



RESEARCH ARTICLE

# Effect of zinc and iron on growth and yield of foxtail millet (*Setaria italica* L.) in the Northern Transitional Zone of Karnataka

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## Abstract

A field experiment was conducted in a randomised complete block design (RCBD) with eight treatments and three replications to assess the response of foxtail millet to the soil incorporation of micronutrients and to determine the micronutrient content in its grain and fodder in order to check whether agronomic bio-fortification through soil application of zinc (Zn) and iron (Fe) fertilisers can offers an immediate and effective route to enhance micronutrient concentrations in foxtail millet. The treatments included combinations of soil-applied Zn and Fe along with the recommended package of practices (RPP), compared with farmers' practice. The findings indicated that applying of zinc sulphate (ZnSO<sub>4</sub>) at 15 kg ha<sup>-1</sup> + iron sulphate (FeSO<sub>4</sub>) at 15 kg ha<sup>-1</sup> along with RPP recorded significantly higher plant height, number of tillers per hill, total dry matter production per plant, test weight, grain yield, stover yield, net returns and benefit : cost (B : C) ratio, followed by RPP + ZnSO<sub>4</sub> at 10 kg ha<sup>-1</sup> + FeSO<sub>4</sub> at 10 kg ha<sup>-1</sup>. It is therefore evident that soil application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> each at 15 kg ha<sup>-1</sup> along with RPP significantly enhances the yield and profitability of foxtail millet, offering greater economic benefits to the farming community.

**Keywords:** agronomic fortification; bio-fortification; foxtail millet; growth; iron; nutrient uptake; yield; zinc

## Introduction

Foxtail millet (*Setaria italica* L.) is the second most widely grown millet globally and a predominant species grown in East Asia. It thrives in arid and semi-arid environments across Asia and Africa and it is also cultivated in several developed nations. Although well suited to marginal soils, it remains largely under-exploited as a food crop. In recent times, its potential in improving nutritional and food security has drawn significant attention. Foxtail millet is known for its strong drought tolerance and much of the existing research on this crop originates from semi-arid tropical regions (1). Owing to its short duration and fast growth habit, it can be raised as a main crop or used as an intercrop. The grain is nutritionally superior and contains notable quantities of macro and micronutrients, vitamins and minerals. Per 100 g of grain, it provides 12.3 g protein, 60.9 g carbohydrates, 4.3 g fat, 8.0 g crude fibre, 31 mg calcium, 3.3 g minerals and 0.59 mg thiamine (2). Malnutrition continues to be a major global concern, especially in developing regions. As millets are nutrient-rich cereals, they are increasingly emphasised in research for bio-fortification to meet the dietary needs of the rising population. Higher crop productivity was achieved through modern technologies without adequate consideration of soil health, which have led to nutrient depletion and declining soil fertility.

Zinc (Zn) and iron (Fe) deficiency are widespread both in human populations and agricultural soils, significantly affecting crop

productivity (3). The overlap of soil-deficient regions with areas of human micronutrient deficiency highlights the necessity to enhance these elements in the food crops (3). In North Karnataka, where millets are commonly grown under rainfed conditions in black soils, generally exhibit low accessibility of Zn and Fe, resulting in deficiency symptoms in plants. While developing bio-fortified genotypes through the breeding techniques is a long-term and cost-effective solution and the process is tedious in nature. Therefore, a quicker alternative is necessary to boost Zn and Fe content in food grains. So, the current experiment concentrates on, whether agronomic bio-fortification through soil application of Zn and Fe fertilisers can offers an immediate and effective route to enhance micronutrient concentrations in foxtail millet.

## Materials and Methods

A field experiment was conducted during kharif season 2019–20 at college farm, College of Agriculture, Hanumanamatti, Ranebennur Taluk, Haveri district which is situated between 14° 39' 26" North latitude and 75° 33' 40" East longitude and at an altitude of 877 m above mean sea level. The experimental site was located in Northern Transitional Zone (Zone-8) of Karnataka. The experimental soil was classified as red sandy loam with an average particle content of 77.00, 12.40 and 10.60 % sand, silt and clay respectively. The soil was normal in reaction (7.08), normal in electrical conductivity

(0.32 dSm<sup>-1</sup>) and with moderate organic carbon content (0.68 %). In addition, the soil available nitrogen (N) (295.00 kg N ha<sup>-1</sup>), potassium (K) (220.00 kg K<sub>2</sub>O ha<sup>-1</sup>) and sulphur (S) (13.60 ppm) was medium and phosphorus (P) (18.00 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>) was low. Among the micronutrients diethylene triamine penta acetic acid (DTPA) i.e., DTPA Fe (3.25 ppm), DTPA Zn (1.20 ppm), DTPA Cu (0.45 ppm), DTPA Mn (2.12 ppm) and hot water-soluble B (1.26 ppm) were sufficient in soil and; soil was non-calcareous (1.28 % of free calcium carbonate) in nature. The study was conducted in randomised complete block design (RCBD) including eight treatments with three replications each. The treatments consists of T<sub>1</sub>: farmers' practice (30 kg diammonium phosphate (DAP) ha<sup>-1</sup> and no farmyard manure (FYM)), T<sub>2</sub>: recommended package of practice (RPP) (30 : 15 : 15 kg NPK ha<sup>-1</sup> + 6 t FYM ha<sup>-1</sup> + 500 g of *Azospirillum* ha<sup>-1</sup>), T<sub>3</sub>: T<sub>2</sub>+ zinc sulphate (ZnSO<sub>4</sub>) at 10 kg ha<sup>-1</sup>, T<sub>4</sub>: T<sub>2</sub>+ ZnSO<sub>4</sub> at 15 kg ha<sup>-1</sup>, T<sub>5</sub>: T<sub>2</sub>+ iron sulphate (FeSO<sub>4</sub>) at 10 kg ha<sup>-1</sup>, T<sub>6</sub>: T<sub>2</sub>+ FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup>, T<sub>7</sub>: T<sub>2</sub>+ ZnSO<sub>4</sub> at 10 kg ha<sup>-1</sup> + FeSO<sub>4</sub> at 10 kg ha<sup>-1</sup> and T<sub>8</sub>: T<sub>2</sub>+ ZnSO<sub>4</sub> at 15 kg ha<sup>-1</sup> + FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup>. The gross plot size was 3.6 × 3.0 m and the net plot size was 3.00 × 2.85 m. The fertilisers were applied as per treatments. The seeds of foxtail millet (DHFT 109-3) were sown by using khera method (dropping of seeds through hands in furrow behind the plough) with seed rate of 7 kg ha<sup>-1</sup> on 07.06.2019 and 11.06.2020 during 2019–20 respectively by following spacing of 30 × 7.5 cm. The seedlings were thinned at 10 days after sowing (DAS) to maintain required plant population. Possible care was taken to keep the plots free from weeds and pests by taking up timely weeding and plant protection measures. The precipitation received throughout the growing season was shown in Table 1. Crop was harvested at their physiological maturity stage; the two years data were pooled and statistically analysed as per standard procedure (4).

## Results and Discussion

### Growth parameters

Various growth parameters observations of foxtail millet were depicted in Table 2. Plant height at harvest did not vary significantly among the treatments. Though, plant height is being determined by environmental factors and management practices, but basically it is a genetically controlled character. In the present investigation no significant variation was observed among the treatments in terms of plant height at harvest. However, significant differences were observed with respect to number of tillers and number of leaves per hill. Application of RPP (30 : 15 : 15 kg NPK ha<sup>-1</sup> + 6 t FYM ha<sup>-1</sup> + 500 g *Azospirillum* ha<sup>-1</sup>) along with soil incorporation of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup> each (T<sub>8</sub>) recorded significantly higher number of tillers per hill (12.17), which was statistically on par with RPP + ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 10 kg ha<sup>-1</sup> each (11.27) (T<sub>7</sub>) and RPP + ZnSO<sub>4</sub> at 15 kg ha<sup>-1</sup> (11.08) (T<sub>4</sub>). A similar trend was observed in total dry matter accumulation per plant.

The treatment (T<sub>4</sub>) receiving RPP along with ZnSO<sub>4</sub> at 15 kg ha<sup>-1</sup> produced a significantly higher leaf count per hill (32.20) in comparison with the remaining treatments. However, this was statistically on par with T<sub>8</sub> (RPP + ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup> respectively) (31.78), T<sub>7</sub> (RPP + ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 10 kg ha<sup>-1</sup> respectively) (31.03) and T<sub>6</sub> (RPP + FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup>) (30.43). Comparable findings were reported in a study where, the treatment M<sub>7</sub>: RDF + soil incorporation of ZnSO<sub>4</sub> at 15 kg ha<sup>-1</sup> and FeSO<sub>4</sub> at 10 kg ha<sup>-1</sup> + foliar spray of 0.5 % ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 30 DAS resulted in markedly higher tillers plant<sup>-1</sup> (4.21), leaf area (41.26, 83.47 and 27.82 cm<sup>2</sup> plant<sup>-1</sup> at 30, 60 DAS and harvest respectively) and total dry matter (2.53, 11.01 and 29.69 g plant<sup>-1</sup> at 30, 60 DAS and harvest respectively) (5). In another study treatment M<sub>6</sub>: RDF + seed

**Table 1.** Meteorological data recorded at College of Agriculture, Hanumanamatti

| Month     | Rainfall (mm) |       | Temperature °C |      |      |      | Relative humidity (%) |       |
|-----------|---------------|-------|----------------|------|------|------|-----------------------|-------|
|           | 2019          | 2020  | 2019           |      | 2020 |      | 2019                  | 2020  |
|           |               |       | Max.           | Min. | Max. | Min. |                       |       |
| January   | 0.0           | 0.0   | 31.1           | 15.2 | 29.8 | 19.8 | 56.0                  | 53.9  |
| February  | 0.0           | 0.0   | 34.1           | 16.2 | 30.3 | 22.1 | 47.0                  | 62.3  |
| March     | 2.6           | 0.0   | 36.9           | 18.9 | 34.2 | 22.3 | 72.0                  | 64.2  |
| April     | 19.0          | 0.2   | 37.9           | 21.6 | 37.6 | 22.1 | 80.0                  | 60.3  |
| May       | 3.0           | 168.8 | 37.4           | 23.6 | 36.1 | 22.5 | 81.0                  | 60.85 |
| June      | 72.6          | 101.0 | 32.6           | 21.3 | 31.0 | -    | 83.0                  | 72.35 |
| July      | 167.5         | 128.0 | 28.3           | 18.6 | 29.4 | -    | 80.0                  | 74.6  |
| August    | 408.8         | 102.6 | 28.2           | 20.6 | 28.1 | -    | 86.0                  | 77.9  |
| September | 148.8         | 163.6 | 28.9           | 19.8 | 29.4 | -    | 83.0                  | 76.1  |
| October   | 444.5         | 185.9 | 30.1           | 20.1 | 30.0 | -    | 80.0                  | 73.4  |
| November  | 9.4           | 1.4   | 28.7           | 19.4 | 31.0 | -    | 78.0                  | 68.65 |
| December  | 0.20          | 0     | 29.2           | 19.1 | 30.3 | 17.1 | 70.0                  | 65.5  |

Max.: maximum; Min.: minimum.

**Table 2.** Effect of zinc and iron on growth parameters of foxtail millet

| Treatments      | Plant height (cm) |        |        | No. of tillers hill <sup>-1</sup> |       |        | No. of leaves hill <sup>-1</sup> |       |        | TDMP (g plant <sup>-1</sup> ) |       |        |
|-----------------|-------------------|--------|--------|-----------------------------------|-------|--------|----------------------------------|-------|--------|-------------------------------|-------|--------|
|                 | 2019              | 2020   | Pooled | 2019                              | 2020  | Pooled | 2019                             | 2020  | Pooled | 2019                          | 2020  | Pooled |
| T <sub>1</sub>  | 123.80            | 124.13 | 123.97 | 7.80                              | 7.47  | 7.63   | 21.67                            | 21.00 | 21.33  | 11.33                         | 11.07 | 11.20  |
| T <sub>2</sub>  | 128.47            | 126.80 | 127.63 | 9.60                              | 9.37  | 9.48   | 24.53                            | 23.83 | 24.18  | 13.53                         | 13.07 | 13.30  |
| T <sub>3</sub>  | 130.27            | 124.07 | 127.17 | 10.37                             | 10.17 | 10.27  | 28.73                            | 27.67 | 28.20  | 14.57                         | 14.23 | 14.40  |
| T <sub>4</sub>  | 133.67            | 129.17 | 131.42 | 11.27                             | 10.90 | 11.08  | 32.90                            | 31.50 | 32.20  | 16.27                         | 16.03 | 16.15  |
| T <sub>5</sub>  | 130.10            | 126.00 | 128.05 | 9.60                              | 9.37  | 9.48   | 25.40                            | 24.30 | 24.85  | 14.97                         | 14.30 | 14.63  |
| T <sub>6</sub>  | 132.07            | 127.50 | 129.78 | 10.73                             | 10.40 | 10.57  | 31.10                            | 29.77 | 30.43  | 15.97                         | 15.30 | 15.63  |
| T <sub>7</sub>  | 134.60            | 130.80 | 132.70 | 11.43                             | 11.10 | 11.27  | 31.37                            | 30.70 | 31.03  | 16.87                         | 16.43 | 16.65  |
| T <sub>8</sub>  | 136.27            | 133.20 | 134.73 | 12.23                             | 12.10 | 12.17  | 32.23                            | 31.33 | 31.78  | 17.53                         | 16.87 | 17.20  |
| SEm±            | 5.41              | 5.38   | 5.00   | 0.42                              | 0.49  | 0.44   | 1.22                             | 1.22  | 1.17   | 0.51                          | 0.36  | 0.38   |
| C.D. (p = 0.05) | NS                | NS     | NS     | 1.26                              | 1.48  | 1.32   | 3.71                             | 3.70  | 3.55   | 1.55                          | 1.08  | 1.16   |

TDMP: total dry matter production; No.: number; NS: non-significant.

treatment with 0.5 % ZnSO<sub>4</sub> and FeSO<sub>4</sub> + foliar spray of 0.5 % ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 30 DAS, recorded 4.06 tillers plant<sup>-1</sup>, leaf area of 40.37, 82.22 and 26.51 cm<sup>2</sup> plant<sup>-1</sup> at 30, 60 DAS and at harvest respectively and total dry matter of 2.30, 10.77 and 28.69 g plant<sup>-1</sup> at the corresponding stages. In the interaction, genotype G<sub>3</sub> (Sia-2644) combined with M<sub>7</sub> recorded the highest number of tillers (4.32), the largest leaf area (41.26, 83.47 and 27.82 cm<sup>2</sup> plant<sup>-1</sup> at 30, 60 DAS and at harvest respectively) and highest buildup of dry matter (2.48, 11.28 and 30.52 g plant<sup>-1</sup> at 30, 60 DAS and at harvest respectively) (6). The beneficial effect may be attributed to foliar feeding, which ensures faster uptake of Zn and Fe through leaf tissues, promoting enhanced cell division, elongation, chlorophyll formation and photosynthetic activity. Additionally, foliar application facilitates better mobilisation of assimilates from source to sink, thereby improving growth and biomass accumulation.

### Yield and yield parameters

The data relating to the yield parameters pertaining to foxtail millet as impacted by application of Zn and Fe is depicted in Table 3. Yield of any crop is determined by its yield components (7). All the yield parameters pertaining to foxtail millet were influenced by supplementation with Zn and Fe. Following RPP along with application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup> (T<sub>8</sub>) was showed better performance and exhibited significantly superior panicle length (19.73 cm), panicle weight (6.37 g), test weight (4.02 g) and grain yield per plant (5.11 g), as compared to the other treatments. However, it was on par with T<sub>7</sub> (following RPP along with application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 10 kg ha<sup>-1</sup> respectively) (17.83 cm, 5.70 g, 3.75 g and 4.69 g of panicle length, panicle weight, test weight and grain yield per plant respectively). The results are in line with the findings of a study conducted on effect of organically bound micronutrients on growth of rice (8). Zinc application created a favourable nutritional environment above and below the soil's surface, which benefited crop growth over the course of its life cycle and ultimately increased yield. Iron, being an essential component of porphyrins, cytochromes, hemes, hematin, ferrichrome and leghemoglobin, plays a key role in cellular redox processes associated with respiration and photosynthesis. Yield enhancement can be attributed to improved nutrient availability in the rhizosphere, which enhances nutrient uptake, boosts photosynthetic activity and supports better assimilate production. Furthermore, *Azospirillum* inoculation enhances plant physiological performance by mitigating the adverse effects of moisture stress during flowering, thereby contributing to higher grain yield (9). Comparable findings were also documented in the studies conducted in earlier studies (7, 10).

The data pertaining to grain yield, stover yield and harvest index of foxtail millet as influenced by application of Zn and Fe is

presented in Table 4. Following RPP along with application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup> (T<sub>8</sub>) resulted in higher grain yield (18.45 q ha<sup>-1</sup>) over rest of the treatments. However, it was on par with T<sub>7</sub> (RPP along with application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 10 kg ha<sup>-1</sup>) (17.20 q ha<sup>-1</sup>). Significantly lower grain yield (10.13 q ha<sup>-1</sup>) was recorded in farmers' practice (T<sub>1</sub>). This is in conformity with the findings of a study conducted in Dharwad on sorghum (11). Comparable outcomes were observed for stover yield, where T<sub>8</sub> and T<sub>7</sub> recorded 53.05 and 49.57 q ha<sup>-1</sup> respectively. These findings are consistent with those reported in earlier study (12) on the effect of Fe and Zn application in rabi sorghum. It was observed that the treatment M<sub>7</sub>, comprising the recommended dose of fertilisers (RDF) along with soil application of ZnSO<sub>4</sub> at 15 kg ha<sup>-1</sup> and FeSO<sub>4</sub> at 10 kg ha<sup>-1</sup>, followed by foliar sprays of 0.5 % ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 30 DAS, resulted in significantly higher grain yield (2272 kg ha<sup>-1</sup>), stover yield (9298 kg ha<sup>-1</sup>), and harvest index (19.63 %). This treatment was statistically at par with M<sub>6</sub>, which consisted of RDF combined with seed treatment using 0.5 % ZnSO<sub>4</sub> and FeSO<sub>4</sub>, followed by foliar application of 0.5 % ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 30 DAS, and recorded a grain yield of 2223 kg ha<sup>-1</sup>, stover yield of 9274 kg ha<sup>-1</sup>, and harvest index of 19.32 %. In terms of interaction, the genotype G<sub>3</sub> (Sia-2644) combined with M<sub>7</sub> produced the highest grain and stover yield along with harvest index values (4.32, 25.73 cm, 11.49 g, 2321 kg ha<sup>-1</sup>, 9363 kg ha<sup>-1</sup> and 19.85 % respectively). The yield improvement can be attributed to a steady supply of micronutrients, particularly Zn and Fe, through soil application. These elements play crucial roles in photosynthesis, assimilate formation and their transport from source organs (leaves) to sink (ear heads) (13). Similar findings have been reported in the different studies (14-16). However, Zn and Fe application did not significantly influence the harvest index of foxtail millet.

### Economics

Economics of foxtail millet for application of Zn and Fe is presented in Table 5. The gross return was ranged ₹ 29583–53524 ha<sup>-1</sup>. But higher gross returns were recorded in T<sub>8</sub> (RPP along with application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup> respectively) (₹ 53524 ha<sup>-1</sup>), closely followed by T<sub>7</sub> (RPP along with application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 10 kg ha<sup>-1</sup> respectively) (₹ 49773 ha<sup>-1</sup>) as compared to all other treatments. But lower gross returns (₹ 29583 ha<sup>-1</sup>) were observed in farmers' practice (T<sub>1</sub>). The cost of cultivation was ranged ₹ 19081–26907 ha<sup>-1</sup>. All the treatments recorded higher cost of cultivation (₹ 24132–26907 ha<sup>-1</sup>) as compared to farmers' practice (₹ 19081 ha<sup>-1</sup>). However, monetary evaluation of the agricultural commodities based on gross returns is not a valid approach. Variations in the cost of cultivation and prevailing prices of component crops may modify the economic efficiency of the system, such that a production system with higher gross returns

**Table 3.** Effect of zinc and iron on yield parameters of foxtail millet

| Treatments      | Panicle length (cm) |       |        | Panicle weight (g) |      |        | Test weight (g) |      |        | Grain yield (g plant <sup>-1</sup> ) |      |        |
|-----------------|---------------------|-------|--------|--------------------|------|--------|-----------------|------|--------|--------------------------------------|------|--------|
|                 | 2019                | 2020  | Pooled | 2019               | 2020 | Pooled | 2019            | 2020 | Pooled | 2019                                 | 2020 | Pooled |
| T <sub>1</sub>  | 11.73               | 11.07 | 11.40  | 3.90               | 4.33 | 4.12   | 2.03            | 3.07 | 2.55   | 2.40                                 | 3.10 | 2.75   |
| T <sub>2</sub>  | 13.47               | 13.10 | 13.28  | 4.23               | 4.80 | 4.52   | 2.27            | 3.36 | 2.82   | 3.00                                 | 3.90 | 3.45   |
| T <sub>3</sub>  | 15.30               | 14.77 | 15.03  | 4.93               | 5.60 | 5.27   | 2.96            | 3.78 | 3.37   | 3.20                                 | 4.32 | 3.76   |
| T <sub>4</sub>  | 17.60               | 16.97 | 17.28  | 4.93               | 5.30 | 5.12   | 3.03            | 4.02 | 3.53   | 3.62                                 | 4.90 | 4.26   |
| T <sub>5</sub>  | 14.17               | 13.57 | 13.87  | 5.17               | 5.50 | 5.33   | 2.83            | 3.58 | 3.21   | 3.12                                 | 4.20 | 3.66   |
| T <sub>6</sub>  | 16.83               | 16.63 | 16.73  | 5.20               | 5.70 | 5.45   | 2.90            | 4.00 | 3.45   | 3.60                                 | 4.78 | 4.19   |
| T <sub>7</sub>  | 18.07               | 17.60 | 17.83  | 5.37               | 6.03 | 5.70   | 3.17            | 4.33 | 3.75   | 4.10                                 | 5.28 | 4.69   |
| T <sub>8</sub>  | 20.10               | 19.37 | 19.73  | 6.27               | 6.47 | 6.37   | 3.50            | 4.54 | 4.02   | 4.38                                 | 5.84 | 5.11   |
| SEm±            | 0.59                | 0.79  | 0.65   | 0.23               | 0.34 | 0.25   | 0.22            | 0.21 | 0.15   | 0.25                                 | 0.31 | 0.28   |
| C.D. (p = 0.05) | 1.80                | 2.40  | 1.97   | 0.69               | 1.02 | 0.75   | 0.68            | 0.63 | 0.47   | 0.75                                 | 0.93 | 0.84   |

**Table 4.** Effect of zinc and iron on yield and harvest index of foxtail millet

| Treatments          | Grain yield (q/ha) |       |        | Stover yield (q/ha) |       |        | Harvest index |      |        |
|---------------------|--------------------|-------|--------|---------------------|-------|--------|---------------|------|--------|
|                     | 2019               | 2020  | Pooled | 2019                | 2020  | Pooled | 2019          | 2020 | Pooled |
| T <sub>1</sub>      | 9.93               | 10.33 | 10.13  | 33.89               | 34.87 | 34.38  | 0.23          | 0.23 | 0.23   |
| T <sub>2</sub>      | 12.23              | 14.17 | 13.20  | 39.54               | 44.11 | 41.82  | 0.24          | 0.24 | 0.24   |
| T <sub>3</sub>      | 13.80              | 15.67 | 14.73  | 43.26               | 47.76 | 45.51  | 0.24          | 0.25 | 0.24   |
| T <sub>4</sub>      | 14.40              | 16.00 | 15.20  | 44.12               | 47.86 | 45.99  | 0.25          | 0.25 | 0.25   |
| T <sub>5</sub>      | 13.03              | 15.00 | 14.02  | 42.48               | 47.40 | 44.94  | 0.23          | 0.24 | 0.24   |
| T <sub>6</sub>      | 14.17              | 15.80 | 14.98  | 44.16               | 48.01 | 46.09  | 0.24          | 0.25 | 0.25   |
| T <sub>7</sub>      | 16.33              | 18.07 | 17.20  | 47.58               | 51.55 | 49.57  | 0.26          | 0.26 | 0.26   |
| T <sub>8</sub>      | 17.73              | 19.17 | 18.45  | 51.38               | 54.72 | 53.05  | 0.26          | 0.26 | 0.26   |
| SEm±                | 0.85               | 0.90  | 0.72   | 2.88                | 2.30  | 2.20   | 0.01          | 0.01 | 0.01   |
| C.D. ( $p = 0.05$ ) | 2.57               | 2.72  | 2.17   | 8.64                | 6.90  | 6.60   | NS            | NS   | NS     |

NS: non-significant.

**Table 5.** Effect of zinc and iron on economics of foxtail millet

| Treatments          | Gross return (₹ ha <sup>-1</sup> ) |       |        | Cost of cultivation (₹ ha <sup>-1</sup> ) |       |        | Net return (₹ ha <sup>-1</sup> ) |       |        | Benefit : Cost ratio |      |        |
|---------------------|------------------------------------|-------|--------|-------------------------------------------|-------|--------|----------------------------------|-------|--------|----------------------|------|--------|
|                     | 2019                               | 2020  | Pooled | 2019                                      | 2020  | Pooled | 2019                             | 2020  | Pooled | 2019                 | 2020 | Pooled |
| T <sub>1</sub>      | 25248                              | 33918 | 29583  | 19055                                     | 19107 | 19081  | 6193                             | 14811 | 10502  | 1.33                 | 1.78 | 1.55   |
| T <sub>2</sub>      | 31136                              | 46504 | 38820  | 24110                                     | 24153 | 24132  | 7026                             | 22351 | 14688  | 1.29                 | 1.93 | 1.61   |
| T <sub>3</sub>      | 35100                              | 51444 | 43272  | 25260                                     | 25303 | 25282  | 9840                             | 26141 | 17990  | 1.39                 | 2.03 | 1.71   |
| T <sub>4</sub>      | 36422                              | 52292 | 44357  | 25835                                     | 25878 | 25857  | 10587                            | 26414 | 18501  | 1.41                 | 2.02 | 1.72   |
| T <sub>5</sub>      | 33525                              | 49691 | 41608  | 24810                                     | 24853 | 24832  | 8715                             | 24838 | 16776  | 1.35                 | 2.00 | 1.68   |
| T <sub>6</sub>      | 36040                              | 51856 | 43948  | 25160                                     | 25203 | 25182  | 10880                            | 26653 | 18767  | 1.43                 | 2.06 | 1.74   |
| T <sub>7</sub>      | 40920                              | 58626 | 49773  | 25960                                     | 26003 | 25982  | 14960                            | 32623 | 23792  | 1.58                 | 2.25 | 1.92   |
| T <sub>8</sub>      | 44629                              | 62419 | 53524  | 26885                                     | 26928 | 26907  | 17744                            | 35491 | 26618  | 1.66                 | 2.32 | 1.99   |
| SEm±                | -                                  | -     | -      | -                                         | -     | -      | -                                | -     | -      | -                    | -    | -      |
| C.D. ( $p = 0.05$ ) | -                                  | -     | -      | -                                         | -     | -      | -                                | -     | -      | -                    | -    | -      |

may ultimately prove less profitable than a comparatively low-cost alternative. Therefore, it is necessary to judge based on net returns per hectare. In the present investigation the net returns were ranged ₹ 10502–26618 ha<sup>-1</sup>. The higher net returns were recorded in T<sub>8</sub> (RPP along with application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup>) (₹ 26618 ha<sup>-1</sup>), closely followed by T<sub>7</sub> (RPP along with application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 10 kg ha<sup>-1</sup>) and (₹ 23792 ha<sup>-1</sup>) as compared to all other treatments. But lower net returns (₹ 10502 ha<sup>-1</sup>) were observed in farmers' practice (T<sub>1</sub>). The benefit : cost (B : C) was ranged 1.55–1.99. But higher B : C ratio was recorded in T<sub>8</sub> (RPP along with application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup>) (1.99) as compared to all other treatments. Among different indicators of economic efficiency in any production system, B : C ratio has greater impact on the practical utility and acceptance of the technology by the farmers. The consequence of higher gross and net returns resulted in higher B : C ratio. This may be attributed due to less expenditure and higher return per rupee invested under these treatments as a result of higher yield and better market price. But lower B : C ratio (1.55) was observed in T<sub>1</sub> (farmers' practice). Similar results were obtained in a study where, an application of 2.5 t ha<sup>-1</sup> FYM + 100 % recommended dose of nitrogen and phosphorus (RDNP) + 4 kg Fe and 2 Kg Zn enriched with 500 kg FYM ha<sup>-1</sup> (T<sub>4</sub>) recorded highest net realisation (₹ 30426.00 per hectare with B : C ratio 1.78) which was followed by application of 100 % RDNP + 4.00 kg Fe and 2.00 Kg Zn ha<sup>-1</sup> (T<sub>2</sub>) earned net realisation of ₹ 29458.00 with B : C value of 1.88 (17). Application of Zn and Fe enriched compost along with foliar spray of panchagavya (₹ 27185 ha<sup>-1</sup> and 2.83 respectively) surpassed all other treatments except Zn and Fe enriched vermicompost with foliar spray of ZnSO<sub>4</sub> and FeSO<sub>4</sub> (₹ 25522 ha<sup>-1</sup> and 2.62 respectively), Zn and Fe enriched vermicompost with foliar spray of panchagavya (₹ 21897 ha<sup>-1</sup> and 2.62 respectively) and lowest is with compost equivalent to 100 % RDN (₹ 12492 ha<sup>-1</sup> and 1.99 respectively). This was due to higher yield of grain and stover in comparison to the rest

of the treatments (18). Maximum increase in straw (48 %) and grain (41 %) yields was achieved respectively at 1.5 and 6 mg Zn kg<sup>-1</sup> soil when applied as ZnSO<sub>4</sub> + FYM compared to control. Root dry matter production also followed a similar pattern with maximum root dry weight was obtained in treatment receiving maximum rate of Zn as ZnSO<sub>4</sub> + FYM (19). Application of ZnSO<sub>4</sub> at 20 kg ha<sup>-1</sup> + FeSO<sub>4</sub> at 10 kg ha<sup>-1</sup> through soil application recorded higher gross returns (₹ 90568 ha<sup>-1</sup>), net returns (₹ 50551 ha<sup>-1</sup>) and a higher B : C ratio (2.26) compared to control without Zn and Fe (20).

### Quality parameters

Zinc and Fe content in foxtail millet grain and stover differed significantly among the different treatments were presented in Table 6. In general, higher Zn and Fe content was recorded in treatments receiving application of Zn and Fe along with RPP. Significantly higher Zn content in foxtail millet grain was observed in T<sub>8</sub> (RPP along with application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup>) (35.95 ppm) followed by T<sub>4</sub> (RPP + ZnSO<sub>4</sub> at 15 kg ha<sup>-1</sup>) (35.87 ppm), T<sub>3</sub> (RPP + ZnSO<sub>4</sub> at 10 kg ha<sup>-1</sup>) (33.77 ppm) and T<sub>7</sub> (RPP + ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 10 kg ha<sup>-1</sup>) (33.73 ppm). However, these treatments were on par with each other. But significantly lower Zn content in foxtail millet grain was recorded in farmers' practice (T<sub>1</sub>) (25.43 ppm). Similarly, significantly higher Fe content in foxtail millet grain was noticed in T<sub>8</sub> (RPP along with application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup>) (238.85 ppm) and was on par with T<sub>6</sub> (RPP + FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup>) (235.93 ppm). These are in conformity with the findings of the studies conducted on wheat and maize crops (21, 22). Significantly lower Fe content in foxtail millet grain was recorded in farmers' practice (T<sub>1</sub>) (192.82 ppm). Sustainable intensification strategies for Haveri district requires improved soil and nutrient management (23). Hence, following RPP along with application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup> (T<sub>8</sub>) had recorded significantly higher Zn content (39.88 ppm) in foxtail millet stover as compared to rest of

**Table 6.** Effect of zinc and iron on micronutrient content in grain and stover of foxtail millet

| Treatments          | Grain      |       |        |            |        |        | Stover     |       |        |            |        |        |
|---------------------|------------|-------|--------|------------|--------|--------|------------|-------|--------|------------|--------|--------|
|                     | Zinc (ppm) |       |        | Iron (ppm) |        |        | Zinc (ppm) |       |        | Iron (ppm) |        |        |
|                     | 2019       | 2020  | Pooled | 2019       | 2020   | Pooled | 2019       | 2020  | Pooled | 2019       | 2020   | Pooled |
| T <sub>1</sub>      | 25.57      | 25.30 | 25.43  | 193.63     | 192.00 | 192.82 | 30.97      | 30.07 | 30.52  | 83.87      | 82.53  | 83.20  |
| T <sub>2</sub>      | 30.03      | 29.70 | 29.87  | 204.20     | 202.70 | 203.45 | 33.70      | 32.63 | 33.17  | 92.73      | 91.27  | 92.00  |
| T <sub>3</sub>      | 33.60      | 33.93 | 33.77  | 213.40     | 210.33 | 211.87 | 36.60      | 35.60 | 36.10  | 92.93      | 91.33  | 92.13  |
| T <sub>4</sub>      | 35.53      | 36.20 | 35.87  | 211.77     | 210.90 | 211.33 | 40.17      | 39.50 | 39.83  | 90.27      | 89.07  | 89.67  |
| T <sub>5</sub>      | 30.33      | 30.10 | 30.22  | 227.83     | 226.43 | 227.13 | 33.00      | 32.20 | 32.60  | 92.07      | 89.73  | 90.90  |
| T <sub>6</sub>      | 30.27      | 30.47 | 30.37  | 237.20     | 234.67 | 235.93 | 33.13      | 32.00 | 32.57  | 102.60     | 101.27 | 101.93 |
| T <sub>7</sub>      | 33.50      | 33.97 | 33.73  | 222.67     | 220.43 | 221.55 | 36.50      | 35.50 | 36.00  | 92.47      | 91.40  | 91.93  |
| T <sub>8</sub>      | 35.80      | 36.10 | 35.95  | 240.40     | 237.30 | 238.85 | 40.47      | 39.30 | 39.88  | 102.80     | 101.93 | 102.37 |
| SEm±                | 1.07       | 1.05  | 1.04   | 5.53       | 5.53   | 3.02   | 0.84       | 0.96  | 0.85   | 2.79       | 2.41   | 2.54   |
| C.D. ( $p = 0.05$ ) | 3.23       | 3.17  | 3.15   | 16.79      | 16.79  | 9.16   | 2.54       | 2.92  | 2.57   | 8.48       | 7.31   | 7.70   |

the treatments. However, it was on par with T<sub>4</sub> (RPP + ZnSO<sub>4</sub> at 15 kg ha<sup>-1</sup>) (39.83 ppm).

Similarly, higher Fe content (102.37 ppm) in foxtail millet stover was recorded in T<sub>8</sub> (RPP along with application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup>) and was on par with T<sub>6</sub> (RPP + FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup>) (101.93 ppm). Significantly lower Zn and Fe content in foxtail millet stover was recorded in T<sub>1</sub> (Farmers' practice) (30.52 ppm and 83.20 ppm respectively). With respect to nutrient uptake, similar findings were reported in a study indicated that the treatment M<sub>7</sub>-soil application of ZnSO<sub>4</sub> at 15 kg ha<sup>-1</sup> and FeSO<sub>4</sub> at 10 kg ha<sup>-1</sup> along with 0.5 % foliar spray of both ZnSO<sub>4</sub> and FeSO<sub>4</sub> resulted in significantly higher Zn concentration in grain, stover and total uptake (33.50, 45.39 and 78.72 ppm respectively). The same treatment also recorded increased Fe concentration in grain, stover and total uptake for the pearl millet genotype G<sub>3</sub> : HFeZn-113 (177.18, 166.71 and 342.26 ppm respectively). Among all micronutrient treatments, M<sub>7</sub> consistently showed the highest Fe content (195.45, 182.18 and 377.68 ppm in grain, stover and total uptake respectively), exhibiting superiority over other treatments (24). Similar observations were documented in a study conducted on maize in Dharwad location (25). The enhanced micronutrient (Zn and Fe) concentration may be attributed to increased absorption facilitated by combined soil and foliar application, which improves nutrient availability throughout the crop growth cycle. Better nutrient uptake may also be linked to an efficient root system with both deep and lateral spread (26). However, despite the observed increase in uptake and concentration, soil-available Zn and Fe did not show any significant variation among the different treatments (Table 7).

**Table 7.** Available zinc and iron content in soil

| Treatments          | Zinc (ppm) |      |        | Iron (ppm) |      |        |
|---------------------|------------|------|--------|------------|------|--------|
|                     | 2019       | 2020 | Pooled | 2019       | 2020 | Pooled |
| T <sub>1</sub>      | 1.15       | 1.13 | 1.14   | 3.23       | 3.17 | 3.20   |
| T <sub>2</sub>      | 1.19       | 1.14 | 1.17   | 3.33       | 3.30 | 3.32   |
| T <sub>3</sub>      | 1.17       | 1.10 | 1.13   | 3.15       | 3.04 | 3.10   |
| T <sub>4</sub>      | 1.13       | 1.07 | 1.10   | 3.13       | 3.07 | 3.10   |
| T <sub>5</sub>      | 1.20       | 1.17 | 1.19   | 3.29       | 3.22 | 3.26   |
| T <sub>6</sub>      | 1.21       | 1.14 | 1.18   | 3.32       | 3.22 | 3.27   |
| T <sub>7</sub>      | 1.16       | 1.12 | 1.14   | 3.15       | 3.11 | 3.13   |
| T <sub>8</sub>      | 1.12       | 1.11 | 1.11   | 3.13       | 3.07 | 3.10   |
| SEm±                | 0.05       | 0.06 | 0.06   | 0.13       | 0.10 | 0.10   |
| C.D. ( $p = 0.05$ ) | NS         | NS   | NS     | NS         | NS   | NS     |

NS: non-significant.

## Conclusion

Significantly higher grain yield, stover yield, net returns and benefit : cost (B : C) ratio was recorded in T<sub>8</sub> (recommended package of practices (RPP), along with application of zinc sulphate (ZnSO<sub>4</sub>) and iron sulphate (FeSO<sub>4</sub>) at 15 kg ha<sup>-1</sup>) (18.45 q ha<sup>-1</sup>, 53.05 q ha<sup>-1</sup>, ₹ 26618 ha<sup>-1</sup> and 1.99 respectively) and was closely followed by T<sub>7</sub> (RPP along with application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 10 kg ha<sup>-1</sup>) (17.20 q ha<sup>-1</sup>, 49.57 q ha<sup>-1</sup>, ₹ 23792 ha<sup>-1</sup> and 1.92 respectively) as compared to all other treatments. Hence, application of ZnSO<sub>4</sub> and FeSO<sub>4</sub> at 15 kg ha<sup>-1</sup> along with RPP helps to increase the yield of foxtail millet in turn adds monetary benefit to the farming community.

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## Authors' contributions

PP prepared the experimental framework and conducted the field research. AP prepared the experimental framework and interpreted the data. RGR statistically analysed the data. JHKN contributed to writing, review and editing. All authors read and approved the final manuscript.

## Compliance with ethical standards

**Conflict of Interest:** Authors do not have any conflict of interests to declare.

**Ethical issues:** None

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