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RESEARCH PAPER

Soil and foliar application of zinc increased pearl millet productivity in calcareous vertisols of Karnataka

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Abstract: A field investigation was conducted in calcareous soil during the *rainy* season of 2021at the Regional Agricultural Research Station,Vijayapura. The experiment was laid out in a factorial randomized block design, with two factors and three replications.The treatments of the first factor consists of soil application of a recommended dose of fertilizers (RDF), RDF + $ZnSO_4$ @ 10 kg ha^{-1} and RDF + $ZnSO_4$ @ 15 kg ha^{-1} and the second factor consists of control (no foliar spray), $ZnSO_4$ @ 0.5%, $ZnSO_4$ @ 0.75%, nano-Zn @ 2 ml L^{-1} and nano-Zn @ 4 ml L^{-1} foliar application.The results revealed that the soil and foliar application of zinc significantly influenced on growth, yield and economics of pearl millet. Soil application of $ZnSO_4$ @ 15 kg ha^{-1} recorded better growth,yield attributes and economics than RDF alone. Among foliar applications, nano-Zn sprays @ 4 ml L^{-1} recorded better growth, yield attributes and economics, which was followed by nano-Zn sprays @ 2 mlL^{-1}. The interaction treatment receiving soil application of $ZnSO_4$ @ 15 kg ha^{-1} with RDF and foliar application of nano-Zn @ 4 ml L^{-1} recorded significantly higher growth attributes *viz.,* plant height (188.5 cm), number of green leaves plant^{-1} (7.97) and total dry matter accumulation (186.9 g plant^{-1}), yield attributes *viz.,*grain weight panicle^{-1} (16.44 g), more productive tillers plant^{-1} (2.60), panicle length (27.51 cm), panicle girth (3.25 cm), grain yield (2169 kg ha^{-1}) and stover yield (7008 kg ha^{-1}) and net returns (₹ 32,353 ha^{-1}) and benefit-cost ratio (2.89) compared to RDF alone. The study concludes that the soil application of $ZnSO_4$ @ 15 kg ha^{-1} with RDF and foliar application of nano-Zn @ 4 ml L^{-1} increase the growth, yield and economic returns of pearl millet grown under zinc deficit dryland soils.

Key words: Dry matter production, Economics, Nanofertilizers, Nano-Zn, $ZnSO_4$

Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the most widely grown warm-season drought-tolerant cereal in some of the harshest semi-arid tropical environments of South Asia and Sub-Saharan Africa. It excels all other cereals due to its unique features of a C_4 plant with high photosynthetic efficiency and high dry matter production capacity. It is grown under the most adverse agro-climatic conditions. It is also consumed as feed and fodder for livestock. In India, pearl millet is the fourth most widely cultivated food crop after rice, wheat and maize. The major pearl millet growing states in India are Rajasthan (52.34%), Maharashtra (14.6%) and Gujarat (9.9%). It occupies an area of 6.93 million hectares with an average production of 8.61 million tonnes and productivity of 1243 kg ha^{-1} (Anon., 2020). Karnataka is also a significant state of pearl millet growing area, accounting for an area of 1.93 million hectares, production of 1.75 million tonnes, and productivity of 956 kg ha^{-1} (Anon., 2019).

Pearl millet is critically important for food and nutritional security as it possesses several advantages, such as early maturing, drought tolerance, requiring minimal inputs, and being mostly free from biotic and abiotic stresses. It has exceptional health benefiting properties for people suffering from lifestyle diseases like diabetes, obesity, *etc*., as it has high proportions of slowly digestible starch (SDS) and resistant starch (RS) that contribute to the low glycemic index (GI). Its grains have high protein content, balanced amino acid and high levels of iron, zinc and insoluble dietary fiber. Pearl millet is gluten-free and retains its alkaline properties even after being cooked, which is ideal for people suffering from gluten allergy and acidity.

Pearl millet also provides nutritional security as it is a "Power House of Nutrition," consisting of most of the important nutrients in good quantity and quality required for maintaining a healthy life. The nutritional value of pearl millet is better than wheat, rice, maize and sorghum. It is a good source of energy, carbohydrate, fat (5-7%), ash, dietary fiber (1.2 g 100 g^{-1}), α-amylase activity, quality protein (9-13%), vitamins A and B, minerals (2.3 mg 100 g^{-1}), unsaturated fatty acids (75%), antioxidants such as ferulic acid and coumaric acids with better fat digestibility (Uppal *et al*., 2015) and higher protein content. It contributes to one-third of iron and zinc requirements (Manga and Kumar, 2011). Intense temperatures and low organic matter content of Indian soils lead to poor soil fertility and low nitrogen status (Rego *et al.,* 2003). The deficient nutrient status decreases the availability of nutrients in grain and ultimately reduces the availability of nutrient-rich food to rural people.

Mineral nutrition, including micronutrients, especially zinc, is considered the limiting factor for plant productivity. Zinc is a transition metal important for auxin and protein synthesis in plants, chlorophyll formation and carbohydrate metabolism. It helps in the growth of stems through elongation. Zinc helps to increase crop yield by improving growth and yield attributes (Arshewar *et al.,* 2018). Zinc deficiency in the plant retards the development and maturation of the panicles of grain crops (Alloway, 2004). As in soils and plants, Zn deficiency is also a common nutritional problem in humans, predominantly in developing countries with diets rich in cereal-based foods and poor animal products. Enhancing Zn in plant derived food is one of the ways to improve human health in developing countries where and when the local population cannot afford food sources from which zinc can be taken up easily in large enough quantities in the human gut. Zinc deficiency in soil can be corrected by applying zinc in soils and foliar sprays.

Foliar application of micronutrients is more beneficial than soil application (Zinzala and Narwade, 2019). Since application rates are lesser than soil application, the same quantity of nutrient application could be supplied easily, and the crop reacts to the nutrient application immediately. Also, it is conducive when the roots cannot provide the necessary nutrients, such as zinc, because of soil properties, such as calcareous soils with high pH, lime or a heavy texture. In this situation, foliar spraying could be more effective than soil application. The foliar Zn application increases yield and also improves grain quality in pearl millet (Zong *et al.,* 2011). Foliar application of $ZnSO_4$ is commonly adopted in different crops, and some recently introduced nano-zinc fertilizers are being used to meet zinc demand and improve crop productivity. In this context, the present investigation was carried out to know the effect of soil and foliar application zinc sources on growth, yield and economics of the pearl millet in zinc deficit soils under rainfed conditions.

Material and methods

A field experiment was conducted during the *rainy* season of 2021 at the Regional Agricultural Research Station, Vijayapura, Karnataka on calcareous *vertisols* having an alkaline reaction (pH 8.17) and with a non-salinity (0.24 dSm^{-1}). The soil was low in organic carbon content (0.40 %), low in available N (168 kg ha^{-1}), medium in available P_2O_5 (31.5 kg ha^{-1}) and high in available K_2O content (351 kg ha^{-1}) with low zinc content (0.46 ppm) in the soil. The experimental site was located at a latitude of 16° 77' North, a longitude of 75° 74' East and an altitude of 592.23 meters above mean sea level in the Northern Dry Zone of Karnataka (Zone 3). During the year 2021, total rainfall of 632.8mm was received in 52 rainy days from January 2021 to December 2021, as against the normal rainfall of 594.4 mm received in 38 rainy days. The highest rainfall of 161.7 mm was received in September, followed by July (146.4 mm). The total rainfall received during the cropping period (July to October 2021) was 409 mm.

The experimental treatments were divided into two factors (soil and foliar applications) and laid out in a factorial randomized block design with three replications. The first factor consists of soil application of a recommended dose of fertilizers (RDF), RDF + $ZnSO_4$ @ 10 kg ha^{-1} and RDF + $ZnSO_4$ @ 15 kg ha^{-1} and the second factor consists of control (no foliar spray), $ZnSO_4$ @ 0.5%, $ZnSO_4$ @ 0.75%, nano-Zn @ 2 ml L^{-1} and nano-Zn @ 4 ml L^{-1} foliar application. The land was ploughed once after the harvest of the previous crop, followed by two harrowings. At the time of sowing, the land was prepared to be a fine seed bed, and the plots were laid out. The pearl millet hybrid VPMH-07 was used in the study. The full dose of fertilizer in the form of urea and diammonium sulphate as per recommended package of practice 50:25:00 kg N, P_2O_5 and K_2O per ha was applied. The fertilizer application was followed based on the recommended package of practice. The nutrients, *viz.,* nitrogen, phosphorus and zinc, were applied as urea, diammonium phosphate (DAP) and zinc sulphate ($ZnSO_4$. $7H_2O$), respectively. Entire quantities of fertilizers were applied to the crops at the time of sowing as basal dose only. The crop was sown with a spacing of 60 × 15 cm. Due to the incidence of fall armyworm (*Spodoptera frugiperda*) infestation,a spray of Emamectin benzoate 5% SG @ 0.2 g per liter of water was taken up to control the pest. Harvesting was done at the physiological maturity of the crop. The net plot area (16.2 m^{-2}), as per the treatments, was harvested by cutting the plants to the ground level and separated the panicles from the plants. After harvesting, the plants were bundled and allowed for sun drying. After complete sun drying, the panicles were threshed by thresher treatment wise. The crop was harvested on 7th November 2021.

The growth parameters were recorded from randomly selected five plants in each net plot and labelled. Periodical observations were taken in these plants at 30, 60 DAS and at harvest. The plant height was measured from the ground level to the tip of the main stem. Where as the total number of green leaves in each plant was counted from five randomly selected plants, and then the mean value for each treatment was determined, and total dry matter production (TDMP) in each plant was weighed from five randomly selected plantsin net plots.

The yield attributes and yield were recorded from the net plots and grain yield was converted to hectare basis in kilograms. The harvest index (HI) was calculated by using the following formula suggestedby Donald (1962).

$$HI = \frac{\text{Economic yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}} \times 100$$

The economics of each treatment was computed with prevailing market prices of the corresponding year (2021). The yield was further computed for gross and net returns as well benefit-costratio (BCR) to assess the profitability. The BCR was worked out by dividing the gross returns by the total cost of cultivation of respective treatments.

The data collected from the experiment at different growth stages and at harvest were subjected to statistical analysis as described by Gomez and Gomez (1984). The level of significance used for 'F' and 't' tests was P=0.05. Critical Difference (CD) values were calculated at 5 per cent probability level if the F test will found to be significant.

Results and discussion

Effect of soil application of zinc

Increasing levels of zinc application significantly increased growth attributes like plant height, number of green leaves and total dry matter production (TDMP) per plant (Table 1). The treatment consisting of soil application of RDF + $ZnSO_4$ @ 15 kg ha^{-1} recorded a significantly higher plant height (180.7 cm), leaves number (6.77) and TDMP (161.0 g $plant^{-1}$) at harvest. The increase was to the tune of 7.86,19.05 and 16.33% more than RDF, respectively. The increase of leaves and TDMP in the treatment may be because zinc is an essential component of enzymes responsible for nitrogen assimilation, helps in chlorophyll formation and plays an important role in nitrogen metabolism, contributing to an increase in the growth and development of a plant. Zinc actively participates in auxin production, increasing the cell size and number and thus increasing the plant height (Dashadi *et al*., 2013). Zinc nutrition is known to increase tillering in pearl millet, which may perhaps cause a significant increase in dry matter accumulation. The result of the current study is in good agreement with the results presented by Choudhary *et al*. (2014).Similarly, Arshewar *et al.* (2018) in Parbhani reported that applying zinc @ 15 kg ha^{-1} produced significantly higher growth attributes in pearl millet than the rest of the zinc levels.

Yield attributes *viz.,* grain weight $panicle^{-1}$, panicle length, panicle girth, productive tillers and test weight of pearl millet were enhanced significantly with soil application of zinc (Table 2). Similarly, Rengel (2001) reported that soil application of zinc increases test weight, which might result from zinc that has high phloem mobility from leaves to roots, stems and developing grains. The treatment consisting of $ZnSO_4$ @ 15 kg ha^{-1} with RDF to pearl millet significantly increased the grain yield per panicle by 21.23%, panicle length by 12.87%, panicle girth by 9.74% and test weight by 6.38% over control. The increased yield attributes might be due to zinc playing an important role in nitrogen metabolism and the formation of chlorophyll and carbohydrate, which leads to maintaining photosynthetic activity for a longer period and finally results in increasing the yield attributes of the crop (Mehta *et al*., 2008).

The grain and stover yield of pearl millet were significantly influenced by soil application of $ZnSO_4$, but the harvest index was found non-significant (Table 3). Significantly higher grain and stover yield were recorded in the treatment receiving soil application of $ZnSO_4$ @ 15 kg ha^{-1} with RDF (1923 kg ha^{-1} and 6379 kg ha^{-1}, respectively) and increased to the tune of 18.56% and 16.16% higher grain and stover yield, respectively than the RDF alone. Since zinc is a crucial component of all classes of enzymes, the rise in yield may be attributable to the

Table 1. Growth attributes of pearl millet at the harvest stage as influenced by soil and foliar application of zinc.

Treatments	Plant height (cm) at harvest	No. of green leaves at harvest	TDMP (g) at harvest
Soil application (S)			
S_1: RDF	166.5	5.48	134.7
S_2: RDF + $ZnSO_4$ @ 10 kg ha^{-1}	174.3	6.32	151.5
S_3: RDF + $ZnSO_4$ @ 15 kg ha^{-1}	180.7	6.77	161.0
S.Em+	2.65	0.08	2.90
C.D. (p = 0.05)	7.67	0.25	8.41
Foliar application (F)			
F_1: Control (no foliar spray)	166.3	5.00	127.3
F_2: $ZnSO_4$ @ 0.5%	171.6	5.61	138.3
F_3: $ZnSO_4$ @ 0.75%	173.9	6.10	149.1
F_4: Nano-Zn @ 2 ml L^{-1}	175.6	6.73	158.0
F_5: Nano-Zn @ 4 ml L^{-1}	181.8	7.49	172.5
S.Em+	3.42	0.11	3.75
C.D. (p = 0.05)	9.90	0.32	10.86
Interactions (S x F)			
S_1F_1	160.6	4.11	114.8
S_1F_2	164.7	4.58	121.9
S_1F_3	166.3	5.38	133.6
S_1F_4	167.7	6.32	144.8
S_1F_5	173.4	7.00	158.2
S_2F_1	165.0	5.37	132.6
S_2F_2	171.1	6.00	143.0
S_2F_3	174.7	6.33	151.3
S_2F_4	177.1	6.68	158.2
S_2F_5	183.6	7.20	172.4
$S3F_1$	173.5	5.53	134.6
S_3F_2	178.9	6.27	150.0
S_3F_3	180.8	7.00	162.3
S_3F_4	182.1	7.20	171.0
S_3F_5	188.5	7.97	186.9
S. Em+	5.92	0.19	6.50
C.D. (p = 0.05)	17.15	0.55	18.82
Absolute control	140.4	3.47	94.10
S. Em+	6.43	0.18	6.43
C.D. (p = 0.05)	18.56	0.53	18.57

RDF: Recommended dose of fertilizers

Table 2. Yield attributes of pearl millet at the harvest stage as influenced by soil and foliar application of zinc.

Treatments	No. of productive tillers	Panicle length (cm)	Panicle girth (cm)	Grain weight per panicle (g)	Test weight (g)
Soil application (S)					
S_1: RDF	2.07	22.08	2.78	11.35	11.60
S_2: RDF + $ZnSO_4$ @ 10 kg ha^{-1}	2.32	24.53	3.01	13.66	12.18
S_3: RDF + $ZnSO_4$ @ 15 kg ha^{-1}	2.43	25.34	3.08	14.41	12.39
S.Em+	0.04	0.30	0.04	0.26	0.19
C.D. (p = 0.05)	0.12	0.87	0.11	0.75	0.56
Foliar application (F)					
F_1: Control (no foliar spray)	2.05	21.69	2.71	11.37	11.68
F_2: $ZnSO_4$ @ 0.5%	2.21	23.08	2.90	12.02	11.88
F_3: $ZnSO_4$ @ 0.75%	2.30	24.00	3.01	13.70	12.04
F_4: Nano-Zn @ 2 ml L^{-1}	2.35	24.94	3.06	14.03	12.26
F_5: Nano-Zn @ 4 ml L^{-1}	2.45	26.21	3.12	14.58	12.43
S.Em+	0.06	0.39	0.05	0.34	0.25
C.D. (p = 0.05)	0.16	1.13	0.15	0.97	NS
Interactions (S x F)					
S_1F_1	1.90	18.40	2.30	10.72	11.29
S_1F_2	1.99	20.11	2.63	11.02	11.44
S_1F_3	2.09	22.75	2.95	11.49	11.52
S_1F_4	2.14	24.02	2.99	11.60	11.71
S_1F_5	2.25	25.12	3.02	11.89	12.05
S_2F_1	2.07	23.03	2.87	11.66	11.81
S_2F_2	2.27	24.53	2.98	12.48	12.00
S_2F_3	2.33	24.50	3.02	13.76	12.07
S_2F_4	2.40	24.60	3.07	14.99	12.45
S_2F_5	2.51	26.00	3.10	15.41	12.59
S_3F_1	2.18	23.64	2.97	11.73	11.94
S_3F_2	2.37	24.61	2.99	12.56	12.22
S_3F_3	2.48	24.74	3.06	15.84	12.51
S_3F_4	2.52	26.19	3.13	15.50	12.63
S_3F_5	2.60	27.51	3.25	16.44	12.66
S.Em+	0.10	0.68	0.09	0.58	0.43
C.D. (p = 0.05)	0.28	1.99	0.25	1.69	NS
Absolute control	1.40	16.10	2.02	8.13	9.89
S.Em+	0.09	0.71	0.09	0.57	0.45
C.D. (p = 0.05)	0.27	2.04	0.25	1.64	1.31

RDF: Recommended dose of fertilizers

productive efficiency of enzyme activities that affect plant pigments. Zinc has satisfactory effects on plant metabolism, which might be responsible for greater metabolite accumulation in reproductive organs (Panday *et al*., 2006). The present findings are in close agreement with Singh and Kumar (2017).

Economic parameters, *viz*., gross returns, net returns and benefit-cost ratio (BCR), increased with zinc application and maximized at the highest level (Table 3 and Fig. 1). It might be attributed to increased grain and stover yields with zinc application. The value of the increased yield was much more than the cost of zinc application, which increased the net return and BCR (Katiyar *et al*., 2017). In our study, soil application of different levels of zinc had a significant effect on gross returns, net returns and BCR was recorded with treatment receiving soil application of RDF + $ZnSO_4$ @ 15 kg ha^{-1}(₹ 43260 ha^{-1}, ₹ 26259 ha^{-1} and 2.54, respectively), followed by RDF + $ZnSO_4$ @ 10 kg ha^{-1} (₹ 41035 ha^{-1}, ₹ 24384 ha^{-1} and 2.46, respectively). These results resembled the findings of Goyal *et al*. (2018) in wheat.

Effect of foliar application of Zinc

The foliar sprays of zinc significantly influenced the growth attributes (Table 1). The increased plant height, number of leavesand TDMP at harvest were recorded with foliar application of nano-Zn @ 4 ml L^{-1} (181.8 cm, 7.49 and 172.5 g $plant^{-1}$, respectively) compared to $ZnSO_4$ foliar application and control. Similar to our studies, nano-Zn showed significantly higher crop improvement by enhancing initial crop establishment, chlorophyll content and ultimately crop growth and yield obtained in Yang *et al*. (2015) in maize and rice. A coupled increase in plant height and photosynthetically active leaf area due to nano-Zn might be the reason for increased dry matter accumulation. Also, they might be due to the complementary effect of other inherent nutrients like magnesium, iron and sulphur with zinc (Koti *et al*., 2009).

Foliar nutrition of zinc also significantly influenced grain yield and stover yield. The foliar spray of nano-Zn @ 4 ml L^{-1} produced significantly higher grain and stover yield (1932 and

Table 3. Yield and economics of pearl millet as influenced by soil and foliar application of zinc.

Treatments	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})
Soil application (S)					
S_1: RDF	1566	5348	22.60	33637	17686
S_2: RDF + $ZnSO_4$ @ 10 kg ha^{-1}	1808	6148	22.82	41035	24384
S_3: RDF + $ZnSO_4$ @ 15 kg ha^{-1}	1923	6379	23.17	43260	26259
S.Em+	37	78	0.27	726	726
C.D. (p = 0.05)	108	227	NS	2103	2103
Foliar application (F)					
F_1: Control (no foliar spray)	1589	5363	23.02	34314	18516
F_2: $ZnSO_4$ @ 0.5%	1692	5688	22.92	36802	20029
F_3: $ZnSO_4$ @ 0.75%	1787	6029	22.84	40376	23514
F_4: Nano-Zn @ 2 ml L^{-1}	1828	6270	22.57	41595	24992
F_5: Nano-Zn @ 4 ml L^{-1}	1932	6443	22.96	43466	26830
S.Em+	48	101	0.35	937	937
C.D. (p = 0.05)	140	293	NS	2714	2714
Interactions (S x F)					
S_1F_1	1475	5098	22.46	31900	16685
S_1F_2	1557	5244	22.89	32623	16433
S_1F_3	1571	5388	22.55	33755	17477
S_1F_4	1584	5424	22.60	34243	18223
S_1F_5	1613	5586	22.50	35664	19611
S_2F_1	1615	5473	23.16	35073	19158
S_2F_2	1752	5977	22.65	38538	21648
S_2F_3	1813	6042	23.07	41909	24931
S_2F_4	1877	6513	22.43	44375	27655
S_2F_5	1983	6734	22.77	45279	28526
S_3F_1	1688	5517	23.44	35969	19704
S_3F_2	1767	5842	23.22	39245	22005
S_3F_3	1977	6658	22.91	45462	28134
S_3F_4	2013	6872	22.68	46168	29098
S_3F_5	2169	7008	23.63	49456	32353
S.Em+	83	175	0.61	1623	1623
C.D. (p = 0.05)	242	508	NS	4702	4702
Absolute control	879	3299	21.01	21264	7944
S.Em+	81	171	0.59	1653	1653
C.D. (p = 0.05)	234	493	NS	4773	4773

RDF: Recommended dose of fertilizers and NS: Non significant

6443 kg ha^{-1}, respectively) than the $ZnSO_4$ foliar spray and control (Table 3). The higher grain yield and stover yield might be due to higher grain weight per panicle (14.58 g), productive tillers (2.45), panicle length (26.21 cm) and panicle girth (3.12 cm) (Table 2). The attributes were mainly due to the nano particles' small size and large effective surface area that could easily penetrate the plant, leading to better zinc uptake.Positive improvement in nano-Zn foliar spray might be due to the quick translocation and assimilation of Zn nanoparticles. Prasad *et al*. (2012) observed that foliar application of nano-ZnO at 15 times lower dose recorded 29.5% and 26.3% higher pod yield of groundnut compared to the chelated $ZnSO_4$.

The foliar nutrition of zinc also significantly influenced gross returns, net return and BCR (Table 3 and Fig. 1). The foliar spray of nano-Zn @ 4 ml L^{-1} produced significantly higher gross returns (₹ 43466 ha^{-1}), net return (₹ 26830 ha^{-1}) and BCR (2.61) compared to no foliar spray. However, it was on par with foliar spray of nano-Zn @ 2 ml L^{-1} (₹ 43466 ha^{-1}, ₹ 24992 ha^{-1} and 2.50, respectively). The lower expense of cultivation and the highest seed yield may have affected the economic returns from pearl millet production. Similar findings were also reported by Sharma *et al*. (2007).

Interaction effect of soil and foliar application of zinc

Combined soil application of $ZnSO_4$ and foliar nano-Zn significantly increased the plant height, number of leaves per plant and TDMP in the pearl millet crop (Table 1). Soil application of $ZnSO_4$ @ 15 kg ha^{-1} with RDF and foliar application of nano-Zn @ 4 ml L^{-1} (188.5 cm, 7.97 $plant^{-1}$ and 186.9 g $plant^{-1}$, respectively) significantly increased the plant height, number of leaves per plant and TDMP in the pearl millet by 14.80%, 48.43% and 38.57% as compared to RDF with no foliar spray. Soil application and foliar sprays might have made adequate availability of Zn, which has facilitated the growth of the plant due to its involvement in many metallic enzyme systems, regulatory functions and auxin production, increased synthesis and transport of carbohdrates to the sink (Muthukumararaja and Sriramachandrasekharan, 2012). Reddy *et al*. (2021) also conveyed that Zn might have released or been involved in the growth-promoting enzymes and nutrients, which play an important role in the metabolic process of the plant, increasing

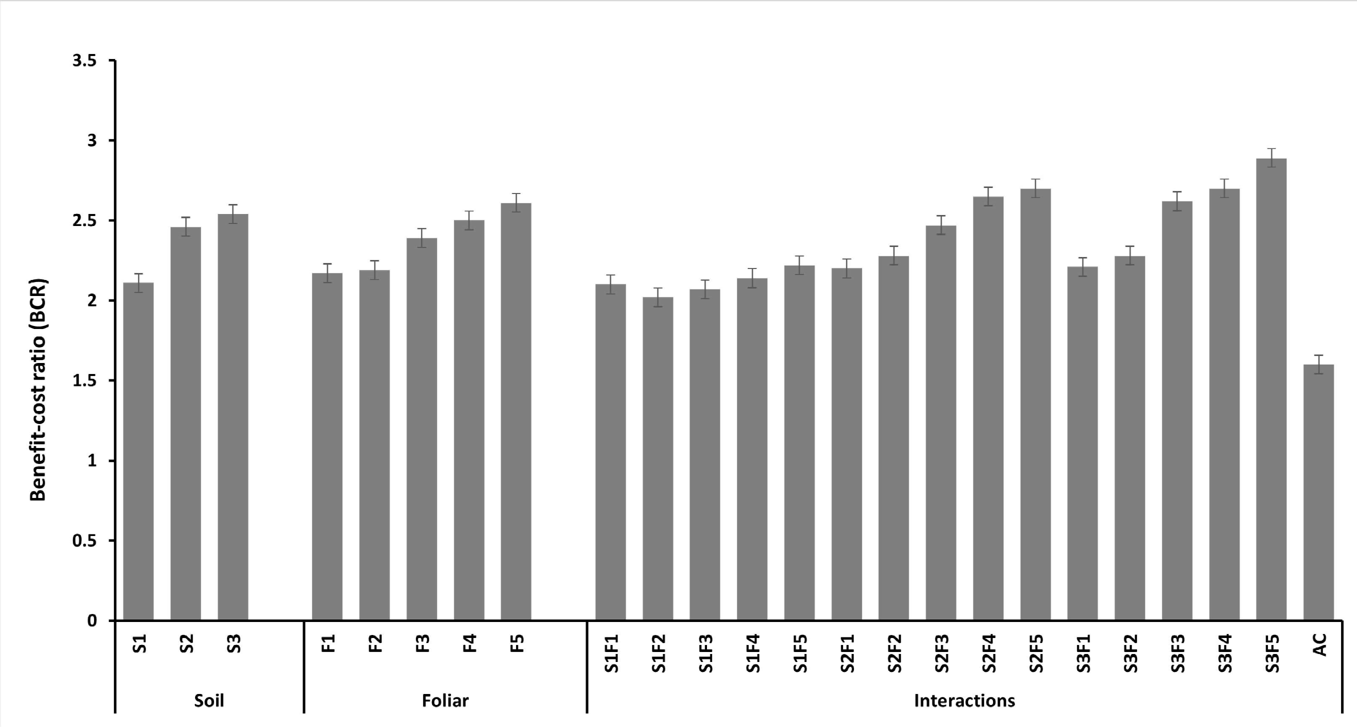

Fig.1 Benefit cost ratio of pearl millet as influenced by soil and foliar application of zinc and their interactions

nutrient uptake and thus enhancing plant height and green leaves. Zn enhanced the activity of meristematic cells and reflected in better vegetative growth such as photosynthetic area and number of tillers and eventually contributed to the increased dry matter production (Shekhawat and Kumawat, 2017). These results corroborate with the findings of Arshewar *et al.* (2018).

Pearl millet yield was significantly affected by soil application of $ZnSO_4$ and foliar application of nano-Zn. Among different treatment combinations, maximum grain yield (2169 kg ha^{-1}) and stover yield (7008 kg ha^{-1}) of pearl millet was recorded with soil application of $ZnSO_4$ @ 15 kg ha^{-1} with RDF and foliar spray of nano-Zn @ 4 ml L^{-1}. The maximum grain yield and stover yield increased up to 47.05% and 37.47% at $ZnSO_4$ @ 15 kg ha^{-1} with RDF and nano-Zn @ 4 ml L^{-1} over RDF alone (Table 3). The increase in yield due to soil and foliar application of zinc may be attributed to the fact that low initial status of available zinc in the experimental soil. Further, increased seed yield is the manifestation of an increase in yield attributes, *i.e.*, grain weight per panicle (16.44 g), productive tillers (2.60 $plant^{-1}$), panicle length (27.51 cm) and panicle girth (3.25 cm) (Table 2). The significant increase in straw yield due to micronutrient fertilization could be attributed to the increased plant growth and biomass production, possibly as a result of the uptake of nutrients. The cumulative beneficial effect of yield attributing characters was finally reflected in the grain yield of pearl millet. These results closely conform with that of Mehta *et al.* (2008). A significant increase in grain yield after both soil and foliar application of Zn could be expected when plants are grown on Zn-deficient soil, as reported by Cakmak (2010).

Data also revealed that the net returns and BCR of pearl millet were significantly influenced by different treatment combinations (Table 3 and Fig.1). The highest net returns (₹ 32353 ha^{-1}) and BCR (2.89) were obtained when pearl millet crop was supplied with RDF + soil application of $ZnSO_4$ @ 15 kg ha^{-1} + foliar application of nano-Zn @ 4 ml L^{-1} compared to the RDF alone.This could be attributed to the higher grain yield of pearl millet and the reduction in the cost of cultivation. These results conform with the findings of Choudhary *et al.* (2017).

Effect of combined application of zinc *vs.* absolute control

A significant variation in plant height, TDMP, number of green leaves per plant, productive tillers per plant, grain weight per panicle, test weight, panicle length, panicle girth, grain yieldand stover yield was also found by comparing the treatment combination with absolute control. The lower growth attributes *viz.,*plant height, number of leaves per plant and TDMP (140.4 cm, 3.47 and 94.10 g $plant^{-1}$, respectively), yield attributes *viz.,*productive tillers, panicle length, panicle girth, grain weight per panicle and test weight (1.40, 16.10, 2.02 cm, 8.13 and 9.89 g, respectively), grain and stover yield (879 kg ha^{-1} and 3299 kg ha^{-1}, respectively) was observed in the absolute control treatment and were found statistically significant comparing treatment combinations.

Conclusion

Soil application of $ZnSO_4$ @ 15 kg ha^{-1} with RDF and foliar application of nano-Zn @ 4 ml L^{-1} helped to increase growth and yield parameters, seed yield, maximum net returns and benefit-cost ratio in pearl millet grown in calcareous vertisols of Karnataka under rainfed conditions.

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