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Influence of soil application of iron and zinc on their content, uptake and total dry matter yield of pearl millet cultivars

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Abstract

A field experiment was conducted at Agricultural College and Research Institute, Madurai, Tamil Nadu, during the summer, 2019 to study the effect of zinc and iron fertilizers on content, uptake and total dry matter yield of pearl millet [*Pennisetum glaucum* (L.)] cultivars. The treatments consisted of five cultivars and five treatments of soil application of iron and zinc replicated twice in factorial randomized block design. The results revealed that soil application of Fe-EDTA @ 6.25 kg ha^{-1} + Zn-EDTA @ 3.12 kg ha^{-1} (SA_4) recorded the highest total dry matter yield of 8627 kg ha^{-1}. Among the cultivars, Kaveri Super Boss (C_4) showed a maximum total dry matter yield of 8960 kg ha^{-1}. The significantly higher total dry matter yield of 9253 kg ha^{-1} was registered by Kaveri Super Boss (C_4) X Fe-EDTA @ 6.25 kg ha^{-1} and Zn-EDTA @ 3.12 kg ha^{-1} (SA_4) combination. Higher zinc uptake of 320 kg ha^{-1} was registered by C_2SA_4 and it was statistically comparable with C_2SA_3 (315 g ha^{-1}). Soil application of Fe-EDTA @ 6.25 kg ha^{-1} and Zn-EDTA @ 3.12 kg ha^{-1} (SA_4) recorded the mean highest iron content and uptake of 250 mg kg^{-1} and 1151 g ha^{-1}, respectively. The cultivar C_2 (ICMH 1301) recorded significantly higher total dry matter iron content and uptake of 255 mg kg^{-1} and 1159 g ha^{-1}, respectively. The higher iron content and uptake of 302 mg kg^{-1} and 1444 g ha^{-1} was observed for C_2 (ICMH 1301) with SA_4 (Fe-EDTA @ 6.25 kg ha^{-1} + Zn-EDTA @ 3.12 kg ha^{-1}) combination. The maximum zinc content and uptake of 58.1 mg kg^{-1} and 254 g ha^{-1} respectively were registered by the soil application SA_4 (Fe-EDTA @ 6.25 kg ha^{-1} + Zn-EDTA @ 3.12 kg ha^{-1}). The maximum zinc uptake (257 g ha^{-1}) was registered by ICMH 1301 (C_2). Higher zinc uptake of 320 g ha^{-1} was registered by C_2SA_4 and it was statistically comparable with C_2SA_3 (315 g ha^{-1}).

Keywords: Cultivars, uptake, dry matter yield, pearl millet

1. Introduction

Pearl millet provides nutritional security as it has higher protein content (10.6%), a more balanced amino acid profile, and contributes about one-third of iron and zinc requirements (Manga and Kumar, 2011) [20]. Worldwide the arid and semi-arid region covers more than 6.09 billion ha and supports the livelihood of 35 percent world population (Van Ginkel *et al.*, 2013) [39]. In India, the arid and semi-arid areas occupied more than 60 percent of the cultivated area and produced around 40 percent of the food (Gulati and Kelley, 2000) [12]. Pearl millet is a well-adapted and widely cultivated staple cereal for the majority of the poor smallholders and consumers (Nagaraj *et al.*, 2012) [25] of the semi-arid region. It ranks first under the category of millets in India, in terms of area, production and productivity and contributing 8.89% to the total production of coarse cereals (NRAA, 2012) [26].

Iron is an important component of enzymes and a constituent of non-heme iron proteins involved in photosynthesis, N_2 fixation, and respiration. Iron is an essential micronutrient for both plants and human beings with numerous physiological functions.

Zinc is essential for the normal healthy growth and reproduction of plants (Marschner, 2011) [22]. In plants, zinc plays a key role as a structural constituent or regulatory cofactor of a wide range of different enzymes in many important biochemical pathways. Zinc also catalyses the biosynthesis of indole acetic acid, acting as a metal activator of the enzyme, thereby ultimately increasing crop yield.

Also, pearl millet is one of the gifted crop plants of the tropical regions and that provide food, feed, stover, dry fodder and fuel to millions of poor farmer families and their livestock. The low productivity of livestock in small landholding crop-livestock systems in the dry regions is due to the limited quantity and low nutritional quality of the available stover.

Management practices like fertilizer application may rectify the nutrient deficiencies might improve total dry matter yield and nutrient content and makes the availability of nourishing fodder for livestock.

Keeping the above points in view, a field experiment was carried out with iron and zinc enriched farmyard manure and chelated forms of iron and zinc on improving the iron and zinc content and total dry matter yield of pearl millet cultivars.

2. Materials and Methods

The field experiment was carried out in a farmer's field in Maikkudi village during the summer season of 2019. The experimental site is located at 9.78672241°N latitude and 78.02363912°E longitude at an altitude of 151 m above MSL. The experimental soil was clayey in texture and it was moderately alkaline (pH: 8.07), low in organic carbon (0.31%), low in available N (120 kg ha^{-1}), medium in available P (10 kg ha^{-1}), medium in available K (280 kg ha^{-1}), deficient in DTPA-Fe (1.75 mg kg^{-1}) and Zn (0.67 mg kg^{-1}) and calcareous ($CaCO_3$: 6.25%) in nature (Table 1).

The treatments consisted of five treatments with soil application of iron and zinc fertilizers with five cultivars replicated twice in a factorial randomized block design (FRBD). The details of treatments for soil application of iron and zinc (SA) were, SA_0-STCR-NPK alone, SA_1- Fe EFYM @ 50 kg ha^{-1} + Zn EFYM @ 25 kg ha^{-1}, SA_2- Fe EFYM @ 62.5 kg ha^{-1} + Zn EFYM @ 31.25 kg ha^{-1}, SA_3- Fe-EDTA @ 5.0 kg ha^{-1} + Zn-EDTA @ 2.5 kg ha^{-1}, SA_4- Fe-EDTA @ 6.25 kg ha^{-1} + Zn-EDTA @ 3.12 kg ha^{-1} and cultivars were C_1-ICMH1201, C_2-ICMH1301, C_3-86M86, C_4-Kaver Super Boss and C_5-TNAU Co-9 (Cumbu hybrid). The $FeSO_4$ and $ZnSO_4$ were incubated with farmyard manure (FYM) at the ratio of 1:10 for 30 days and applied to the field as basal. Plant spacing of 45 x 15 cm was adopted and fertilizers were calculated based on Soil Test-based Crop Recommendation (STCR) with a targeted yield of 4 tonnes ha^{-1}. The N, P_2O_5, and K_2O of 183, 95 and 84 kg ha^{-1} applied as basal to all the plots based on initial soil test values.

The plant samples of pearl millet were washed with distilled water for removal of soil contaminants and dried in a hot air oven at about 75°C, then ground in Wiley mill and was analysed in ICP-OES for total iron and zinc content as shown in table 1. The nutrient values obtained for plant samples were computed by multiplying with the corresponding total dry matter yield for calculating their uptake. Also, the total dry matter yield was recorded for individual treatment and expressed in kg ha^{-1}.

3. Results and Discussion

The effect of soil application of iron and zinc on total dry matter yield, their content and uptake in pearl millet cultivars are depicted in Figures 1, 2 and table 2, 3 and 4.

3.1 Total dry matter yield

Application of zinc and iron through enriched manures and chelated forms had a significant impact on the total dry matter yield of pearl millet. Higher total dry matter yield (8627 kg ha^{-1}) was recorded by treatment receiving Fe-EDTA @ 6.25 kg ha^{-1} + Zn-EDTA @ 3.12 kg ha^{-1} (SA_4) and it was comparable with SA_3, SA_2 and SA_1. Significantly, a lower total dry matter yield of 7779 kg ha^{-1} was recorded by SA_0 (control). The higher total dry matter yield in SA_4 may be due to higher soil availability of iron would have been there with the application of the chelated form of iron fertilizers than $FeSO_4$ (Priyadarshini *et al*., 2019) [30] and its better absorption and translocation (Patil, 1975) [28], coupled with the application of iron in combination with RDF would have enhanced the distribution of iron within the plant which occurs through xylem and re-translocation in phloem increases vegetative tissue formation resulted in improved photosynthetic activity which boosted the growth of the plant parts and increment in dry matter (Nadim *et al*., 2012) [24]. The beneficial effect of Fe-EDTA application to soil increased the Fe availability and its better absorption and translocation (Patil, 1975) [28], which in turn might have helped the cellular activity and directly or indirectly participated in the formation of chlorophyll thus increasing photosynthesis.

The higher total dry matter yield recorded in the treatments that received iron and zinc enriched manures may be attributed to the fact that enhanced uptake of nutrients by the plants and beneficial effect of humic substances would have enhanced photosynthetic activity and increased production and accumulation of carbohydrates, which would have made a favourable effect on vegetative growth that might have contributed to higher total dry matter yield. It was also supported by Singh *et al.* (1989) [36] who observed that increase in total dry matter might be due to the involvement of iron in chlorophyll formation, which might have helped to favour cell division, meristematic activity in apical tissue, expansion of cell and formation of the new cell wall and plant growth. The favourable influence of applied iron and zinc on total dry matter production might be due to its catalytic or stimulatory effect on most of the physiological and metabolic processes of plants (Singh *et al.*, 1989) [36]. The impact of iron on total dry matter yield might be due to iron would have helped in photosynthesis and better plant growth (Ghulam Abbas, 2012) [11]. It is also in line with the findings of Rana and Kashif (2014) [34] who reported that the application of chelated zinc enhanced a progressive increase in the dry matter production of rice at critical growth stages.

Among the different pearl millet cultivars, the maximum total dry matter yield of 8960 kg ha^{-1} was observed in C_4 (Kaveri Super Boss) followed by C_2 (ICMH 1301) with a total dry matter yield of 8455 kg ha^{-1} which differed significantly among themselves. This was followed by C_5 (8455 kg ha^{-1}) and C_2 (8403 kg ha^{-1}) were on par with each other. The significantly minimum total dry matter yield (7695 kg ha^{-1}) was noticed in ICMH 1201 (C_1).

The variation in total dry matter yield of cultivars might be owing to the fact that the zinc efficient cultivars may have the ability to absorb enough amount of nutrients from the soil and utilize them for better metabolic activities, which would have improved crop growth and dry matter (Chaab *et al*., 2011) [3]. Also, the iron absorbed by plants participates in plant metabolic activities and increases the photosynthetic rate which might be attributed to a higher photosynthetic rate that inturn would have increased the total dry matter yield of the crop (Rajamani and Shanmugasundaram, 2014) [33]. The increase in total dry matter yield might be due to the additive response of cultivars to applied iron and zinc. Zinc fertilization, leading to higher total dry matter yield, has a beneficial effect on the physiological process, plant metabolism and plant growth (Jemila and Shanmudasundaram, 2017) [14]. Rai (2016) [31] reported a significant increase in the straw yield of direct-seeded rice due to the application of chelated zinc. Zinc plays a major role in the biosynthesis of IAA especially due to its role in the initiation of the shoot which in turn increased the vegetative parts of the plant (Jemila and Shanmudasundaram, 2017) [14]. This is in line with the findings of Lodha *et al.* (1985) [19] and Chaube *et al*. (2007) [5] who observed that increased total dry matter yield attributed to higher photosynthetic rate as well as increased nutrient acquisition and utilization.

Also increased yield due to application of enriched farm yard manure was also reported by Mani *et al.* (2001) [21] who observed increased yield due to the application of zinc enriched farmyard manure in red loamy soil at Paiyur (TN).

The interaction effect of iron and zinc with pearl millet cultivars on total dry matter yield was found to be significant at 5 percent level. The higher dry matter yield was registered by C_4SA_4 (9253 kg ha^{-1}) and it was on par with C_4SA_2 (9079 kg ha^{-1}). The lowest dry matter production of 6964 kg ha^{-1} was recorded by C_1SA_0.

3.2 Iron content and uptake

There was a significant increase in iron content and uptake in all the pearl millet cultivars owing to soil application of iron and zinc fertilizer. The range of total iron content and uptake ranged from 124 to 302 mg kg^{-1} and 457 to 1444 g ha^{-1} respectively. Soil application of Fe-EDTA @ 6.25 kg ha^{-1} and Zn-EDTA @ 3.12 kg ha^{-1} (SA_4) recorded the significantly highest iron content and uptake of 250 mg kg^{-1} and 1151 g ha^{-1}, respectively. This was followed by SA_3 (226 mg kg^{-1}) and SA_2 (219 mg kg^{-1}) which were comparable each other. In case of uptake, the remaining treatments are in descending order as follows: SA_3 (1009 g ha^{-1})>SA_2 (980 g ha^{-1})>SA_1 (867 g ha^{-1})>SA_0 (605 g ha^{-1}) which differed significantly from each other. Similarly, SA_0 (STCR NPK alone) registered significantly the lowest iron content and uptake of 158 mg kg^{-1} and 605 g ha^{-1}, respectively.

The increased iron content and uptake in the soil application of Fe-EDTA @ 6.25 kg ha^{-1} and Zn-EDTA @ 3.12 kg ha^{-1} may be due to the chelated form of iron might have facilitated more availability of iron to the plants and that might have released the ions slowly during the crop growth (Dhanalakshmi, 2019) [7].

The higher iron content and uptake recorded under the treatments (SA_1 and SA_2) that received iron enriched manures may be attributed to the fact that the enriched FYM acts as the nutrient reservoir and upon decomposition releases, numerous compounds like organic acid (humic and fulvic acid), amino acid and polyphenols act as a chelating agent to form stable complexes with iron and prevent added iron sulphate from precipitation with carbonates resulting in improvement iron content in crop (Rajamani and Shanmugasundaram, 2014) [33].

As regards the performance of cultivars, C_2 (ICMH 1301) recorded significantly higher total iron content and uptake of 255 mg kg^{-1} and 1159 g ha^{-1}, respectively. The lower mean iron content and uptake (174 mg kg^{-1} and 779 g ha^{-1}) were recorded by C_4 (Kaveri Super Boss). The cultivar ICMH 1301 (C_2) may be efficient in terms of iron absorption from the soil as the roots of efficient genotype generally secrete iron solubilizing organic compounds which would have solubilized insoluble iron in the rhizosphere and that would have helped the plants to absorb more iron from soil (Zheng-Yi and Zhang-Fusuo, 2000) [41]. Also, the higher iron uptake by crop may be attributed to higher DMP recorded in those treatments.

This is also in line with the findings of Kadivala *et al.* (2018) [15] who found higher utilization of iron by crop might have resulted in the higher uptake of iron by the crop in iron-treated plots.

The interaction effect between treatments and cultivars was also found to be significant in increasing the iron content and uptake of pearl millet. The higher iron content of 302 mg kg^{-1} was observed for C_2 (ICMH 1301) with SA_4 (Fe-EDTA @ 6.25 kg ha^{-1} + Zn-EDTA @ 3.12 kg ha^{-1}) combination. The lowest iron content of 124 mg kg^{-1} was recorded by C_3SA_0 and which was statistically comparable with C_4SA_0 (127 mg kg^{-1}).

Similarly, maximum iron uptake of 1444 g ha^{-1} was registered for C_2SA_4 was followed by C_2SA_2 (1335 g ha^{-1}), which statistically differed from each other. The lowest iron uptake was recorded by C_4SA_0 (457 g ha^{-1}).

The higher soil availability of iron and zinc under the treatment SA_4 and the efficiency of cultivar C_2 would have helped for increased iron and zinc content and uptake under the combination C_2SA_4. The increased iron concentration of cereals with iron addition to soil has been reported by several workers (Cakmak *et al.*, 2010; Dhaliwal *et al.*, 2010) [2, 6].

3.3 Zinc content and uptake

Soil application of iron and zinc show a marked variation with respect to zinc content and uptake of pearl millet cultivars. The mean values of zinc content and uptake ranged from 10.7 to 12.3 mg kg^{-1} and 53 to 151 g ha^{-1}, respectively.

The maximum zinc content and uptake of 58.1 mg kg^{-1} and 254 g ha^{-1} respectively was registered by the soil application SA_4 (Fe-EDTA @ 6.25 kg ha^{-1} + Zn-EDTA @ 3.12 kg ha^{-1}) and followed by SA_3 (56.0 mg kg^{-1} and 238 g ha^{-1}), SA_2 (55.5 mg kg^{-1} and 228 g ha^{-1}), SA_1 (50.9 mg kg^{-1} and 204 g ha^{-1}) and SA_0 (42.3 mg kg^{-1} and 152 g ha^{-1}) which differed statistically from each other. The significantly lowest zinc content and uptake of 42.3 mg kg^{-1} and 152 g ha^{-1} was recorded by SA_0 (NPK alone). The DTPA-Zn in the soil would have been maintained adequately due to less reaction of chelated Zn with various components of soil coupled with chelated zinc fertilizers might have released the zinc slowly during crop growth which eventually might have resulted in the higher zinc content and uptake in SA_4. The Zn-EDTA was more effective than $ZnSO_4$ in maintaining a higher amount of available Zn in the soil for a longer period (Chatterjee and Mandal, 1985) [4]. It was supported by Karak *et al.* (2005) [16] who reported that the amount of zinc content in the plant was always significantly higher with the application of chelated-Zn (Zn-EDTA) as compared to $ZnSO_4$ application.

The higher zinc content and uptake recorded under the treatments (SA_1 and SA_2) that received zinc enriched manures may be attributed to the fact that the enriched FYM acts as the nutrient reservoir and upon decomposition releases, numerous compounds like organic acid (humic and fulvic acid), amino acid and polyphenols act as a chelating agent to form stable complexes with zinc and prevent added zinc sulphate from precipitation, fixation and leaching may resulting in improvement zinc content (Dwivedi and Thakur, 2002) [9].

As regards cultivars, the application of iron and zinc in soil markedly influenced the zinc content and uptake of the crop. The maximum zinc content (63.8 mg kg^{-1}) and uptake (257 g ha^{-1}) were registered by ICMH 1301 (C_2). The remaining cultivars were arranged in descending order as follows: C_1>C_5>C_3>C_4, which were different significantly from each other. The lowest zinc content and uptake of 42.3 mg kg^{-1} and 152 g ha^{-1} respectively were recorded by C_4 (Kaveri Super Boss). The cultivars differed in nutrient absorption and utilization may be associated with root geometry, the ability of plants to take up sufficient nutrients from lower or subsoil concentration, plants abilities to solubilize nutrients in the rhizosphere, better transport, distribution and utilization within plants and balance source-sink relationships (Fageria and Baligar, 2003) [10]. An increase in the total zinc accumulation in crops might be due to the application of zinc, which preferentially moved zinc and deposited in the plant parts (Dvorak *et al*., 2003) [8]. The results were in accordance with the findings of Latha *et al*. (2001) [17], Shanmugasundaram and Savithri (2006) [35], Jemila and Shanmugasundarm (2017) [14] and Abishek *et al*. (2018) [1]. Higher iron and zinc uptake in mustard with iron and zinc enriched FYM was also observed by Meena *et al*. (2008) [23].

The interaction between iron and zinc with cultivars was found to be non-significant in influencing the zinc content and uptake.

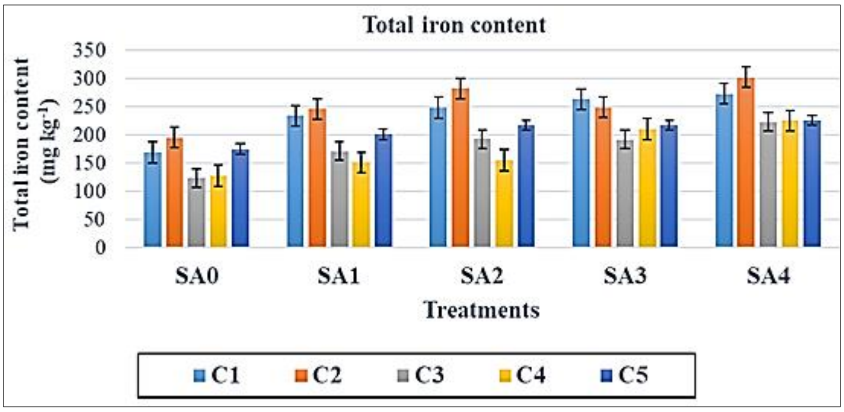

Fig 1: Effect of soil application of iron and zinc on dry matter iron content (mg kg^{-1}) of pearl millet cultivars

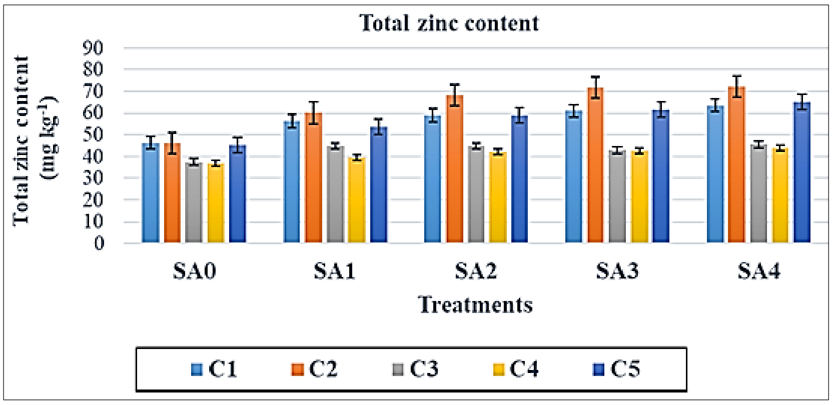

Fig 2: Effect of soil application of iron and zinc on dry matter zinc content (mg kg^{-1}) of pearl millet cultivars

Table 1: Methods of analysis of soil and plant samples

S. No.	Estimation	Method	Reference
Soil analysis			
1.	Textural fractions	International pipette method	Piper (1966) [29]
2.	Soil reaction (pH)	Potentiometry (soil-water suspension of 1:2 ratio)	Jackson (1973) [13]
3.	Electrical Conductivity (EC)	Conductometry (soil- water suspension of 1:2 ratio)	Jackson (1973) [13]
4.	Soil Organic Carbon	Chromic acid wet digestion method	Walkley and Black (1934) [40]
5.	Available Nitrogen	Alkaline permanganate method	Subbiah and Asija (1956) [38]
6.	Available Phosphorus	0.5 M $NaHCO_3$	Olsen (1954) [27]
7.	Available Potassium	Neutral Normal NH_4OAC method	Standford and English (1949) [37]
9.	Micronutrients available Fe and Zn	DTPA extraction (ICP-OES)	Lindsay and Norvell (1978) [18]
Grain analysis			
1.	Total Fe and Zn	Triple acid extract (ICP-OES)	Piper (1966) [29]

Table 2: Effect of soil application of iron and zinc on total dry matter yield (kg ha^{-1}) of pearl millet cultivars

Treatments	Total dry matter yield (kg ha-1)					
	C1	**C2**	**C3**	**C4**	**C5**	**Mean**
SA0	6964	7657	8016	8581	7676	7779
SA1	7736	8618	8257	8900	8456	8394
SA2	7966	8696	8571	9079	8649	8592
SA3	7850	8555	8388	8989	8573	8471
SA4	7959	8752	8509	9253	8660	8627
Mean	7695	8455	8348	8960	8403	-
SEd	C	47	T	47	CXT	104
CD (0.05%)	C	97	T	97	CXT	216

Treatments for soil application of iron and zinc (SA)		Cultivars	
SA0	Control	C1	ICMH 1201
SA1	Fe EFYM @ 50 kg ha-1 + Zn EFYM @ 25 kg ha-1	C2	ICMH 1301
SA2	Fe EFYM @ 62.5 kg ha-1 + Zn EFYM @ 31.25 kg ha-1	C3	86M86
SA3	Fe-EDTA @ 5.0 kg ha-1 + Zn-EDTA @ 2.5 kg ha-1	C4	Kaveri Super Boss
SA4	Fe-EDTA @ 6.25 kg ha-1 + Zn-EDTA @ 3.12 kg ha-1	C5	TNAU Cumbu hybrid Co-9

Table 3: Effect of soil application of iron and zinc on total iron uptake (g ha^{-1}) of pearl millet cultivars

Treatments	Total iron uptake (g ha-1)					
	C1	C2	C3	C4	C5	Mean
SA0	612	773	506	457	677	605
SA1	968	1122	661	718	863	867
SA2	1056	1335	678	858	974	980
SA3	1104	1121	1004	846	968	1009
SA4	1156	1444	1103	1016	1035	1151
Mean	979	1159	790	779	904	-
SEd	C	8	T	8	CXT	18
CD (P = 0.05)	C	16	T	16	CXT	37

Treatments for soil application of iron and zinc (SA)		Cultivars	
SA0	Control	C1	ICMH 1201
SA1	Fe EFYM @ 50 kg ha-1 + Zn EFYM @ 25 kg ha-1	C2	ICMH 1301
SA2	Fe EFYM @ 62.5 kg ha-1 + Zn EFYM @ 31.25 kg ha-1	C3	86M86
SA3	Fe-EDTA @ 5.0 kg ha-1 + Zn-EDTA @ 2.5 kg ha-1	C4	Kaveri Super Boss
SA4	Fe-EDTA @ 6.25 kg ha-1 + Zn-EDTA @ 3.12 kg ha-1	C5	TNAU Cumbu hybrid Co-9

Table 4: Effect of soil application of iron and zinc on total zinc uptake (g ha^{-1}) of pearl millet cultivars

Treatments	Total zinc uptake (g ha-1)					
	C1	C2	C3	C4	C5	Mean
SA0	142	151	154	142	174	152
SA1	222	218	176	181	222	204
SA2	242	281	187	193	237	228
SA3	247	315	194	184	251	238
SA4	269	320	203	206	271	254
Mean	224	257	183	181	231	-
SEd	C	6	T	6	CXT	12
CD (P = 0.05)	C	13	T	13	CXT	25

Treatments for soil application of iron and zinc (SA)		Cultivars	
SA0	Control	C1	ICMH 1201
SA1	Fe EFYM @ 50 kg ha-1 + Zn EFYM @ 25 kg ha-1	C2	ICMH 1301
SA2	Fe EFYM @ 62.5 kg ha-1 + Zn EFYM @ 31.25 kg ha-1	C3	86M86
SA3	Fe-EDTA @ 5.0 kg ha-1 + Zn-EDTA @ 2.5 kg ha-1	C4	Kaveri Super Boss
SA4	Fe-EDTA @ 6.25 kg ha-1 + Zn-EDTA @ 3.12 kg ha-1	C5	TNAU Cumbu hybrid Co-9

4. Conclusions

The soil application of Fe-EDTA @ 6.25 kg ha^{-1} + Zn-EDTA @ 3.12 kg ha^{-1} increased the dry matter iron content, uptake and yield of pearl millet cultivars. The cultivar ICMH 1201, ICMH 1301 and TNAU Cumbu hybrid (Co-9) found to be highly responsive in increasing the dry matter iron and zinc content and uptake with externally applied iron and zinc. The commercial hybrids Kaveri Super Boss and 86M86 also recorded higher total dry matter yield but they failed to respond in externally applied iron and zinc.

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