Effect of Micronutrient Application with Different Sources of NPK on Growth and Yield of Finger Millet Crop in Red Laterite Zone

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Abstract: A field experiment had been conducted during spring season of 2016-2017 and 2017-2018 at Regional Research Sub-station of Bidhan Chandra Krishi Viswavidyalaya, Raghunathpur, Purulia, West Bengal with the objective to study the effect of micronutrient application with different sources of NPK on growth and productivity of finger millet. The experiment was laid out in split plot design with two main plot treatments (sources of NPK, F_1 : 100% recommended dose of NPK (RDF) i.e., $N:P_2O_5:K_2O$, 40:20:20 kg/ha, F_2 : 75% RDF + 2.5 t/ha farmyard manure (FYM)) and six subplot treatments (method and dose of micronutrient application, M_1 : $ZnSO_4$ at a rate 12.5 kg/ha as soil application, M_2 : $ZnSO_4$ at a rate 0.5% as foliar spray, M_3 : borax at a rate 10 kg/ha as soil application, M_4 : borax at a rate 0.5% as foliar spray, M_5 : $ZnSO_4$ at a rate 12.5 kg/ha + borax at a rate 10 kg/ha as soil application and M_6 : $ZnSO_4$ at a rate 0.5% + borax at a rate 0.5% as foliar spray) with three replications. The results of the experiment indicated (from pooled data) that there was a significant influence of sources of NPK and application of micronutrients on growth and performance of finger millet. The highest grain yield (2.24 and 2.30 t/ha) was recorded by 2.5 t/ha FYM + 75% RDF in combination with $ZnSO_4$ at a rate 0.5% + borax at a rate 0.5% foliar spray. So, organic and inorganic combination of NPK (75% RDF + 2.5 t/ha FYM) along with foliar application of both the micronutrients (Zn and B) together can boost up the yield and could be recommended for the cultivation of finger millet crop in red and laterite zone of West Bengal.

Key words: Finger millet, micronutrient, NPK, FYM, grain yield.

1. Introduction

Finger millet (*Eleusine coracana* L.) is an important small millet crop grown in India and has the pride of place in having the highest productivity among millets. It is also known as African millet or bird's foot millet and serves as an important staple food crop in parts of Eastern and Central Africa and India. Among millets finger millet has capacity to produce rational yield, even with minimum care. Finger millet has many health benefits. It helps in weight loss, controls diabetes, reduces cholesterol, increases bone strength, works as natural relaxant, serves as good source of protein and amino acids, treats anaemia, improves digestion, reverts skin aging

and increases lactation. The straw has an immense utility as fodder for both draught and milch animals. It makes good fodder and contains up to 61% of total digestible nutrients [1]. Good quality silage can be made from finger millet forage at flowering stage. Finger millet husk, a byproduct from brewing as spent grain, has been reported to be a source of fiber as well as a good source of protein and is especially used in household poultry feeding [2].

Micronutrients are essential for plant growth and play an important role in balanced crop nutrition. Micronutrients are as important to plant nutrition as primary and secondary nutrients, though plants do not require as much of them. They play major role in plant growth like protein synthesis, improving seed quality, cell division and pollen tube growth. Deficiency of micronutrients during the last three decades has grown in both, magnitude and extent because of increased

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use of high analysis fertilizers, use of high yielding crop varieties and increase in cropping intensity. The deficiency of Zn, B and Fe are 49%, 33% and 12%, respectively in Indian soils [3]. Amongst the seven micronutrient elements (Fe, Mn, Cu, Zn, B, Mo and Cl) essential for plant growth, Zn has assumed extensively important place in Indian agriculture [4]. B is also one of the seven essential micronutrients, which is required in very small amounts for the crop production.

In the Indian subcontinent, about 24% of the total geographical areas or 79.7 million hectares of soils are alfisols, making it the most dominant soil order in dryland regions of India. These soils encounter several problems including water erosion, shallow soil depth, subsurface gleying, restricted rooting depth, low water and nutrient retention, hard setting tendencies and crust formation [5]. These soils are also nearly exhausted of organic matter and thus have poor structure, low water retention capacity and low fertility [6]. West Bengal is comprised of six different agro ecological zones of which red and lateritic zone is very vulnerable to any change in weather parameters due to inherent problems of water holding capacity of soil [7, 8]. Rainfed agriculture is largely practiced in this zone. Besides, this zone experiences wider range of both maximum and minimum temperatures. Owing to poor status of organic matter, N, P, S and acidic soil reaction, the soils in the red and laterite agro-climatic zone of West Bengal are hungry and light and porous texture have made it thirsty, too [9]. The soils are generally acidic (pH 5.0-6.5), high in Fe and Al oxide, poor in Ca, organic matter, available phosphate and bases. B deficiency is becoming more pronounced in red and lateritic, acidic, coarse textured alluvial soils of India leading to 33% of grid samples to be deficient altogether (68% of soil samples from West Bengal are deficient) [4]. Adsorption by Al and Fe oxide minerals in acid soils of high rainfall areas causes leaching of B, thus decreasing availability of B [10]. This highlights the urgency of applying B

fertilizers in such soils to check further deterioration of agricultural production [11].

Soil fertility is the primary limiting factor which influences production under intensive crop cultivation. Introduction of exhaustive high yielding varieties and hybrids in many crops increasing the use of high analysis chemical fertilizers devoid of micronutrients and inadequate application of organic manures due to scarcity has resulted in wide spread micronutrient deficiency and nutrient imbalance which adversely affected yield of many crops. Therefore, it is essential to supply macro and micro nutrients in a balanced ratio in required quantity for obtaining higher yield. These micronutrients can be added to crop through soil fertilization, foliar sprays and seed treatment. Each method has the potential to affect plant micronutrient nutrition both in the treated plant directly and in the progeny plants through enrichment of the seeds by micronutrient treatment of the parent. Foliar applications of micronutrient sprays prove to be best to achieve both [12]. Foliar application has been proved to avoid the problem of leaching out in soils and prompts a quick reaction in the plant. Foliar application of Zn and Fe brings the greatest benefit in comparison with addition to soil where they become less available [13]. Keeping in view of research need of study on micronutrient deficiency, the present investigation has been carried out with the objective to study the effect of micronutrient application with different sources of NPK on growth and yield of finger millet in red and laterite zone of West Bengal.

2. Materials and Methods

2.1 Experimental Site

A two-year experiment was conducted at the Regional Research Sub-station, Raghunathpur, Bidhan Chandra Krishi Viswavidyalaya, Purulia, West Bengal (latitude 23.55° N, longitude 86.67° E and altitude of 155 m above mean sea level) during spring 2016-2017 and 2017-2018. The mean maximum temperature ranged from 29.58 °C to 33.68 °C and 26.58 °C to

31.32 °C during 2016-2017 and 2017-2018, respectively. The mean minimum temperature for the corresponding period ranged from 16.61 °C to 18.64 °C and 16.19 °C to 20.52 °C, respectively. The mean relative humidity (RH I) ranged from 46.04% to 56.48% during 2016-2017 and 45.47% to 52.35% during 2017-2018. The mean relative humidity (RH II) ranged from 25.06% to 28.47% during 2016-2017 and 24.21% to 33.33% during 2017-2018. A total four irrigations were given throughout the crop growth period in both the years. The soil was sandy clay loam in texture, moderately acidic in reaction and non-saline. It was low in available N and available P and medium in available K. The bulk density was found to be slightly higher than ideal bulk density. The physical and chemical properties of experimental site were given in Table 1.

2.2 Treatment Details and Plant Sampling

The experiment was laid out in split plot design with three replications. Two sources of nutrients were set in the main plot treatments and six micronutrient treatments in subplot treatments in 5 m × 4 m plots. The main plot treatments are F₁: 100% recommended dose of NPK (RDF) i.e., N:P₂O₅:K₂O, 40:20:20 kg/ha;

F₂: 75% RDF + 2.5 t/ha farmyard manure (FYM) and subplot treatments are M₁: ZnSO₄ at a rate 12.5 kg/ha as soil application; M₂: ZnSO₄ at a rate 0.5% as foliar spray; M₃: borax at a rate 10 kg/ha as soil application; M₄: borax at a rate 0.5% as foliar spray; M₅: ZnSO₄ at a rate 12.5 kg/ha + borax at a rate 10 kg/ha as soil application; M₆: ZnSO₄ at a rate 0.5% + borax at a rate 0.5% as foliar spray. Basal application of FYM at a rate 2.5 t/ha has been done in respective treatment plots one week before sowing. On the date of sowing half of the recommended dose of N, entire dose of P and K, in the form of urea, single super phosphate (SSP) and muriate of potash, respectively, were mixed with soil in respective treatment plots. Remaining half dose of N was top dressed in two equal splits one at the time of tillering and second one at the time of panicle initiation. Borax (Na₂B₄O₇·10H₂O containing 11% B, as source of B) and Zn sulphate (ZnSO₄·7H₂O, containing 22.35% Zn, as source of Zn) were also mixed with the soil at the required dosage as per treatment set up, one week before sowing. Spraying of borax and Zn sulphate, wherever necessary had been undertaken at the required doses on the 40th and 55th day after sowing. Bold seeds of finger millet (VR-708) were selected for sowing. Seeds were line sown manually

Table 1 Physical and chemical properties of soil in experimental field.

S. No	Particulars	Value	Method adopted
I	Physical properties		
	Mechanical analysis	56.1	
1	(a) Sand (%)	22.7	Bouyoucos hydrometer method [14]
	(b) Silt (%)	15.4	
	(c) Clay (%)		
2	Textural class	Sandy clay loam	
3	Bulk density (g/m ³)	1.52	Core sampler method [15]
II	Chemical properties		
1	pH (1:2.5 soil:water)	5.49	Glass electrode pH meter [16]
2	Electrical conductivity (dS/m) (1:2.5 soil:water)	0.16	Solubridge method [16]
3	Organic carbon (%)	0.59	Walkley and Black's modified method [17]
4	Available N (kg/ha)	187.35	Alkaline permanganate method [18]
5	Available P ₂ O ₅ (kg/ha)	23.01	Olsen's method using Spectro photometer [19]
6	Available K ₂ O (kg/ha)	219.34	Neutral ammonium acetate method using Flame photometer [14]
7	Available S (mg/kg)	5.7	CaCl ₂ -extractable S method [20]
8	Available B (mg/kg)	0.45	Hot water extraction and colorimetry using Azomethane-H [21]
9	Available Zn (mg/kg)	0.71	Diethylene triamine penta acetic acid (DTPA) extraction method [22]

with a spacing of 25 cm between rows. All remaining field management practices including weeds, insects and diseases followed local high-yielding practice to avoid yield loss.

2.3 Plant Growth and Yield Parameters

The harvest of the crop was done after 100 d and 103 d after sowing during 2016-2017 and 2017-2018. The crop was harvested with the help of a sickle. Observations on different plant growth parameters (plant height, dry matter (DM) production and leaf area index (LAI)), yield attributes (number of productive tillers/m², number of filled grains/earhead and test weight (g)) and yield (grain yield (t/ha), straw yield (t/ha) and biological yield (t/ha)) were recorded at the time of harvesting. From each plot, 10 plants were randomly selected for observations and a value of each parameter was averaged to get the mean value.

2.4 Statistical Analysis

The data on parameters studied during the course of investigation were statistically analysed, applying the technique of analysis of variance. The performance of crop was varying considerably from season to season as well as year to year due to environmental factors. For this purpose, Bartlett's test for homogeneity of variances (chi-square) had been done, then after testing (if chi-square test is significant then) weighted analyses had been made otherwise unweighted analyses, i.e., pooled analysis as described by Gomez, K. A. and Gomez, A. A. [23], wherever the treatment differences were found significant (*F* test), critical difference was worked out at 5% probability level and the values furnished. The treatment differences that were not significant were denoted by "NS".

3. Results and Discussion

3.1 Weather and Crop Growth

Weather condition during the period of

experimentation was favorable for the growth of finger millet. The maximum and minimum temperatures varied during the cropping season. In all, fair weather conditions prevailed during the period of experimentation for growth and development of finger millet. This was reflected in terms of better growth and yield of finger millet crop. The temperature regimes and relative humidity that prevailed during the period of experimentation were conducive to the growth and development of finger millet. Establishment of finger millet crop was uniform and crop stand was good during both the years of experimentation. The crop was free from major pests and diseases.

3.2 Growth Parameters

3.2.1 Plant Height

The plant height of finger millet was influenced significantly due to different combinations of nutrients during both the years of experimentation (Table 2). Among the main plot treatments significantly higher plant height (83.65 cm) was obtained from 75% RDF + 2.5 t/ha FYM as compared to 100% RDF (74.21 cm) irrespective of subplot treatments. Among subplot treatments foliar application of ZnSO₄ at a rate 0.5% + borax at a rate 0.5% recorded maximum plant height (88.83 cm) which were at par with soil application of ZnSO₄ at a rate 12.5 kg/ha + borax at a rate 10 kg/ha (86.36 cm) irrespective of different sources of NPK in both the years of experimentation. The interaction effect was found to be non-significant and from the pooled data it was observed that, the plant height at harvest ranged from 66.24 cm to 96.34 cm.

The reason for maximum heights of crop with the application of 75% RDF + FYM 2.5 t/ha might be due to the increased availability of nutrients in the soil through mineralization of organic sources which could have triggered cell elongation and multiplication resulting in the higher growth rate of shoots. The results obtained from the experiment were in agreement with those of Refs. [24-26]. Zn probably

Table 2 Effect of sources of NPK with micronutrient application on growth parameters of finger millet at harvest (pooled data of two years).

Treatment	Plant height (cm)			Dry matter (DM) production (g/m ²)			Leaf area index (LAI)		
	F ₁	F ₂	Mean	F ₁	F ₂	Mean	F ₁	F ₂	Mean
M ₁	68.47	71.78	70.13	461.50	492.01	476.75	2.22	2.18	2.20
M ₂	75.98	86.41	81.19	531.53	598.75	565.14	1.96	1.97	1.96
M ₃	66.25	69.95	68.10	448.31	500.53	474.42	2.18	2.28	2.23
M ₄	74.10	83.87	78.99	509.50	572.09	540.80	1.88	2.12	2.00
M ₅	79.15	93.56	86.36	550.19	634.53	592.36	2.33	2.51	2.42
M ₆	81.31	96.34	88.83	563.00	703.61	633.31	1.85	2.59	2.22
Mean	74.21	83.65	78.93	510.67	583.59	547.13	2.07	2.27	2.17
	S.Em (±)		LSD ($p \leq 0.05$)	S.Em (±)		LSD ($p \leq 0.05$)	S.Em (±)		LSD ($p \leq 0.05$)
F	0.95		3.72	7.08		27.79	0.02		0.09
M	2.05		5.97	11.78		33.69	0.07		0.20
F × M	2.90		NS	16.67		NS	0.10		NS
M × F	2.82		NS	16.78		NS	0.10		NS

F₁: 100% recommended dose of NPK (RDF); F₂: 75% RDF + 2.5 t/ha farmyard manure (FYM); M₁: ZnSO₄ at a rate 12.5 kg/ha as soil application; M₂: ZnSO₄ at a rate 0.5% as foliar spray; M₃: borax at a rate 10 kg/ha as soil application; M₄: borax at a rate 0.5% as foliar spray; M₅: ZnSO₄ at a rate 12.5 kg/ha + borax at a rate 10 kg/ha as soil application; M₆: ZnSO₄ at a rate 0.5% + borax at a rate 0.5% as foliar spray.

activated the activity of carbonic anhydrase enzyme (plays a role in converting bicarbonate ions back to carbon dioxide for photosynthesis) in leaves which had an important role in cell division and cell elongation. These two factors (cell division and cell elongation) led to the increase of the stem height. These results were in agreement with the reports of Malik *et al.* [27], Nadergoli *et al.* [28] and Manasa and Devaranavadagi [29]. Increase of crop height with B application might be due to the effect of B for proper development and differentiation of tissues, particularly growing tips, phloem and xylem [30]. The enhancement of photosynthetic and other metabolic activities led to an increase in various metabolites responsible for cell division and cell elongation of shoot and roots. Similar results were also reported by Hemantharajan *et al.* [31], Dixit and Elamathi [32] and Sathya *et al.* [33]. With the change in levels and methods of application of Zn and B from soil application to foliar application, the plant height gradually increased, which might be attributable to greater photosynthetic activity and chlorophyll synthesis due to Zn and B fertilization resulted into better vegetative growth. In this study, a synergistic

effect of Zn and B had been noticed in increasing plant height of finger millet which corroborated the findings of Arif *et al.* [34], Singh *et al.* [35], Singh *et al.* [36] and Baraich *et al.* [37].

3.2.2 DM Production (g/m²)

DM production at harvest was significantly regulated by the application of 75% RDF + 2.5 t/ha FYM (583.59 g/m²) when compared with 100% RDF (510.67 g/m²) regardless of subplot treatments i.e., different micronutrient method and levels of application. Among subplot treatments, foliar application of ZnSO₄ at a rate 0.5% + borax at a rate 0.5% significantly determined maximum DM production (633.30 g/m²) which was at par with soil application of ZnSO₄ at a rate 12.5 kg/ha + borax at a rate 10 kg/ha (592.36 g/m²) irrespective of different sources of NPK in both the years of experimentation. The interaction effect was settled up to be non-significant and it ranged from 448.31 g/m² to 703.61 g/m² (Table 2).

The improvement in DM production might be due to the increased photosynthetic activity of the plant. As the soil was low in available N, the crop responded well to applied N. Organic and in organic combination

led to improved soil properties with long term availability which led to increased nutrient absorption. The results were in conformity with the findings of Kumar *et al.* [38]. Betterment in the growth of crop might be due to the combined application of NPK + organics with borax which might increase the plant DM production. The applied nutrients by their effect on the metabolism of the cell, promoted the meristematic activity of the crop and its better uptake would have resulted in increased DM accumulation as explained by Elayaraja and Singaravel [30]. The increase in DM production might be attributed to the optimum and uniform availability of micronutrients in the entire growth period by means of application of nutrients through the soil [39]. There was increased dry weight at successive stages of growth, with the Zn and B application. Again, the increased tillering due to nutrient supplementation might have resulted in significant increase in plant dry weight. Matching results were also reported by Singh *et al.* [36].

3.2.3 Leaf Area Index (LAI)

At harvest, LAI of finger millet was significantly persuaded by the inclusion of 75% RDF + 2.5 t/ha FYM (2.27) when compared to 100% RDF (2.06) regardless of subplot treatments i.e., different micronutrient methods and levels of application. Among subplot treatments, foliar spray of ZnSO_4 at a rate 0.5% + borax at a rate 0.5% significantly determined the highest LAI (2.42) which was at par with ZnSO_4 at a rate 12.5 kg/ha + borax at a rate 10 kg/ha as soil application (2.22) irrespective of different levels of NPK in both the years of experimentation. The interaction effect was noted as non-significant on LAI at harvest and it ranged from 1.85 to 2.59 (Table 2).

Significantly highest LAI was registered by 75% RDF + 2.5 t/ha FYM. The conjunctive use of NPK with FYM might be attributed to the improvement of source size (leaf) which evidenced the improvement of LAI over sole application of NPK [40, 41]. Micronutrient application increased LAI which might

be due to better utilization and mobilization of carbohydrates to form more protoplasm. The cells produced under such conditions tend to be larger and to have thin walls, which might cause an increase in leaf area. The higher LAI indicated better leaf area expansion. This leaf expansion helped in a subsequent interception and efficient utilization of solar radiation, resulting in increased accumulation of DM in leaves and shoots. These results were in agreement with the reports of Gobi and Vaiyapuri [39]. Increase in LAI by Zn application might be due to increase in tryptophan amino acid and indole acetic acid hormone which were two main factors in leaf area expansion as elucidated by Mohsin *et al.* [42]. Higher LAI means bigger assimilatory system which resulted in more photosynthesis, and might be due to the fact that B had a synergistic effect on the uptake of N and P which increased the leaf area. The results obtained from the experiment were analogous with those of Tariq *et al.* [43], Hussain *et al.* [44] and Ali *et al.* [45]. Plant leaves acted as a source for capturing light and assimilating production. In the current study, plants treated with foliar application of Zn and B mixture produced more LAI with respect to their sole application which might be due to increased indole acetic acid hormone production through micronutrient fertilization as interpreted by Wasaya *et al.* [46].

3.3 Yield Attributes

3.3.1 Number of Productive Tillers/m²

The data pertaining to number of productive tillers/m² had been tabulated in Table 3. The tiller number/m² was statistically significantly influenced by levels of NPK and method and doses of micronutrient. The interaction effect was noticed as non-significant. From the pooled data, it was observed that 75% RDF + 2.5 t/ha FYM recorded significantly more productive tiller number/m² (160.77) as compared to 100% RDF (149.99) regardless of subplot treatments. Among subplot treatments, ZnSO_4 at a rate 0.5% + borax at a rate 0.5% as foliar spray

Table 3 Effect of sources of NPK with micronutrient application on yield attributes of finger millet (pooled data of two years).

Treatment	Number of productive tillers/m ²			Number of filled grains/earhead			1,000 grain weight (g)		
	F ₁	F ₂	Mean	F ₁	F ₂	Mean	F ₁	F ₂	Mean
M ₁	139.43	149.62	144.52	1,114.20	1,186.04	1,150.12	2.74	2.76	2.75
M ₂	154.12	164.89	159.50	1,264.23	1,441.20	1,352.72	2.76	2.73	2.75
M ₃	136.96	149.32	143.14	1,090.72	1,165.12	1,127.92	2.74	2.75	2.75
M ₄	151.64	162.07	156.85	1,218.63	1,391.30	1,304.96	2.75	2.73	2.74
M ₅	156.96	167.02	161.99	1,303.19	1,472.82	1,388.00	2.75	2.78	2.76
M ₆	160.82	171.70	166.26	1,360.33	1,509.67	1,435.00	2.76	2.77	2.77
Mean	149.99	160.77	155.38	1,225.22	1,361.02	1,293.12	2.75	2.75	2.75
	S.Em (±)		LSD ($p \leq 0.05$)	S.Em (±)		LSD ($p \leq 0.05$)	S.Em (±)		LSD ($p \leq 0.05$)
F	1.12		4.41	13.89		54.54	0.002		NS
M	2.12		6.05	21.06		60.20	0.005		NS
F × M	2.99		NS	29.79		NS	0.008		NS
M × F	2.95		NS	30.53		NS	0.007		NS

F₁: 100% recommended dose of NPK (RDF); F₂: 75% RDF + 2.5 t/ha FYM; M₁: ZnSO₄ at a rate 12.5 kg/ha as soil application; M₂: ZnSO₄ at a rate 0.5% as foliar spray; M₃: borax at a rate 10 kg/ha as soil application; M₄: borax at a rate 0.5% as foliar spray; M₅: ZnSO₄ at a rate 12.5 kg/ha + borax at a rate 10 kg/ha as soil application; M₆: ZnSO₄ at a rate 0.5% + borax at a rate 0.5% as foliar spray.

inscribed more productive tiller number/m² (166.26) which was at par with soil application of ZnSO₄ at a rate 12.5 kg/ha + borax at a rate 10 kg/ha (161.99) irrespective of main plot treatments. The interaction effect was non-significant and it ranged from 136.96 to 171.69.

3.3.2 Number of Filled Grains/Earhead

The number of filled grains/earhead significantly influenced by main and subplot treatments and their interactions were found to be non-significant (Table 3). Significantly higher number of filled grains/earhead (1,361.03) was perceived in 75% RDF + 2.5 t/ha FYM when compared to 100% RDF (1,225.23) irrespective of subplot treatments i.e., method and level of micronutrient. Significantly increased number of filled grains/earhead (1,435.01) was registered with foliar application of ZnSO₄ at a rate 0.5% + borax at a rate 0.5% which was statistically at par with ZnSO₄ at a rate 12.5 kg/ha + borax at a rate 10 kg/ha as soil application (1,388.01) regardless of main plot treatments. The interactions were found to be statistically at par with respect to number of filled grains/earhead and ranged from 1,090.72 to 1,509.67, respectively.

3.3.3 1,000 Grain Weight (g)

No significant difference was noticed in 1,000 grain weight (g) across the treatments in main plot, subplot and their interactions (Table 3). It ranged from 2.73 g to 2.78 g with the mean value of 2.75 g among the treatments.

From the pooled data it was observed that 75% RDF + 2.5 t/ha FYM recorded significantly higher number of productive tillers/m² and higher number of filled grains/earhead. This might be due to the reason that NPK were essential nutrients required for the promotion of the meristematic and physiological activities. The beneficial effect on yield attributing characters by FYM along with NPK could be due to increased supply of all essential nutrients, which might have resulted in more synthesis of photosynthate and its subsequent portioning to sink and due to role of Zn in biosynthesis of indole acetic acid (IAA) and especially its role in initiation of primordial and reproductive parts and partition of photosynthates to them. This coincides with the results obtained by Giribabu *et al.* [26], Kumar *et al.* [40], Ramamoorthy and Lourduraj [47], Pratap *et al.* [48] and Nigade and More [49]. ZnSO₄ at a rate 0.5%

+ borax at a rate 0.5% as foliar spray inscribed significantly more productive tiller number/m² and increased number of filled grains/earhead. Application of Zn significantly affected total number of tillers. Increase in productive tillers/m² might be ascribed to adequate supply of Zn that might have increased the uptake and availability of other essential nutrients, which resulted in improvement of plant metabolic activities and finally increased the crop growth as explained by Mustafa *et al.* [50]. Spraying of Zn and B elements showed no significant effect on 1,000 grain weight [51]. The more number of grains/earhead and higher grain weight by B application might be due to the involvement of B in reproductive growth as B improved the panicle fertility in the crop. The effect on yield components was marginally higher than growth parameters [44]. Anther and pollen grain development in Zn-applied plants were largely increased, possibly as a result of increased levels of IAA and proteins and B application enhanced plant growth by increased photosynthetic translocation through vascular bundles of petioles, causing growth and reproductive tissue development, the micronutrient acted as catalyst in the uptake and use of certain other macronutrients [34]. This trend might be due to the fact that Zn and B were active ingredients of energy metabolism pathway of plants. It played a major role in photosynthesis and was a structural constituent of many intermediaries in the process of photosynthesis and carbohydrate metabolism. Thus, Zn and B application method (foliar application) led to greater availability of Zn and B to the plants, which increased their metabolic efficiency and ultimately led to increased vegetative growth and number of effective tillers. These results were in agreement with the reports of Singh *et al.* [36]. The highest productive tiller number/m² and more number of filled grains/earhead were recorded by FYM + 75% RDF in combination with ZnSO₄ at a rate 0.5% + borax at a rate 0.5% foliar spray. The higher values of yield attributing characters might be

due to combination of micronutrients along with FYM and NPK which might have activated the availability of more plant nutrients and also helped in releasing unavailable nutrients into available form to the crop plants effectively as described by Sridhara *et al.* [52].

3.4 Yield

3.4.1 Grain Yield (t/ha)

Grain yield is the functions of several yield attributing characters viz., number of productive tillers/m², number of filled grains/earhead and 1,000 grain weight (g). The cumulative effect of all growth, physiological and yield attributing characters were reflected on grain yield. From the pooled data, it was perceived that grain yield also followed the similar trend like number of productive tillers/m² and number of filled grains/earhead, and significantly influenced by different sources of NPK and method and doses of micronutrients and their interactions were found to be non-expressive (Table 4).

Regardless of application of micronutrients, incorporation of 2.5 t/ha FYM with 75% RDF registered significantly higher grain yield (1.92 t/ha) over 100% RDF (1.70 t/ha). ZnSO₄ at a rate 0.5% + borax at a rate 0.5% foliar spray significantly inspired the grain yield (2.08 t/ha) which was at par with soil application of ZnSO₄ at a rate 12.5 kg/ha + borax at a rate 10 kg/ha (1.96 t/ha) in both the years of experimentation irrespective of main plot treatments. The interaction effect was statistically at par with respect to grain yield and it ranged from 1.50 t/ha to 2.27 t/ha. The highest grain yield was recorded by 2.5 t/ha FYM + 75% RDF in combination with ZnSO₄ at a rate 0.5% + borax at a rate 0.5% foliar spray (2.27 t/ha).

3.4.2 Straw Yield (t/ha)

From the pooled data it was noticed that finger millet straw yield was significantly influenced by main plot and subplot treatments, but their interactions were noticed as statistically at par (Table 4). Application of 75% RDF with 2.5 t/ha FYM significantly

Table 4 Effect of sources of NPK with micronutrient application on yield (t/ha) and harvest index (HI) (%) of finger millet (pooled data of two years).

Treatment	Grain yield (t/ha)			Straw yield (t/ha)			Biological yield (t/ha)			HI (%)		
	F1	F2	Mean	F1	F2	Mean	F1	F2	Mean	F1	F2	Mean
M ₁	1.54	1.65	1.59	3.08	3.27	3.18	4.62	4.92	4.77	33.33	33.47	33.40
M ₂	1.76	2.00	1.88	3.56	3.99	3.77	5.32	5.99	5.65	33.05	33.34	33.19
M ₃	1.50	1.62	1.56	2.98	3.39	3.18	4.48	5.01	4.74	33.49	32.36	32.92
M ₄	1.70	1.90	1.80	3.40	3.82	3.61	5.10	5.72	5.41	33.33	33.22	33.27
M ₅	1.82	2.11	1.96	3.68	4.24	3.96	5.50	6.35	5.92	33.05	33.20	33.12
M ₆	1.88	2.27	2.08	3.75	4.76	4.26	5.63	7.04	6.33	33.33	32.31	32.82
Mean	1.70	1.92	1.81	3.41	3.91	3.66	5.11	5.84	5.47	33.26	32.98	33.12
	S.Em (±)		LSD (<i>p</i> ≤ 0.05)	S.Em (±)		LSD (<i>p</i> ≤ 0.05)	S.Em (±)		LSD (<i>p</i> ≤ 0.05)	S.Em (±)		LSD (<i>p</i> ≤ 0.05)
F	0.02		0.09	0.05		0.19	0.07		0.28	0.001		NS
M	0.04		0.11	0.08		0.22	0.12		0.34	0.003		NS
F × M	0.05		NS	0.11		NS	0.17		NS	0.004		NS
M × F	0.06		NS	0.11		NS	0.17		NS	0.003		NS

F₁: 100% recommended dose of NPK (RDF); F₂: 75% RDF + 2.5 t/ha FYM; M₁: ZnSO₄ at a rate 12.5 kg/ha as soil application; M₂: ZnSO₄ at a rate 0.5% as foliar spray; M₃: borax at a rate 10 kg/ha as soil application; M₄: borax at a rate 0.5% as foliar spray; M₅: ZnSO₄ at a rate 12.5 kg/ha + borax at a rate 10 kg/ha as soil application; M₆: ZnSO₄ at a rate 0.5% + borax at a rate 0.5% as foliar spray.

increased the straw yield of finger millet (3.91 t/ha) as compared to 100% RDF application (3.41 t/ha) irrespective of subplot treatments. From the pooled data, it was confirmed that foliar application of ZnSO₄ at a rate 0.5% + borax at a rate 0.5% (4.26 t/ha) recorded significantly the highest straw yield which was at par with ZnSO₄ at a rate 12.5 kg/ha + borax at a rate 10 kg/ha as soil application (3.96 t/ha) regardless of main plot treatments. The interaction effect of main plot and subplot were noticed as non-significant corresponding to straw yield of finger millet and it ranged from 2.98 t/ha to 4.76 t/ha. The highest straw yield was enrolled by 2.5 t/ha FYM + 75% RDF in combination with ZnSO₄ at a rate 0.5% + borax at a rate 0.5% foliar spray (4.76 t/ha).

3.4.3 Biological Yield (t/ha)

From the pooled data it was recorded that biological yield of finger millet was significantly influenced by main plot and subplot treatments, but their interactions were noticed to be non-significant (Table 4). Application of 75% RDF with 2.5 t/ha FYM significantly increased the biological yield of finger millet (5.84 t/ha) as compared to 100% RDF (5.11 t/ha) irrespective of subplot treatments. Maximum

biological yield of finger millet (6.33 t/ha) had been registered with the foliar application of ZnSO₄ at a rate 0.5% + borax at a rate 0.5% which was statistically at par with ZnSO₄ at a rate 12.5 kg/ha + borax at a rate 10 kg/ha as soil application (5.92 t/ha) regardless of main plot treatments. The interaction effect was statistically at par with respect to biological yield of finger millet and it ranged from 4.48 t/ha to 7.04 t/ha. The highest biological yield 7.04 t/ha was recorded by 2.5 t/ha FYM + 75% RDF in combination with ZnSO₄ at a rate 0.5% + borax at a rate 0.5% foliar spray.

3.4.4 Harvest Index (HI)

The data regarding HI had been tabulated in Table 4. From the pooled data, it was noticed that main plot and subplot treatments with their interactions were found to be non-significant, and 100% RDF application recorded higher HI (33.26%) as compared to 75% RDF + 2.5 t/ha FYM (32.98%) irrespective of subplot treatments. Among subplot treatments, soil application of ZnSO₄ at a rate 12.5 kg/ha registered more HI (33.40%) followed by foliar application of borax at a rate 0.5% (33.27%). Among interactions, borax at a rate 10 kg/ha as soil application with 100%

RDF recorded the highest HI (33.49%) over other treatment combinations.

Incorporation of 2.5 t/ha FYM with 75% RDF registered significantly higher grain yield over 100% RDF. Grain yield was the ultimate end product of many yield contributing components, physiological and morphological processes took place in plants during growth and development. The conjunctive use of organic and inorganic sources had a beneficial effect on the physiological process of plant metabolism and growth, thereby leading to higher grain yield. The easy availability of N due to mineralization of organics influenced the shoot and root growth favoring absorption of other nutrients. The results were in conformity with the findings of Yakadri and Reddy [53]. The nutrients also enhanced the carbohydrates supply to seeds and increased yield components like productive tillers/m² and number of filled grains/earhead which had direct influence on grain yield [54, 55]. Significant increase in yield with organics and inorganics together was attributed to buildup of humus and organic carbon which improved the soil properties and increased availability of nutrients [56, 57]. Application of 75% RDF with 2.5 t/ha FYM significantly increased the straw yield of finger millet. Higher straw yield under conjoint organic and inorganic sources was due to higher plant height, LAI, DM accumulation, more nutrient availability and uptake. These results were in agreement with the reports of Giribabu *et al.* [26] and Jagathjothi *et al.* [58]. ZnSO₄ at a rate 0.5% + borax at a rate 0.5% as foliar spray significantly inspired the grain yield followed by soil application of ZnSO₄ at a rate 12.5 kg/ha + borax at a rate 10 kg/ha. In the present experiment, foliar application was the most beneficial method, because low soil pH decreased the efficiency of soil application of Zn and B. The Zn sulfate foliar application had the positive effect on the growth, yield and yield components of finger millet [59]. Response of crop to Zn application may be due to deficiency of this nutrient in soil which was

improved by Zn application. Matching results were also reported by Tabrizi *et al.* [60]. Foliar application of Zn increased grain yield. The increase in the grain yield was attributable to the improved physiology of plants with the added Zn which consequently corrected the efficiency of different enzymes, chlorophyll content, IAA hormone and improved the nitrate conversion to ammonia in plant. The results were in conformity with the findings of Moghadam *et al.* [51]. The higher yield due to Zn fertilization might be attributed to the enhanced synthesis of carbohydrates and their transport to the site of grain production. Increase in the biological yield might be attributed to better nutrition with Zn application and increased DM production [42]. Maximum yield was obtained from the treatment plot, where B was applied as a foliar spray. An increase in yield might be due to foliar spray of B and this improvement was attributed to direct absorption of B from aerial parts of plants [43]. Increased grain yield by application of B might be the direct effect of higher number of grains/earhead due to reduced panicle sterility by B application appreciably. Higher yields were found with foliar spray than soil application due to the fact that B application had been done just before panicle initiation as B nutrition is more important during the reproductive stage as compared to the vegetative stage of the crop [44]. The combined application of NPK + organics in the presence of borax increased the yield of the crop. B exerts its significant role in metabolism of nucleic acid, carbohydrate, protein and auxins. Efficient metabolism and translocation of carbohydrates from source to sink might have increased the seed yield. Further, the addition of organics along with borax facilitated the release of nutrient ions from organic manures, which helped in maintaining the continuous availability of nutrients during the entire life cycle of the plant [30, 33]. The highest grain yield was recorded by 2.5 t/ha FYM + 75% RDF in combination with ZnSO₄ at a rate 0.5% + borax at a rate 0.5% foliar spray. The increase in

growth parameter, chlorophyll contents, biochemical profile and yield components was improved with the combined use of micronutrients which resulted in increased grain and straw yield [34]. Grain yield depended on the synthesis and accumulation of photosynthetic and their distribution among various plant parts. The synthesis, accumulation and translocation of photosynthates depend upon efficient photosynthetic structure as well as the extent of translocation into the sink (grains) and also on plant growth and development during the early stages of crop growth. This may be attributed to the fulfillment of the demand of the crop by higher assimilation and translocation of photosynthates from source (leaves) to sink (grains), through the supply of required nutrients by foliar spray of micronutrients [29, 61]. Foliar application of micronutrients is important when the roots could not be able to provide the necessary nutrients and hence the application on the foliage helped in the rapid absorption of the required nutrients by the crop for higher production. The effect of fertilizer application methods was significant on all agronomic parameters which in turn increased the straw and biological yield of the crop. The probable reason for improved agronomic traits of finger millet with foliar application of micronutrients might be ascribed to the direct and rapid absorption of these micronutrients on the foliage of the crop [37].

4. Conclusions

From the results of the present investigation, keeping in view of finger millet crop growth, yield attributes and yield, it might be concluded that combination of organic and inorganic nutrient sources (75% RDF + 2.5 t/ha FYM) was proved to be beneficial resulting in significantly higher crop yield and addition of micronutrients (Zn and B) with combined organic and inorganic nutrient sources (75% RDF + 2.5 t/ha FYM) proved to be superior over application of micronutrients (Zn and B) with 100% RDF (N:P₂O₅:K₂O, 40:20:20 kg/ha) in red and laterite

zone of West Bengal. Sole application of Zn as well as B proved to be inferior to the combined application of both the micronutrients (Zn and B), however, foliar application (0.5%) of ZnSO₄ and borax proved to be superior to the soil application of these micronutrients. So, organic and inorganic combination of NPK (75% RDF + 2.5 t/ha FYM) along with foliar application of both the micronutrients (Zn and B) together can boost up the yield and could be recommended for the cultivation of direct seeded upland finger millet crop in red and laterite zone of West Bengal in spring season with limited irrigations.

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