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Chemical assessment of the zinc status of some soils of the semi-arid region of India

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Abstract. To find critical tissue levels of Zn for wheat, and to evaluate various chemical extractants, a screen-house experiment was conducted on 21 diverse soils representing semi-arid regions in Haryana State, India. The extractants differed in the amounts of Zn extracted and the order was: 0.1 N HCl > EDTA-NH_4OAc > EDTA-$(NH_4)_2CO_3$ > DTPA + $CaCl_2$. The amounts ($mg\,kg^{-1}$) of extractable Zn associated with a yield reduction of 20% were: DTPA + $CaCl_2$, 0.60; EDTA – $(NH_4)_2CO_3$, 0.80; EDTA-NH_4OAc, 0.92 and 0.1 N HCl, 1.20. The corresponding critical Zn concentration in ten weeks old plants was found to be 17 $mg\,gm^{-1}$. The DTPA + $CaCl_2$ method gave the best correlation (r = 0.85) between extracted Zn and Bray's per cent yield. It is recommended for assessing Zn status of soils of semi-arid region.

Introduction

Several chemical extractants have been used to estimate the plant available Zn in soils. The suitability of the extractants depends upon the soils characteristics and therefore one extractant cannot be used for routine analysis of all soils. Some common extractants that have been used for Zn are: 0.1 N HCl [13]; EDTA-NH_4OAc [12]; and EDTA-$(NH_4)_2CO_3$ [11]. Several studies on Zn availability in alkaline soils have indicated the usefulness of DTPA + $CaCl_2$ extractant [1, 6, 8] for fixing critical levels of Zn for cereal crops due to its ability to extract an amount of the nutrient that correlates well with plant growth and its capability for extracting four micronutrient cations simultaneously. The critical limits of Zn as determined by different extractants varies from soil to soil and from crop to crop [1, 3, 5, 7]. The efficacy of a soil zinc test is usually measured in terms of its accuracy in predicting the responsiveness of a crop to applied zinc. Therefore, the present study was planned to investigate the critical levels of Zn in soil and plant, and to suggest a suitable extractant in semi-arid region soils for estimating available Zn to wheat.

Materials and methods

Samples of twenty one non-calcareous, surface soils (0–20 cm) were collected from different sites in Hisar, Bhiwani, Rohtak Gurgaon and Mohindergarh districts, representing soils of the semi-arid region of Haryana state (India). Some properties of these soils are given in Table 1. The pH (1:2) ranged from 7.9 to 9.3, EC from 0.21 to 1.14 mS cm^{-1}, organic carbon from 0.04 to 1.11% and the clay content from 1 to 28.

Zinc was extracted from the soil samples with: 0.005 M DTPA, 0.01 M $CaCl_2$, 0.1 M TEA (pH 7.3), 0.01 M EDTA, 1 M $(NH_4)_2CO_3$ (pH 8.6), 0.01 M EDTA, 1 M NH_4OAc (pH 7.0) and 0.1 N HCl [6, 11, 12, 13].

Zinc extracted by the different methods was determined by atomic absorption spectrophotometry.

The experiment was conducted with 4 kg soil in polythene-lined earthen pots. Wheat (*Triticum aestivum* L.) variety HD-1941 was grown as the test crop for ten weeks. Three levels of zinc, (0, 5 and 10 mg Zn kg^{-1}) were used along with a basal dose of N, P, K, Fe, Mn and Cu. The sources were the following reagent grade chemicals: urea, KH_2PO_4, KCl, $FeSO_4$, $MnSO_4$ and $CuSO_4$ and the levels were: 100, 50 and 50, 5, 5 and 1 mg kg^{-1}, respectively. All the nutrients were mixed thoroughly with the dry soil before sowing. Each treatment was replicated three times. The plant samples after harvest were washed with distilled water then with acidified deionized water and finally with deionized water. The oven-dried plant samples were ground in a Wiley mill having stainless steel blades.

Table 1. Amount of zinc extracted by various extractants and some properties of the soils.

Soil No.	Extracted Zn (mg kg^{-1})				Soil properties			
	DTPA-$CaCl_2$	EDTA-$(NH_4)_2CO_3$	EDTA-NH_4OAc	HCl	pH	EC (mS cm^{-1})	Org. C. (%)	Clay (%)
1	0.48	0.52	0.90	1.10	8.4	0.41	0.64	20
2	0.52	0.56	0.80	1.40	9.2	0.68	0.31	10
3	0.38	0.40	0.70	1.20	8.6	0.48	0.42	14
4	0.38	0.52	0.70	0.90	9.3	0.48	0.28	4
5	0.34	0.54	0.80	0.60	8.9	0.58	0.14	1
6	0.66	0.84	1.10	1.20	8.6	0.71	0.78	10
7	0.54	1.04	1.00	1.80	8.6	0.71	0.13	12
8	1.10	0.56	1.30	0.80	8.6	0.56	0.19	10
9	0.62	1.12	1.00	1.30	8.6	0.33	0.17	4
10	0.66	0.84	1.10	0.90	8.7	0.35	0.21	6
11	0.48	0.86	0.90	0.70	8.5	0.30	0.13	6
12	0.46	0.60	0.60	0.70	8.5	0.43	0.09	4
13	1.06	2.16	1.90	2.40	7.9	0.21	1.11	28
14	1.02	1.00	1.50	1.80	8.7	0.93	0.63	4
15	0.44	0.38	0.60	0.60	8.5	0.71	0.04	2
16	1.10	1.40	1.30	1.40	8.9	0.49	0.10	6
17	0.56	1.00	1.50	2.60	8.2	0.31	0.15	18
18	0.82	1.08	1.10	2.00	8.3	0.66	0.27	2
19	0.82	1.60	1.40	2.10	8.3	0.47	0.41	8
20	0.92	0.80	1.90	1.20	8.3	1.14	0.24	4
21	0.58	0.88	1.70	2.40	8.3	0.61	0.07	10
Mean	0.66	0.89	1.04	1.44	8.6	0.55	0.31	9

After wet digestion with HNO_3 and $HClO_4$ (4:1), the digests were analysed for Zn by a Varian Techtron AA-120 atomic absorption spectrophotometer. Bray's per cent yield [2] was used as an index of soil-Zn availability (Table 2) and was calculated as:

$$\frac{\text{Yield without Zn application}}{\text{Yield with optimum Zn level } (5\,\text{mg kg}^{-1})} \times 100.$$

Results and discussion

The Zn extracted by the different extractants ranged between 0.34 to 2.60 mg kg^{-1} (Table 1). The amounts extracted by various extractants were in the order: 0.1 N HCl > EDTA-NH_4OAc > EDTA-$(NH_4)_2CO_3$ > DTPA + $CaCl_2$.

Response to Zn application and soil critical values

Applying 5 mg kg^{-1} Zn to soils from different locations significantly enhanced the dry matter accumulation of wheat over no Zn treatment (Table 2). Further

Table 2. Effect of zinc application on dry matter yield of shoots (g pot^{-1}) of wheat in 21 soils.

Soil No.	Rates of Zn application (mg kg^{-1})			Bray's per cent yield at 5 ppm Zn
	0	5	10	
1	2.5	3.4	3.4	73.5
2	2.8	3.5	3.5	80.0
3	2.1	3.0	2.3	70.0
4	3.1	4.2	3.4	73.8
5	2.9	4.6	4.3	63.0
6	3.6	4.1	4.0	87.8
7	2.8	3.8	3.1	73.7
8	2.7	3.1	3.9	87.1
9	3.2	3.9	3.6	82.0
10	3.9	4.4	4.2	88.6
11	3.3	4.6	4.8	71.7
12	2.5	3.5	3.5	71.4
13	2.8	3.1	4.1	90.3
14	3.8	4.3	3.8	88.4
15	3.5	5.0	4.5	70.0
16	4.4	4.9	4.8	89.8
17	3.1	3.9	4.7	79.5
18	4.6	5.7	4.7	80.7
19	3.9	4.8	4.5	81.2
20	4.3	5.2	4.7	82.7
21	1.8	2.4	2.7	75.0

LSD ($P = 0.05$): Zinc level mean = 0.38; location mean = 0.66; Zinc × Location mean = 1.14.

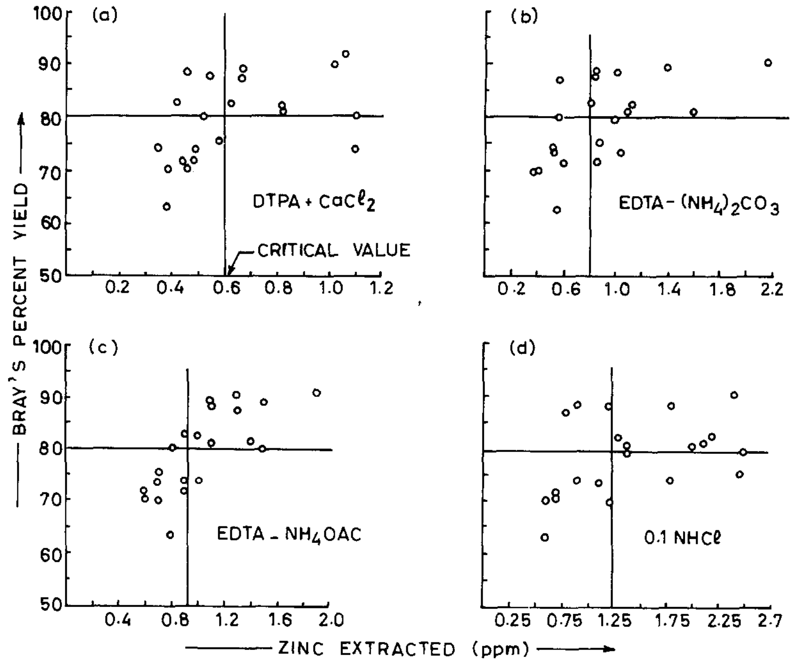

Fig. 1. Relationship between soil test levels and Bray's percent yields.

addition of 10 mg kg^{-1} Zn led to a slight decrease in dry matter production. This indicated that 5 mg kg^{-1} Zn was probably enough for proper growth of wheat. Response was variable between the soils but in majority of the soils, Zn application significantly and progressively increased the wheat yield indicating the necessity for Zn fertilization to maintain the soil Zn status at a sufficient level for better crop production. Bray's per cent yield at 5 mg kg^{-1} applied Zn (Table 2) ranged from 63 to 90. The Cate and Nelson [4] graphical method was followed for determining the critical value of Zn in soil and plant by plotting the Bray's per cent yield against soil extractable Zn and plant tissue Zn concentration respectively (Figs. 1 and 2). In this method two lines—one parallel to the

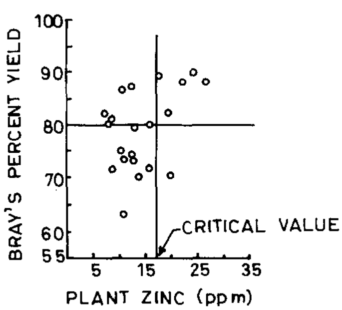

Fig. 2. Relationship between plant Zn concentration and Bray's percent yields.

X-axis and the other parallel to the Y-axis are drawn so that there are a minimum number of observations in the upper left hand and the lower right hand quadrants. The intersection of the line parallel to the Y-axis with the X-axis is the critical value.

Keeping in view some of the earlier work, we chose to use a yield response of 20% (Bray's per cent yield = 80) or more as the criterion of Zn deficiency in soils and plant.

About half of the soils with less than 0.60 mg kg^{-1} of DTPA + $CaCl_2$ extractable Zn responded to zinc application (Fig. 1a) which is in agreement with the value reported by Takkar et al. [10] and Gupta et al. [5] for wheat, Response to Zn occurred in 33% of the soils with less and in 19% of the soils with more than 0.80 mg kg^{-1} EDTA-$(NH_4)_2CO_3$ extractable Zn (Fig. 1b). About 43% of the soils containing less than 0.92 mg kg^{-1} of EDTA-NH_4OAc extractable Zn recorded responses to applied Zn. Only 9% of the soils with more than this level responded. Hydrochloric acid (0.1 N) extracted more Zn than the other extractants and a critical value of 1.20 mg Zn kg^{-1} separated the responsive ones from the non-responsive soils. Below this value, yield response to Zn treatment was noticed in 33% of the soils (Fig. 1d).

The lack of response in some soils low in extracted Zn and response in soils high in extracted Zn might be attributed to a combination of several factors like pH, organic matter, available P, clay content and nature of clay minerals. These factors may be influencing the plant availability of Zn in these soils. This needs further investigation. However, P/Zn in soils seems to have affected the availability of Zn as the values of P/Zn greater than 15 have been observed in soils with DTPA extractable Zn from 0.6–1.0 mg kg^{-1}. Takkar et al. [9] reported that P/Zn greater than 7.5 in the soil indicated a significant response to Zn application.

Critical Zn concentration in plant

The Zn concentration in ten weeks old plants below which the Zn responses were obtained was found to be 17 $\mu g\ gm^{-1}$ (Fig. 2). Zinc concentration in no added Zn treatment ranged from 7.5 to 26.7 mg kg^{-1}. About half of the soils with less than 17 $\mu g\ gm^{-1}$ Zn in plant responsed to Zn fertilization. The plant tissue Zn concentration was positively correlated with Bray's per cent yield (r = 0.39). However, the low 'r' value was obtained because the range in data was small and it further suggested that Zn concentration accounted for only a small percentage of the variation in response of dry matter formation to Zn supply to the soil.

Correlation of soil test with crop yield

Linear correlations between extractable Zn and Bray's per cent yield were calculated (Table 3). The DTPA + $CaCl_2$ method gave the best correlation to

Table 3. Average, range and critical values of Zn ($mg\,kg^{-1}$) extracted by four extractants and correlations with Bray's per cent yield.

Extractant	Average	Range	Critical value	r with Bray's per cent yield
DTPA + $CaCl_2$	0.66	0.34–1.10	0.60	0.85**
EDTA – $(NH_4)_2CO_3$	0.89	0.38–2.16	0.80	0.69**
EDTA – NH_4OAc	1.04	0.60–1.90	0.92	0.59**
0.1 N HCl	1.44	0.60–2.60	1.20	0.29NS

**Significant at the 1% level.
NS = Not significant at the 5% level.

yield ($r = 0.85$**). Similar observations were made by Brown et al. [3], Takkar et al. [10] and Gupta et al. [5].

The DTPA + $CaCl_2$ test has been favoured as an index of Zn availability at several research centres [3, 6, 7, 8] with an advantage of being a multi-elemental extractant but in the present investigation, EDTA-NH_4OAc and EDTA-$(NH_4)_2CO_3$ have also proved effective when correlated with Bray's per cent yield. However, fewer correlative data are available for the EDTA-NH_4OAc procedure and, for the EDTA-$(NH_4)_2CO_3$ extractant, the high concentration of $(NH_4)_2CO_3$ in solution creates problem in analysis by atomic absorption spectrophotometer. However, an acid treatment before analysis will overcome this problem.

No significant correlations were obtained between DTPA + $CaCl_2$ extractable Zn and various soil properties.

The study describes an attempt to characterise plant availability of Zn by chemical soil extraction methods comparing different soil extractants. Differences were found between methods in predicting growth response to Zn application to different soils.

Thus our study comes to the conclusion that DTPA + $CaCl_2$ is a suitable chemical extractant with $0.60\,mg\,kg^{-1}$ as the critical value for assessing soils deficient in Zn and for predicting response of wheat to Zn fertilization.

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