

Original Research Article

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Zinc and Iron Nutrition to Increase the Productivity of Pearl Millet-Mustard Cropping System in Salt Affected Soils

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ABSTRACT

The abiotic stresses, such as soil salinity and sodicity are largely responsible for the low productivity of crops mainly due to low availability of micro-nutrients especially as zinc (Zn) and iron (Fe). Therefore, judicious management of plant nutrients in these soils is as important as their reclamation. A field experiment was conducted for 4 consecutive years, consisting of 12 treatments laid out in randomized block design to evaluate the effect of rate and methods of zinc and iron as single or combined soil as well as foliar application in pearl millet-mustard cropping system grown on salt affected soils. Soil application of Zn and Fe were applied at the time of sowing with FYM or without FYM (addition of FYM done only in pearl millet) and foliar application of respective nutrients were also applied at 30 and 45 days after sowing of crops. The results of experiment showed that, application of FYM 10 t ha⁻¹ along with 5 kg Zn+10 kg Fe significantly (p=0.05) improved the yield parameters of pearl millet and mustard followed by 5 kg ha⁻¹ Zn and 10 kg ha⁻¹ Fe as soil application. The results also indicated that combined soil application of 5 kg Zn+10 kg Fe +10 t FYM increased the pearl millet grain yield (36.6 q ha⁻¹) and mustard seed yield (22.7 q ha⁻¹) by 57.1% and 42.8% higher over control, however, yield improvement was 35.6 and 20.7 % due to application of 5 kg Zn+10 kg Fe without FYM, respectively, in pearl millet and mustard over control. Ferrous-iron content in both crops proved to be a better index of Fe nutrition status compared to total plant Fe and DTPA- extractable soil Fe under salt affected soils. Salt affected soils are having vast potential to produce a significant amount of food grain by applying optimum dose of Zn, Fe and FYM in pearl millet and mustard. Combined foliar application of Zn and Fe also increased the yields of pearl millet and mustard grown in saline soils. Ferrous iron (Fe²⁺) is better indicator for iron nutrition in crops.

Keywords

Ferrous iron, Iron, Zinc, Pear millet, Mustard, Salt Affected Soils

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Introduction

Pearlmillet [*Pennisetum glaucum* (L.) R. Br. Emend Stuntz] - mustard [*Brassica juncea* (L.) Czernj and Coss.] cropping system is one of the predominant cropping systems in marginal and sub-marginal land including salt

affected soils in India under scarcity of good quality water and rainfed conditions. The north-western parts of Indian states are having predominantly saline and alkaline soils with poor fertility. Poor availability of micronutrients mainly zinc (Zn) and iron (Fe) as well as poor agronomic practices further

reduces the availability of these nutrients to plants which led to reduced growth and yield (Raja *et al.*, 2012; Meena *et al.*, 2014). The various physico-chemical processes also mediated the Zn and Fe availability in alkaline soils (Meena *et al.*, 2013), *i.e.* variation in chemical composition of salt affected soils, precipitation-dissolution reactions, adsorption kinetics, transformations of nutrients, and crop responses to applied nutrients greatly vary (Katyal and Sharma, 1980; Datta *et al.*, 2013). Application of micronutrients decides the yield potential of crops in deficient soil with low carbon content (Shukla *et al.*, 2014; Ray *et al.*, 2014). Use of FYM and other organic manures produce various types of organic acids during the microbial decomposition and converted the plant nutrient from immobile to mobile in the soil solution (Dotaniya *et al.*, 2016). Combined soil application of micronutrients with FYM significantly enhanced the mustard yield in normal soil (Meena *et al.*, 2006). Organic manures not only supply micronutrients but also influence the transformation of native micronutrients in soil, thereby enhancing their availability to crops (Pal *et al.*, 2008; Meena *et al.*, 2018). The contributions of soil organic matter to available pools of micronutrients are limited and thus, prone to deficiency of one or more micronutrients especially Zn and Fe in salt affected soils (Sharma *et al.*, 2009). Straight or alone application of zinc and Fe fertilizer in normal soil increased the biological produce in mustard (Singh *et al.*, 2010) and in pearl millet (Shukla *et al.*, 2014). In contrast to Zn fertilizer, soil application of inorganic Fe salts is ineffective in controlling Fe-deficiency in alkaline soil, except when application rates are as higher as 150 kg FeSO₄ ha⁻¹ under aerobic rice (Pal *et al.*, 2008). Also, the efficacy of foliar spray of Zn and Fe varies with species and cultivars (Meena *et al.*, 2016). It is well documented that application of Zn in saline soil increased the its concentration in maize (Rahman *et al.*, 1993) and tomato (Knight *et*

al., 1992) and decreased in case of cucumber leaves (Al- Harbi, 1995). Influences of Fe application in plants were also inconsistent as Zn concentration in plants (Achakzai *et al.*, 2010). Ferrous iron (Fe²⁺) content in rice and other plants proved to be a better index of Fe-nutrition status compared to total plant Fe and chemically extractable soil Fe (Katyal and Sharma, 1980; Meena *et al.*, 2016). Limited information is available on the adequate level of Fe²⁺ in pearl millet and mustard under field conditions which can be used for monitoring purpose.

The available information pertaining to ways and means for optimizing Zn and Fe requirements to ameliorate deficiencies of these nutrients in various crops have mostly been confined to normal soil conditions. Such information is yet to be generated for pearl millet and mustard cropping sequence grown under salt affected soils. Therefore, the judicious Zn and Fe management of plant nutrients in salt affected soils can enhance the food grain production potential of degraded soils. For this, a hypothesis was formulated to assess the requirement of Zn and Fe application with FYM and its effect on pearl millet- mustard cropping system.

Materials and Methods

Physico-chemical properties of experiment soil

A field experiment on pearl millet–mustard cropping system was carried out during 2013–2017 at the experimental farm Nain (29°19'7.09" N latitude and 76°47'30.0" E longitude), district, Panipat of ICAR-Central Soil Salinity Research Institute (CSSRI), Karnal, India. The soil of the experimental site was sandy loam and the climate is semi-arid, sub-tropical with hot summers (May–June) and cold winters (December–January). Initial soil samples were collected (0–15 cm depth)

from the experimental site and physicochemical properties of the experimental soil and FYM are given in Table 1. Soil samples were extracted with 0.005M DTPA (Lindsay and Norvell, 1978) and Fe in the extract was determined with the help of Flame Atomic Absorption Spectrophotometer (Model-ZEEnit 700). For analysis of total Zn and Fe in soil and FYM samples were extracted with aqua regia ($\text{HNO}_3 + 3\text{HCl}$) on a hot plate and metal contents in the digest were determined as per the procedure of Quevauviller (1998) using AAS.

Treatment details

There were 12 treatments combinations, i.e. T₁- Control, T₂- 5 kg Zn ha⁻¹, T₃- 6.25 kg Zn ha⁻¹, T₄- 7.5 kg Zn ha⁻¹, T₅- 7.5 kg Fe ha⁻¹, T₆- 10 kg Fe ha⁻¹, T₇- 12.5 kg Fe ha⁻¹, T₈- 5 kg Zn+10 kg Fe ha⁻¹, T₉- 5 kg Zn+10 kg Fe + 10 t FYM ha⁻¹, T₁₀- Foliar sprays of 0.5% ZnSO₄ (twice), T₁₁- Foliar sprays of 1% FeSO₄ (twice at 30 and 45 DAS) and T₁₂- Combined foliar sprays (0.5% ZnSO₄+1% FeSO₄; twice). Zinc and iron were applied by ZnSO₄.7H₂O and FeSO₄.7H₂O, respectively at the time of sowing of pearl millet and mustard. Foliar sprays of Zn and Fe were applied through inorganic salt of Zn and Fe (ZnSO₄.7H₂O and FeSO₄.7H₂O) in both the crops at 30 and 45 days after sowing.

Plant analysis

Zinc and iron content

For the determination of ferrous-iron (Fe^{2+}) at 50 days after sowing (DAS) plant samples were transported immediately to the laboratory in closed polythene bags and washed copiously with running tap water, followed by 0.1 N hydrochloric acid (HCl) and distilled water. The samples were freed-off the sticking water drops by placing them between sheets of clean blotting papers. They were cut

into small pieces of approximately 1-2 mm, with the help of stainless steel scissors. The Fe^{2+} concentration in fresh plant samples was determined by the ortho- phenanthroline method as developed by Katyal and Sharma (1980). In order to remove discrepancies arising due to varying moisture contents of plant samples, the duplicate fresh chopped plant samples were dried to a constant weight at 50-60°C in an oven and moisture content was computed. Ferrous-iron concentration in the plant was expressed on dry weight basis. The crop was harvested at maturity and grain and straw samples per plot were collected.

The samples were rinsed thoroughly with 0.1 N HCl (AR) and then with the deionised water in order to eliminate the contamination of the foliar fertilizer. Plant samples were dried in hot air oven at 60-70°C, after attaining constant weight, plant samples were ground with a stainless steel sample grinder. The ground samples of the grain and straw were stored in sealed plastic bags at room temperature until they were analyzed. Total plant Zn and Fe were digested in di-acid [nitric acid (HNO_3): perchloric acid (HClO_4):: 9:4] mixture (Jackson, 1973) and determined with the help of Flame Atomic Absorption Spectroscopy (FAAS).

Total chlorophyll content

Chlorophyll content was estimated according to the method of Hiscox and Israelstam (1979) using dimethyl sulfoxide (DMSO). Fully expanded leaf from plant was detached and weighed 200 mg then kept into a test tube containing 5 ml of DMSO. The test tube was then placed into oven at 60°C for about 4 h to facilitate the extraction of pigment. After 2 hours and attaining the room temperature, the absorption was read at 645 and 665 nm on spectrophotometer. The DMSO was used as blank. Calculations for different pigments were made according to Wellburn (1994).

Chl 'a' ($\mu\text{g/ml}$) - $12.19 A_{665} - 3.45 A_{645}$

Chl 'b' ($\mu\text{g/ml}$) - $21.99 A_{645} - 3.32 A_{665}$

Total chlorophyll - Chl 'a' + Chl 'b'

Quantity of all these pigments was calculated in mg g^{-1} tissue dry weight.

Proline content

Proline content was estimated by using the method of Bates *et al.*, (1973). The 300 mg of leaves was homogenized in 5 ml of 3 per cent sulphosalicylic acid and then centrifuged at 5000 rpm for 15 minutes and supernatant was taken. Two ml of supernatant was taken and 2.0 ml reagent acid ninhydrin + 2.0 ml acetic acid was added. This mixture was then kept in boiling water bath for 1 h at 100°C and thereafter, reaction was terminated by keeping tubes in ice-bath. Then 4.0 ml of toluene was added. After vigorous shaking, the upper organic phase was taken after attainment of room temperature and absorbance was recorded at 520 nm by using toluene as blank. A standard curve was prepared by using graded concentration of proline in 3% sulphosalicylic acid. The proline content was expressed as $\mu\text{g g}^{-1}$ dry weight.

Statistical analysis

Statistical analysis was done in the randomized block design with three replications as per method given by Snedecor and Cochran, 1967. The mean values of treatments were considered for comparison using the critical difference at the 5 % level of significance.

Results and Discussion

Effect of Zn and Fe on yield

The results indicated that with combined application of 5 kg Zn +10 kg Fe +10 t FYM ha^{-1} pearl millet grain yield (36.6 q ha^{-1}) and

mustard seed yield (22.7 q ha^{-1}) were 57.1% and 42.8% higher over control. However, yield improvement was only 35.6 and 20.7 % higher over control in pearl millet and mustard, respectively, with the application of 5 kg Zn + 10 kg Fe ha^{-1} without FYM. Alone soil application of 7.5 kg Zn ha^{-1} and 12.5 kg Fe ha^{-1} also significantly increased yields of pearl millet and mustard than control. Among the foliar applications, spray of 0.5 % ZnSO_4 +1% FeSO_4 twice was equally effective in increasing the yields of pearl millet and mustard similar to that obtained with the soil application of 5 kg Zn ha^{-1} and 7.5 kg Fe ha^{-1} alone (Table 2).

The direct effect of FYM in pearl millet and its residual effect in mustard were found useful in getting higher yield of crops, which might be due to the favorable effect of FYM on physical, chemical and biological properties in increasing the availability of nutrients in the soil solution. Comparatively less improvement in grain yield of pearl millet was recorded in alone application of 5 kg Zn and 7.5 kg Fe than combined application treatment T_8 (5 kg Zn +7.5 kg Fe ha^{-1}) and it was found to decrease by 18.8% and 22.9%, respectively. Similarly, in case of mustard, the seed yield decreased by 15.0 and 11.6% in alone application of 5 kg Zn ha^{-1} and 7.5 kg Fe ha^{-1} as compared to combined application (5 kg Zn +7.5 kg Fe ha^{-1}), respectively. This might be due to the favorable synergistic effect of combined application of Zn and Fe in the soils which enhanced the better translocation of nutrients by developing good root growth. Subsequently, the treatment T_9 (5 kg Zn+7.5 kg Fe + 10 t FYM ha^{-1}) receiving combined application of Zn and Fe along with FYM in pearl millet and FYM residual effect in mustard increased the yield of both crops significantly. It could be attributed due to the favorable effect of organic manures in soils, decreasing EC and maintaining the higher amounts of available micronutrients in salt

affected soils (Kumar *et al.*, 2012). Also, combined foliar application of Zn and Fe was better than foliar application/sprays of an individual nutrient. Straw yield of both crops followed the same trend as that of grain yield. The response of Zn and Fe application was higher for yield in pearl millet than mustard. The different response of Zn and Fe application to pearl millet and mustard in terms of yield may be related to inherent characteristics of crop to perform under salt affected soils.

The superiority of foliar application of Fe over soil application has earlier been reported by many researchers (Pal *et al.*, 2008; Zhang *et al.*, 2009; Gomez-Galera *et al.*, 2010). Iron is easily translocated acropetally and re-translocated basipetally after foliar application as long as Fe does not get immobilized. However, Fe (II) salts rapidly oxidize upon exposure to ambient air after soil application (Fernandez and Ebert, 2005). Relative ineffectiveness of soil application of Fe through inorganic source can be attributed to quick conversion of Fe^{2+} to Fe^{3+} under field conditions with high pH rendering its unavailability to plants (Sarkar *et al.*, 2008).

Effect on physiological parameters

Chlorophyll and proline content were measured in both the crops. In pearl millet, alone soil application of Zn through fertilizer significantly ($p=0.05$) improved total chlorophyll content from 5.07 to 5.16, 6.17 and 6.65 $\mu\text{g/g}$ in the treatment T_2 , T_3 and T_4 , respectively. In similar way, alone soil application of Fe fertilizer improved the chlorophyll content from 5.07 to 5.63, 5.94 and 7.19 $\mu\text{g/g}$ in response to treatments of T_5 , T_6 and T_7 kg Fe ha^{-1} , respectively. Combined soil application of 5 kg Zn + 10 kg Fe ha^{-1} (T_8) increased chlorophyll content by 48.5% over control; whereas, same treatment with 10 t FYM ha^{-1} (T_9) increased chlorophyll content

92.9% than control (Table 3). Treatment T_{12} receiving combined foliar application of 0.5% ZnSO_4 + 1% FeSO_4 had significantly higher chlorophyll content than control in pearl millet. The proline content in pearl millet was also affected by the external application of Zn and Fe and its combination (Table 3). Increasing the levels of Zn from control to highest level of Zn (7.5 kg Zn ha^{-1}) reduced the proline content from 14.43 to 14.11 $\mu\text{g/g}$. Proline content in pearl millet decreased (14.95 to 14.09 $\mu\text{g/g}$) in response to increased levels of soil applied Fe (7.5 to 12.5 kg ha^{-1}). Among the treatments, combined application of 5 kg Zn+ 10 kg Fe + 10 t FYM ha^{-1} (T_9) reduced proline content by 10.95% than control. Foliar application treatments (T_{10} , T_{11} and T_{12}) of Zn and Fe did not significantly affect proline content in pearl millet.

The chlorophyll and proline content also measured in mustard crop with respect to Zn, Fe and combined application (Table 3). Similar patterns of Zn application effect on mustard was observed as that in pearl millet and found that increasing the level of Zn (5 to 7.5 kg ha^{-1}) enhanced the chlorophyll content from 2.76, to 2.89 $\mu\text{g/g}$. Soil application of Fe also enhanced chlorophyll content from 2.48 to 2.70, and 2.90 in 7.5, 10 and 12.5 kg Fe ha^{-1} , respectively.

Highest chlorophyll content was measured in the combined application of 5 kg Zn+10 kg Fe + 10 t FYM (3.48 $\mu\text{g/g}$) which was 41.1% higher than control. The combined spray application of Zn and Fe significantly increased the chlorophyll content by 10.1% over control in mustard. In general, proline content in mustard leaves decreased with application of Zn + Fe either through soil or foliar sprays individually or in combination. However, marked decreased in proline content (30-50%) was recorded with combined application of 5 kg Zn+ 10 kg Fe either with FYM (6.51 $\mu\text{g/g}$) or without FYM (9.18 $\mu\text{g/g}$).

Table.1 Some selected physico-chemical properties of experimental soil and farm yard manure

Parameter	Value
<i>Soil Properties</i>	
pH _s (1:2)	8.43
EC _e (dS m ⁻¹)	10.71
Organic carbon (%)	0.42
DTPA extractable Zn (mg kg ⁻¹)	0.65
Total Zn (aqua regia extractable, mg kg ⁻¹)	39
DTPA extractable Fe (mg kg ⁻¹)	4.43
Total Fe (aqua regia extractable, %)	1.13
<i>FYM (Farm Yard Manure)</i>	
Moisture content (%)	49
Total Zn (mg kg ⁻¹)	60
Total Fe (mg kg ⁻¹)	200
Total Cu (mg kg ⁻¹)	22
Total Mn (mg kg ⁻¹)	60

Table.2 Effect on zinc and iron application methods on yield of pearl millet and Mustard (pooled of 4 years)

Treatment	Pearl millet		Mustard	
	Grain	Stover	Seed	Stover
	(q ha ⁻¹)		(q ha ⁻¹)	
T ₁ - Control	23.3	53.9	15.9	55.3
T ₂ - 5 kg Zn ha ⁻¹	26.6	62.2	16.7	60.6
T ₃ - 6.25 kg Zn ha ⁻¹	28.5	71.7	18.2	66.4
T ₄ - 7.5 kg Zn ha ⁻¹	30.7	77.6	19.4	71.6
T ₅ - 7.5 kg Fe ha ⁻¹	25.7	64.2	17.2	60.0
T ₆ - 10 kg Fe ha ⁻¹	27.6	69.9	18.0	62.5
T ₇ - 12.5 kg Fe ha ⁻¹	29.2	75.5	18.5	70.7
T ₈ - 5 kg Zn+10 kg Fe ha ⁻¹	31.6	76.5	19.2	79.4
T ₉ - T ₈ +10 t FYM ha ⁻¹	36.6	91.0	22.7	85.4
T ₁₀ - 0.5% ZnSO ₄ sprays twice	24.1	58.6	16.6	59.7
T ₁₁ - 1.0% FeSO ₄ sprays twice	27.0	64.5	17.0	60.7
T ₁₂ - Combined sprays (T ₁₀ +T ₁₁)	28.1	67.7	17.3	62.2
LSD (P=0.05)	5.8	9.6	2.3	6.3

Table.3 Effect of zinc and iron application rate on total chlorophyll and Proline content (pooled of 4 years)

Treatment	Pearlmillet		Mustard	
	Total Chlorophyll ($\mu\text{g ml}^{-1}$)	Proline ($\mu\text{g g}^{-1}$)	Total Chlorophyll ($\mu\text{g ml}^{-1}$)	Proline ($\mu\text{g g}^{-1}$)
T ₁ - Control	5.07	14.43	2.48	13.14
T ₂ - 5 kg Zn ha ⁻¹	5.16	13.75	2.76	13.54
T ₃ - 6.25 kg Zn ha ⁻¹	6.17	15.01	2.95	12.00
T ₄ - 7.5 kg Zn ha ⁻¹	6.65	14.11	2.89	11.58
T ₅ - 7.5 kg Fe ha ⁻¹	5.63	14.95	2.70	13.54
T ₆ - 10 kg Fe ha ⁻¹	5.94	14.51	2.90	11.19
T ₇ - 12.5 kg Fe ha ⁻¹	7.19	14.09	2.55	13.25
T ₈ - 5 kg Zn+10 kg Fe ha ⁻¹	7.53	14.85	2.88	9.18
T ₉ - T ₈ +10 t FYM ha ⁻¹	9.78	12.85	3.48	6.51
T ₁₀ - 0.5% ZnSO ₄ sprays twice	3.92	13.80	1.91	12.84
T ₁₁ - 1.0% FeSO ₄ sprays twice	4.28	14.22	2.18	12.10
T ₁₂ - Combined sprays (T ₁₀ +T ₁₁)	5.16	14.32	2.73	12.08
LSD (P=0.05)	0.41	0.73	0.23	0.91

Table.4 Effect of Zn and Fe application on Fe²⁺ and total iron and zinc content in pearl millet and mustard at 50 DAS (pooled of 4 years)

Treatment	Pearl millet			Mustard		
	Fe ²⁺	Total Fe	Total Zn	Fe ²⁺	Total Fe	Total Zn
	(mg kg ⁻¹)			(mg kg ⁻¹)		
T ₁ - Control	10.9	40.1	32.1	18.5	53.4	49.4
T ₂ - 5 kg Zn ha ⁻¹	11.9	40.4	43.8	18.9	53.9	53.7
T ₃ - 6.25 kg Zn ha ⁻¹	12.5	40.2	49.5	19.0	54.2	54.2
T ₄ - 7.5 kg Zn ha ⁻¹	12.9	40.6	53.5	19.5	54.9	56.5
T ₅ - 7.5 kg Fe ha ⁻¹	13.2	42.9	37.7	20.2	56.2	51.0
T ₆ - 10 kg Fe ha ⁻¹	13.6	44.8	39.4	20.6	58.4	52.5
T ₇ - 12.5 kg Fe ha ⁻¹	13.7	46.7	40.8	20.9	59.5	52.8
T ₈ - 5 kg Zn+10 kg Fe ha ⁻¹	14.6	46.0	47.6	21.4	60.4	56.4
T ₉ - T ₈ +10 t FYM ha ⁻¹	15.1	45.3	51.7	23.1	63.1	59.9
T ₁₀ - 0.5% ZnSO ₄ , twice	11.7	41.4	40.3	18.8	53.8	53.0
T ₁₁ -1.0% FeSO ₄ , twice	13.2	43.0	37.1	20.1	56.0	50.9
T ₁₂ - Combined sprays (T ₁₀ +T ₁₁)	13.3	45.5	42.1	20.8	57.8	54.1
LSD (P=0.05)	2.39	4.89	8.61	2.21	4.22	5.54

Both pearl millet and mustard are the most preferred crops in the northern belt of Punjab, Haryana and Rajasthan. The application of Zn in saline and alkaline soils improved the physiological parameters of the wheat (Ebrahim and Aly, 2004). Singh *et al.*, (2013) reported that application of Zn fertilizers in saline soil improved the water content, transpiration rate, protein, chlorophyll content, carbohydrate and starch content in crops. The results of the present study also proved that plant physiological parameters improved by the addition of Zn and Fe. Application of FYM produced various types of organic acids, which lower down the soil pH and enhance the availability of Fe and Zn in soil. It also left the priming effect on plant nutrients and mobilize the native immobile nutrients in soil. The FYM improved the soil physical, chemical and biological properties and enhance the plant uptake pattern and nutrient mineralization kinetics in soil. Increasing the Zn concentration in plant enhanced the nucleic acid metabolism and promotes the synthesis of the photosynthesis sink capacity of plants (Cakmak and Kutman, 2018). Rhizospheric manipulation of micronutrients enhanced the crop uptake dynamics and improves the crop yield (Meena *et al.*, 2006; Dotaniya *et al.*, 2016). Proline is a physiological parameter and produced under the stress conditions. Application of Zn and Fe reduced the proline content in linseed (Ghildiyal *et al.*, 1986). Similar types of findings were reported in various crops, *i.e.* barley (Abou Hossein *et al.*, 2002), tomato (Alpaslan *et al.*, 1999) and wheat (Cakmak and Kutman, 2018).

Effect on concentration of Zn and Fe

Total Fe content in whole plant of pearl millet was significantly higher in treatment T₇ (46.7 mg kg⁻¹) as compared to control (40.1 mg kg⁻¹); whereas, in case of mustard highest total Fe content was observed under combined soil

application of 5 kg Zn+10 kg Fe + 10 t FYM ha⁻¹ (63.1 mg kg⁻¹) than control (Table 4). Mustard is probably better extractor of soil Fe from the reserve pools. The lowest total Fe in straw of experimental crops under control is due to its inherently poor Fe supplying capacity related to low DTPA-extractable Fe and high CaCO₃ content (Meena *et al.*, 2013, Meena *et al.*, 2017) of alkaline soils. Among foliar application, highest Fe content in straw of pearl millet and mustard was observed under combined foliar spray of Zn and Fe followed by alone application of 1% FeSO₄.

Highest Fe²⁺ content in fresh leaves of pearl millet (15.1 mg kg⁻¹; dry wt.) and mustard (23.1 mg kg⁻¹; dry wt.) was estimated in treatment T₉ (5 kg Zn+10 kg Fe + 10 t FYM ha⁻¹) which was significantly higher than control treatment at 50 days after sowing of crops. Such variability in Fe content between these two crops is attributed to the inherent genetic differences in ability of the crop to mine Fe from the soil pool (Pal *et al.*, 2008; Meena *et al.*, 2016). On an average, Fe content in shoot of crop plants was highest in combined soil application of Zn and Fe with FYM, followed by straight soil application, combined foliar application of Zn and Fe (Table 4). Straight or alone soil and two foliar application of Fe were equally effective in maintaining the Fe²⁺ content in plants.

Saline and alkaline soils are having potential to produce a significant amount of food grain, but having Fe and Zn micronutrient limitation due to poor availability. In this experiment, external application of Zn, Fe and FYM enhanced grain yield by 57.1 % in pearl millet and 42.8% in mustard. The other plant parameters (total Zn and Fe²⁺, chlorophyll content, etc.) were also improved with the application of Zn and Fe and also by the combined application with FYM. Ferrous iron (Fe²⁺) at 50 DAS can be used as an indicator for assessing Fe deficiency in crops. Such

findings can be considered for planning and improvement of pearl millet and mustard crop yield in saline and alkaline soils of India for sustainable crop yield for food security.

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