.45	221.6	59.5	242	1.31	11.78

and significantly superior to rest of the treatments. Lowest soil available zinc was recorded with 150% RDF (1.11 ppm) followed by 100% RDF (1.18 ppm). Soil available Fe was recorded highest with the treatment 150% RDF+$FeSO_4$ 0.2% foliar spray (17.84 ppm) which was at par with 150% RDF+$ZnSO_4$ 0.5% foliar spray+$FeSO_4$ 0.2% foliar spray (17.77 ppm) and 150% RDF+$ZnSO_4$ @50 kg/ha as soil application+$FeSO_4$ 0.2% foliar spray (15.58 ppm). These treatments were significantly superior to rest of the treatments. Lowest quantity of available Fe in soil was recorded with 100% RDF (12.39 ppm). Similarly, foliar spray of different micronutrients and increased dose of NPK fertilizers has been reported to be equally or more effective as soil application by Rangaraj *et al.*(2007).

Among all the tested nutrient management practices in finger millet, it is clear that increase in the recommended dose of fertilizer from 100% RDF to 150% RDF has contributed to better plant growth yield and soil properties. Moreover, application of micronutrients (Fe and Zn) through foliar application in combination with RDF has contributed in further increase in plant, soil and grain quality. The treatment with 150% RDF+$ZnSO_4$ 0.5% foliar spray+$FeSO_4$ 0.2% foliar spray proved to be the best which was at par with 150% RDF+$ZnSO_4$ soil application @50 kg/ha + $FeSO_4$ 0.2% foliar spray. Hence, agronomic biofortification offers sustainable solution to escalating micronutrient related malnutrition.

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