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Zinc fractions and Barley productivity under zinc fertilization and sodic irrigation water management

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ABSTRACT

An experiment was conducted to know the effect of different residual sodium carbonate (RSC) water, farmyard manure (FYM) and different levels of zinc fertilization on different zinc fractions of soil, yield attributes and yield of barley in loamy sand soil under semi-arid climatic conditions. The three levels of RSC of irrigation water (2.5, 5 and 10 mmol/ L), two levels of FYM (control and 15 t/ha) and four levels of zinc (control, 15, 30 and 45 kg $ZnSO_4$/ha) were evaluated on barley production in split plots design. Results indicated that application of high RSC irrigation water (10 mmol/ L) significantly reduced the different fractions of soil Zn (except Occ-Zn), plant height, total and effective tillers, test weight and yield of barley during both the years, while 5 mmol/L of RSC irrigation level found at par with 2.5 mmol/L. Application of FYM significantly increased the different Zn fractions in soil (except Occluded-Zn) as well as yield attributes, grain and straw yield of barley. The increasing level of zinc application significantly increased the different fractions of soil Zn (except Occ-Zn), available soil Zn, yield attributes and yield of barley. It was observed that the grain yield of barley positive and significantly correlated with different fractions of Zn, *viz.* DTPA-Zn (r=0.888), Ads-Zn (r=0.525), Occ-Zn (r = 0.670), OC-Zn (r = 0.948) and Res-Zn (r = 0.923). The optimum dose of zinc for barley computed as 37.6 kg / ha $ZnSO_4$ with corresponding optimum yield of 4365 kg/ha.

Keywords: Barley, FYM, RSC irrigation water, Yield, Yield attributes, Zinc, Zinc fractions

Salt affected soils in India are predicted to increase from 6.73 M-ha to 16.2 M-ha by 2050 due to planned expansion in irrigation network, use of poor-quality irrigation water and climate change impacts (ICAR-CSSRI 2015). The role of FYM in promoting reclamation of sodic soils through improvement of soil physical conditions, greater mobilization of native Ca, reduction in pH and enhancement of biological activities is well known. Barley is an ancient cereal crop, used as food grain and malt production (Pourkheirandish and Komatsuda 2007, Baik and Ullrich 2008). Barley has 7% share in global cereal production, which makes it 4th highest grown cereal crop in the world (Pal *et al*. 2012). India ranks first in world under barley production with 6.5-million-hectare area, annual production of 1.73 million tones and productivity of 26.2 q/ (Anonymous 2018–19). Rajasthan stands second with regard to its acreage and production. It is cultivated on about 2.55 lakh ha area in the state with an annual production of 7.55 lakh tones and productivity of 29.5 q/ha (Anonymous 2018-19). Zinc deficiency in soils of India is likely to increase from 49 to 63% by the year 2025 as most of the marginal soils brought under cultivation are now showing zinc deficiency (Singh 2006). Continuous use of high RSC water increases the sodicity and *p*H of soil which decreases the availability of Zn to plant. Although, zinc helps in inducing alkalinity tolerance in crop by enhancing its efficiency in utilizing K, Ca and Mg and decreases the adverse effect of sodicity (Jan *et al.* 2017). A knowledge of the transformation of applied zinc into different forms is important, as crop plants utilize only 1–4% of the freshly applied zinc (Zn) and the remaining goes into the formation of different Zn compounds of varying solubility (Dhaliwal *et al.* 2019). So, keeping this in mind the present experiment was carried out to study the effect of applied Zn with and without FYM on Zn distribution in different fractions and yield attributes of barley under irrigation with varying levels of RSC water.

MATERIALS AND METHODS

The experiment was conducted at Agronomy Farm, Sri Karan Narendra Agriculture College, Jobner, Jaipur, Rajasthan during winter (November-March) of 2013–14 and 2014–15. The experimental soil had *p*H 8.10, EC 2.56 dS/ m, organic carbon- 1.80 g/kg, available N- 133.60 kg/ha, available P-9.48 kg/ha, available K-159.15 kg/ ha and available Zn- 0.38 ppm in the surface soil (0–15

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cm). The experiment was laid out in a split plot design with 24 treatment combinations of three levels of RSC water, two levels of FYM and four levels of $ZnSO_4$ with four replications. The different RSC of irrigation waters were prepared by dissolving required quantities of NaCl, Na_2SO_4, $NaHCO_3$, $CaCl_2$ and $MgSO_4$ in available water of 2.5 mmol/L. To check the lateral movement of water and salts, buffer strips around each irrigation channel were kept. The RSC water levels were 2.5 mmol/l (available tubewell water), 5.0 and 10.0 mmol/L. Nitrogen was applied as per recommended dose of 100 kg N/ ha (Half of N was applied as basal; the remaining half was applied before first irrigation). The FYM was applied @ 15 t/ha in treatment plots before 15 days sowing of crop. The farmyard manure contained 16.40% total carbon, 0.55% N, 0.25% P, 0.51% K and had a C: N ratio of (29.8). After harvest of the crop, soil samples were collected, air-dried, processed and analyzed for DTPA-Zn (Lindsay and Norvell 1978) and different zinc fractions, viz. water soluble plus exchangeable (Zn_{wsex}) analyzed by 1 N NH_4OAc (*p*H 7.0), adsorbed Zn (Zn_{Ads}) estimated by 0.005 M DTPA (*p*H 7.3), zinc associated with organic matter (Zn_{OC}) analyzed by 30% H_2O_2 and 0.005 M DTPA (*p*H 7.3), occluded Zn (Zn_{Occ}) by 0.1 N HCl and Residual Zn estimated by total Zn minus sum of other all fractions, Total Zn in soil was determined using procedure given by Page *et al.* (1982), this sequential fractionation procedure proposed by Iyengar and Deb (1977). The concentration of different zinc fractions in the extracts was estimated using AAS (Model no. Element AS AAS4141). The plants height at harvest stage, total numbers of tillers per meter row length at 60 DAS and number of effective tillers per meter row length at harvest, 1000 grain weight were recorded by standard procedure. The grain and straw yields of barley were also recorded after harvest of crop. Optimum dose of Zn for yield of Barley under zinc levels was worked out with the help of quadratic equation (Croxton *et al.* 1973). Statistical analyses were performed using analysis of variance (ANOVA) for split plot design (Gomez and Gomez 1984). Correlation and step wise regression were carried out using SPSS software package.

RESULTS AND DISCUSSION

Yield attributes and yields: Results showed that the plant height, total tillers and effective tillers per meter row length, test weight were significantly decreased with high RSC irrigation water (W3), while W2 found at par with W1. In plant height under W3 was significantly decreased by 11.98% and 10.73% over W1 and W2, respectively (Table 1). The reduction could be due to the adverse effect of RSC which affects the plant growth in two ways, i.e. toxic effect of sodium ions and nutritional imbalance caused by such ions. High concentration of Na also adversely affects root growth which ultimately affects plant height. The grain and straw yield of barley was significantly decreased with higher RSC irrigation water level (W3), while the RSC irrigation water level @ 5 mmol/ l (W2) was found similar to the RSC irrigation water level @ 2.5 mmol/ l (W1). The maximum pooled grain and straw yield was recorded under W1 and reduced by 20.3% and 12.4% under applied W3 and W2 over RSC irrigation water level @ 2.5 mmol/ l level (W1). The higher amount of Na may adversely affect the physiological, metabolic and enzymatic activities in plant,

Table 1 Effect of RSC irrigation water, FYM and zinc levels on growth and yield attributes and yield of barley (mean of two years)

Treatment	Plant height(cm) at harvest	Total tillers (per meter row length)	Effect tillers (per meter row length)	Test weight (g)	Grain yield (q/ ha)	Straw yield (q/ ha)
RSC levels						
W1 (2.5 mmol/L)	93.74	99.84	72.94	31.95	45.64	65.96
W2 (5 mmol/L)	92.75	99.10	72.46	31.53	44.68	65.35
W3 (10 mmol/L)	83.76	78.16	67.01	28.10	37.93	58.67
SEm±	0.51	0.66	0.38	0.18	0.47	0.66
CD(P=0.05)	1.46	1.91	1.10	0.52	1.35	1.91
FYM levels						
0	89.08	82.38	62.03	29.73	41.23	61.74
15	91.09	102.35	79.58	31.32	44.28	64.91
SEm±	0.41	0.54	0.31	0.15	0.38	0.54
CD(P=0.05)	1.19	1.56	0.90	0.43	1.11	1.56
Zinc levels						
0	88.26	80.25	60.98	29.21	41.32	60.43
15	89.07	89.51	65.64	30.37	42.37	62.06
30	91.20	99.14	80.72	31.18	43.60	65.29
45	91.80	100.56	81.88	31.34	43.72	65.53
SEm±	0.62	0.69	0.48	0.21	0.39	0.58
CD(P=0.05)	1.72	1.93	1.34	0.58	1.09	1.63

resulting into poor root development and plant growth and ultimate decrease in yield of barley (Haq *et al.* 2007, Naga *et al*. 2013).

The application of FYM @ 15 t/ha showed significant increases in plant height, effective tillers, total tillers per meter row length, grain yield and straw yield of barley by 2.26%, 28.39%, 24.17% 7.40% 5.13% respectively over control (Table 1). It is due to addition of FYM in the soil improved overall physico-chemical as well as biological properties of the soil which created favorable environment for nutrients availability and the plant growth. The result of the study corroborates with the findings of (Yadav and Chippa 2007, Yupeng *et al.* 2018).

With increasing levels of Zn up to 30 kg $ZnSO_4$ significantly increased plant height (3.40%), test weight (6.74%), total tillers per plant (23.52%), effective tillers per meter row length (32.37%), test weight (6.74%), grain yield (5.52%) and straw yield (8.04%) at harvest over control. The favourable influence of applied Zn on these characters may be attributed to its stimulatory effect on most of the physiological and metabolic process of plants. Application of zinc to the soil has favorable effect on the grain and straw yield of crop (Dogra *et al.* 2014), this might be due to role of Zn in biosynthesis of indole acetic acid (IAA) and especially due to its role in initiation of primodia for reproductive parts and partitioning of photosynthate towards them (Barua and Saikia 2018).

Fractions and availability of zinc: There was noticed a significant decrease in zinc fractions, *i.e.* total and DTPA-Zn, Zn_{wsex}, Zn_{Ads} and Zn_{OC} (except Zn_{Occ}) with increasing levels of RSC irrigation water (Table 2). The maximum Zn under different fractions was estimated in the form of residual Zn (Zn_{Res}) followed by Zn_{Ads}, Zn_{OC}, Zn_{Occ}, Zn_{wsex} and DTPA-Zn. Relatively low value of Zn fractions was obtained at higher level of RSC irrigation water as compared to lower level of RSC irrigation water perhaps, related to low organic carbon content and high soil *p*H. The correlation coefficient values again confirmed that DTPA-Zn content of soil negatively correlated with *p*Hs (r=-0.876**) and ESP (r=-0.861**) of soil. The application of FYM @ 15 t/ha had significant improvement in all the Zn fractions in soil except Zn_{Occ} (Table 2). The formation of metallo-organic complexes with ligands, mineralization and solubilization from the organic source could be a reason for increasing the concentration of different Zn fractions (Narwal *et al*. 2010, Mandal and Das 2013). The increasing levels of applied Zn did significant improvement in all the Zn fractions in soil except occluded Zn (Zn_{Occ}) fraction (Table 2). Application of 45 kg Zn/ha significantly increased the amount of zinc present in different Zn fractions except Zn_{Occ} fraction, it might be due to higher solubility and mobility of the added $ZnSO_4$. The higher value of Zn_{Ads} had possibly resulted from the dissolution of some precipitated Zn fractions of applied Zn.

The DTPA-Zn content in soil increased with increasing levels of Zn possibly due to higher solubility, diffusion and

Table 2 Effect of RSC irrigation water, FYM and zinc levels on different zinc fractions in soil after harvest of crop (mean of two years)

Treatment	Zn_{wsex} (mg/ kg)	Zn_{Ads} (mg/ kg)	Zn_{Occ} (mg/ kg	Zn_{OC} (mg/ kg)	Zn_{Res} (mg/ kg)	Total- Zn (mg/kg)	DTPA-Zn (mg/kg)
RSC levels							
W1 (2.5 mmol/L)	0.75	6.90	4.30	6.14	41.37	59.47	0.52
W2 (5 mmol/L	0.74	6.82	4.26	5.85	40.69	58.38	0.45
W3 (10 mmol/L)	0.66	6.37	4.24	4.57	38.30	54.16	0.38
SEm±	0.00	0.02	0.02	0.02	0.22	0.25	0.002
CD (P=0.05)	0.01	0.07	NS	0.05	0.65	0.71	0.006
FYM levels							
0	0.71	6.14	4.24	5.42	39.73	56.25	0.42
15	0.73	7.26	4.29	5.62	40.51	58.43	0.48
SEm±	0.00	0.02	0.01	0.01	0.18	0.20	0.002
CD (P=0.05)	0.00	0.06	NS	0.04	0.53	0.58	0.005
Zinc levels							
0	0.62	5.10	4.26	5.36	39.07	54.43	0.43
15	0.70	6.14	4.26	5.47	39.88	56.47	0.43
30	0.72	7.22	4.27	5.57	40.68	58.46	0.46
45	0.83	8.33	4.27	5.68	40.85	59.98	0.48
SEm±	0.00	0.02	0.02	0.02	0.28	0.29	0.002
CD(P=0.05)	0.01	0.07	NS	0.06	0.78	0.82	0.006

NS = Non significant at 5% level of significance, Zn_{wsex} = Water soluble + exchangeable zinc, Zn_{Ads} = Adsorbed zinc, Zn_{Occ} = Occluded zinc, Zn_{OC} = Organic carbon bound zinc and Zn_{Res} = Residual zinc mobility of the applied inorganic Zn fertilizer leading to increased available Zn status of soil.

The correlation values varied from 0.140–0.917** amongst different forms of Zn. The lowest values were found between Zn_{wsex} fraction and Zn_{Occ} fraction and highest ones was with Zn_{Res} fraction and Zn_{OC} fraction. Data interrelationship revealed that grain yield of barley showed positive significant correlations with DTPA-Zn (r =0.888**) and different fractions of soil zinc viz., Zn_{Ads} (r =0.525**), Zn_{Occ} (r =670**), Zn_{OC} (r =0.948**) and Zn_{Res} (r =0.923**). Moreover, zinc uptake was also correlated positive significantly with DTPA-Zn (r =0.884**) and different zinc fractions of soil, viz. Zn_{Ads} (r =0.665**), Zn_{Occ} (r =0.689**), Zn_{OC} (r =0.908**) and Zn_{Res} (r =0.933**).

To describe the relationship between yield of barley (Y) and applied zinc (as $ZnSO_4$) at different RSC irrigation water and FYM, multiple regression studies were made. Second degree polynomials describing the relationship was established by the least square as describe by Croxton *et al.* (1973). The regression analysis revealed very high closeness to the observed yields as evidenced by very high coefficient of determination R^2 (0.9784^{++}) in pooled values. The optimum level of zinc as zinc sulphate recording the predicted yield of 4299.3 kg/ha/ (2013-14), 4442.8 kg/ha (2014-15) and 4365.6 kg/ha (pooled) have been worked out to be 43.4 kg/ha (2013-14), 34.4 kg/ha (2014-15) and 37.5 kg/ ha (pooled). The optimum level of Zn was worked out at prevailing market price of $ZnSO_4$ @ 37.5 kg and barley grain @ ₹ 15/kg. The response at optimum level of P (P_{opt}) was higher only by 251.3 kg (2013–14), 238.8 kg (2014–15) and 240.06 kg (pooled) in comparison to the observed yields.

From the present study, it is evident that the farmers having high RSC irrigation water, should use FYM @ 15 t/ha and 30 kg $ZnSO_4$/ha in barley crop to reduce adverse effect of sodicity on barley growth and yield attributes. The optimum dose of zinc for barley under semi-arid climatic conditions was computed as 37.59 kg $ZnSO_4$/ha with corresponding optimum yield of 4365.61 kg/ha.

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