

Phytoavailability of Zinc and Cadmium as Affected by Salinity and Zinc in Wheat (*Triticum aestivum* L.) Grown on Cadmium Polluted Soil

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Abstract: Deficiency of zinc in the soil and the salinity are two factors that may change the phytoavailability of zinc and cadmium. The purpose of this study was to evaluate the effect of salinity and zinc fertilization on soil cadmium and zinc solubility and their concentration in wheat shoot. Green house experiment with wheat (*Triticum aestivum* L. Cv. WH-147) consisting four levels of saline irrigation water (0, 60, 120 and 180 mM NaCl) and three zinc levels (0, 15 and 25 mg Zn Kg⁻¹ soil in the form of ZnSO₄) in triplicate was conducted. Higher salinity increased cadmium concentration in soil solution while decreased Zn concentration in both soil solution and wheat shoot. With the application of zinc fertilizer, cadmium concentration in wheat shoot was decreased whereas zinc concentration was increased. Every enhanced level of saline irrigation water decreased plant dry matter, especially when no zinc was applied. Application of zinc had positive effects on the salt tolerance of plant so increased dry matter yield. After harvesting, electrical conductivity, pH and the concentration of anions and cations were also determined in the soil saturation extracts.

Key words: Salinity % Zinc % cadmium % phytoavailability and wheat

INTRODUCTION

Although adverse effects of salt accumulation in soil and crops have been investigated, but relatively little or no attention has been paid to the influence of either soil salinity or irrigation water salinity on heavy metal uptake [1]. Cd can operate a stress factors in the plants environment. Besides adversely influencing plant growth, the toxic effect of Cd gets amplified along the food chain at each stage of food web.

Soil is the principal source of cadmium accumulated by plants. Many characteristics such as concentration and form of metals in the soil, pH of the soil, organic matter content, clay content, Zn concentration, other cations and fertilization practices have been recognized as a major factor that determines the bioavailability of Cd in the soil [2,3]. In addition there is evidence of enhanced Cd uptake by many crops due to elevated salinity or chloride concentrations [4-8]. These studies suggest that enhanced Cd uptake due to high salinity or chloride concentration may be expected for many crops.

Heavy use of P fertilizers in salt affected soils of Allahabad region of Uttarpradesh, India from last 35 years have increased Cd concentration in soils of this region. The Cd that has been applied with P fertilizers is highly plant available and adversely affects food quality. Agricultural sustainability of such production system depends to a large extent upon the maintenance or enhancement of soil quality that is rapidly deteriorating due to Cd accumulation in them.

Low Zn availability is common in alkaline soils of the world. Although large amount of Zn have been removed from the soils via crop removal, limited attention has been paid to fertilizing with Zn [9]. Soils of Uttarpradesh are frequently deficient in Zn because of their alkaline nature. Salinity may reduce Zn uptake due to stronger competition by salt cations at the root surface [10]. In addition salinity may enhance Cd uptake and thus decrease Zn accumulation due to well known antagonistic relationship that exist between Zn and Cd [11].

Crop species differ widely in their ability to absorb, accumulate and tolerate Cd [12]. Natural variation occurs in the uptake and distribution of Cd and Zn in crop

species. Sensitive crops, which have high potential for transfer of Cd into the food chain, should be grown on soils which contain low level of phytoavailable Cd [13]. However, selecting plant species with great ability for the Cd uptake in their non edible tissues may be an important approach to reduce Cd concentration.

The main aim of this study was to investigate the influence of salinity on the solubility of Cd and Zn in soil and their uptake by wheat.

MATERIALS AND METHODS

Cd polluted surface soil (0-25 cm) was collected from commercial field of Allahabad Agricultural Institute-Deemed University, Allahabad, India. The experimental soil was analyzed for important properties by using standard methods. The soil was sandy clay loam in texture. Cd accumulation in this area is mainly attributed to many years high application of P fertilizers. Selected properties of soil are shown in Table 1.

Soil pH and EC were estimated in the 1:2 (soil: water) suspension by using digital pH meter and conductivity meter. The CaCO_3 equivalent was determined by neutralizing with HCl and back titration with NaOH [14]. Percentage of sand, silt and clay were measured by using Hydrometer method [15]. Available nitrogen was determined by alkaline permanganate method [16] whereas available phosphorus was extracted from the soil with 0.5M NaHCO_3 [17] and available potassium was extracted with ammonium acetate and determined on flame photometer [15]. DTPA-extractable Zn and Cd was determined by resorting method of Lindsay and Norvell [1]. One hundred mg of air dried soil sub sample were digested in a mixture of HNO_3 - HClO_4 -HF on a hot plate until the digest turned into a light yellowish sticky mass. A 10% HNO_3 solution was added to the digest until a volume of 10ml was obtained for analysis of total Cd and Zn [14] and then was determined by using atomic absorption spectrophotometer.

A bulk soil sample (about 400 kg's) was dried, thoroughly mixed and sieved to remove particles >5mm. Homogenized soil weighing 3 kg's was put into polythene pots (35cm height and 20 cm diameter). A greenhouse experiment with three levels of Zn (0, 15 and 25mg kg^{-1} dry soil, in the form of ZnSO_4) and four salinity levels of 0, 60, 120 and 180 mM NaCl. At planting time uniform dose of N and K fertilizers at the rate of 100mg kg^{-1} N and K each as $(\text{NH}_4)_2\text{SO}_4$ and K_2SO_4 were applied. Wheat seeds were sown, thinned to five plants per pot after 16 days and grown for 55 days. For the first 5 days after sowing,

Table 1: Selected properties of soil used in the experiment

Characteristics	Amount
pH (1:2)	7.75
EC dSmG ⁻¹ (1:2)	1.40
CaCO_3 equivalent %	23.00
Sand %	58.00
Silt %	14.00
Clay %	28.00
Available N mg KgG ⁻¹ soil	126.00
Available P mg KgG ⁻¹ soil	17.00
Available K mg KgG ⁻¹ soil	170.00
DTPA-TEA extractable Zn mg KgG ⁻¹ soil	0.57
DTPA-TEA extractable Cd mg KgG ⁻¹ soil	1.04
Total Zn mg KgG ⁻¹ soil	20.12
Total Cd mg KgG ⁻¹ soil	2.83

soil moisture was maintained near field capacity using deionized water. Thereafter the pots were maintained near water holding capacity with frequent saline watering to weight. At harvest shoots were cut and concentration of Zn and Cd were determined.

After harvesting, samples of 800g soil was collected from each pot, air dried, sieved by 2mm diameter sieve. Each soil sample saturated with deionized water, mixed to paste of uniform consistency and after standing overnight was transferred to a suction flask for extraction of soil solution [18]. Soil pH, EC and concentration of Ca, Mg, Na, K, SO_4 , HCO_3 as well as the trace metal Cd and Zn were measured using methods described earlier.

The experiment was set up in a completely randomized design with factorially arranged treatments and three replications.

RESULTS AND DISCUSSION

Every enhanced level of saline irrigation water with both Zn and without Zn addition was associated with significant increase in Cd concentration in shoots. Smolders *et al.*, [3] explained the fact that Cd-chloride complexes in soil solution are also available for plant uptake, so increased Cd concentration in wheat shoot. Cd concentration in shoots was lower in those treatments which were treated with Zn than those which were without Zn. Increase in Cd concentration in shoots is due to well known effects of salt on solubility of Cd in soil.

In contrast every increased level of saline irrigation water decreased Zn concentration in wheat probably due to increase in available Cd in the soil. A negative relationship between Cd and Zn in the soil and plant has been reported previously [11,19]. The change in Cd

Table 2: Effect of salinity and Zn fertilization on concentration of metals in wheat shoot and on shoot dry weight

	Zn mg kg ⁻¹				Zn mg kg ⁻¹							
	Zn ₀	Zn ₁₅	Zn ₂₅	Mean	Zn ₀	Zn ₁₅	Zn ₂₅	Mean	Zn ₀	Zn ₁₅	Zn ₂₅	Mean
Salt rates (mM)	Zn content in shoot mg kg ⁻¹				Cd content in shoot mg kg ⁻¹				Shoot weight g plant ⁻¹			
NaCl ₀	24.60	51.20	62.60	46.13	0.97	0.58	0.36	0.63	7.50	10.50	12.30	10.10
NaCl ₆₀	22.30	45.50	55.30	41.03	1.38	1.09	0.92	1.13	6.20	8.40	9.80	8.13
NaCl ₁₂₀	19.70	36.20	39.80	31.90	2.06	1.76	1.62	1.81	5.40	6.70	7.40	6.50
NaCl ₁₈₀	16.50	32.30	34.50	27.77	2.99	2.40	2.18	2.52	4.70	5.50	5.90	5.37
Mean	20.78	41.30	48.05		1.85	1.46	0.85		5.95	7.78	8.85	
	S.E.	C.D.(p=0.05)		F.test	S.E.	C.D.(p=0.05)		F.test	S.E.	C.D.(p=0.05)		F.test
NaCl	0.341	0.702		S	0.218	0.450		S	0.308	0.634		S
Zn	0.297	0.613		S	0.191	0.393		S	0.296	0.553		S

Table 3: Effect of salinity and Zn fertilization on pH, concentration of soluble cations and anions and total Cd and Zn concentration in saturated paste soil solution at crop harvest

Zn mg kg ^l					Zn mg kg ^l			
	Zn ₀	Zn ₁₅	Zn ₂₅	Mean	Zn ₀	Zn ₁₅	Zn ₂₅	Mean
Salt rates (mM)	pHs				Cl ⁻ (mMLG ^l)			
NaCl ₀	7.11	7.18	7.16	7.15	13.00	17.00	20.00	16.67
NaCl ₆₀	7.15	7.11	7.19	7.15	25.00	27.00	31.00	27.67
NaCl ₁₂₀	7.14	7.10	7.09	7.11	41.00	42.00	39.00	40.67
NaCl ₁₈₀	7.19	7.20	7.16	7.18	57.00	56.00	52.00	55.00
Mean	7.15	7.15	7.15		34.00	35.50	35.50	
	S.E.	C.D.(p=0.05)		F.test	S.E.	C.D.(p=0.05)		F.test
NaCl	0.238	0.489		NS	0.387	0.797		S
Zn	0.207	0.427		NS	0.338	0.696		NS
	SO ₄ ²⁻				HCO ₃ ⁻			
NaCl ₀	15.00	16.00	16.00	15.67	1.40	1.30	1.30	1.33
NaCl ₆₀	17.00	19.00	19.00	18.33	1.60	1.40	1.30	1.43
NaCl ₁₂₀	18.00	20.00	21.00	19.67	1.70	1.70	1.50	1.63
NaCl ₁₈₀	20.00	23.00	24.00	22.33	2.00	1.90	1.70	1.87
Mean	17.50	19.50	20.00		1.67	1.57	1.45	
	S.E.	C.D.(p=0.05)		F.test	S.E.	C.D.(p=0.05)		F.test
NaCl	0.752	1.549		NS	0.339	0.699		NS
Zn	0.656	1.352		NS	0.296	0.610		NS
	Ca ²⁺				Mg ²⁺			
NaCl ₀	25.00	25.00	24.00	24.67	4.30	4.60	4.60	4.50
NaCl ₆₀	25.00	23.00	24.00	24.00	4.60	4.70	4.80	4.70
NaCl ₁₂₀	26.00	24.00	23.00	24.33	4.80	5.00	5.10	4.97
NaCl ₁₈₀	24.00	24.00	24.00	24.00	5.10	5.20	5.30	5.20
Mean	25.00	24.00	23.75		4.70	4.87	4.95	
	S.E.	C.D.(p=0.05)		F.test	S.E.	C.D.(p=0.05)		F.test
NaCl	0.266	0.548		NS	0.166	0.342		NS
Zn	0.232	0.479		NS	0.144	0.298		NS
	Na ⁺				K ⁺			
NaCl ₀	9.00	10.00	11.00	10.00	0.50	0.70	0.80	0.67
NaCl ₆₀	17.00	19.00	20.00	18.67	0.60	0.60	0.70	0.63
NaCl ₁₂₀	29.00	28.00	27.00	28.00	0.80	0.80	0.90	0.83
NaCl ₁₈₀	41.00	40.00	36.00	39.00	1.00	1.00	1.10	1.03
Mean	24.00	24.25	23.50		0.72	0.77	0.87	
	S.E.	C.D.(p=0.05)		F.test	S.E.	C.D.(p=0.05)		F.test
NaCl	0.283	0.582		S	0.153	0.315		NS
Zn	0.247	0.508		NS	0.134	0.275		NS

Table 3: Continued

	Total Cd (mgLG ¹)				Total Zn (mgLG ¹)			
NaCl ₀	0.01	0.01	0.01	0.01	0.13	0.15	0.17	0.15
NaCl ₆₀	0.13	0.10	0.11	0.11	0.12	0.13	0.15	0.13
NaCl ₁₂₀	0.23	0.23	0.24	0.23	0.12	0.15	0.15	0.14
NaCl ₁₈₀	0.43	0.42	0.41	0.42	0.11	0.15	0.16	0.14
Mean	0.20	0.19	0.19		0.12	0.14	0.16	
	S.E.	C.D.(p=0.05)		F.test	S.E.	C.D.(p=0.05)		F.test
NaCl	0.047	0.097		S	0.147	0.302		NS
Zn	0.041	0.085		NS	0.128	0.264		NS

concentration that resulted from Zn treatment appeared to be related in part to increase in shoot dry matter (dilution effect); and suggests that Zn fertilization may lower Cd concentration in crops in part by ameliorating salinity stress. Application of Zn decreased Cd accumulation and increased Zn accumulation in wheat in all of the salinity treatments (Table 2).

Saline irrigation water significantly decreased the growth and shoot dry matter yield of wheat. Decline in plant growth is proportional to the water salinity levels. Application of Zn counteracted adverse effect of saline irrigation water on plant growth. Zn is required for maintaining integrity of biomembrane [20]. Under Zn deficient conditions there is a typical increase in plasma membrane permeability of root cells so plant growth and yield of shoot dry matter may decrease [20].

Salinity of irrigation water and Zn application showed non significant effect on soil pH. Concentration of Ca²⁺, Mg²⁺, K⁺, SO₄²⁻ and HCO₃⁻ in saturated extracts were mostly unchanged by saline irrigation water and Zn application while Na⁺ and Cl⁻ concentration increased more or less proportionally to the applied NaCl levels. Cd concentration in soil solution was significantly increased with every enhanced level of NaCl concentration for both where Zn was applied and for those treatments where Zn was not applied. Effect of NaCl salinization, on other hand, was significant and proportional to the NaCl rates for both with and without Zn treatments. The effect of NaCl on Cd solubility may be attributed to the formation of Cd-chloride complexes. Similar findings were earlier reported by Smolders *et al.*[3]. Zn concentration was found independent of added NaCl levels but the treatments with Zn had little or no effect on total dissolved Zn (Table 3).

CONCLUSION

NaCl salinity mobilized Cd and increased its phytoavailability. Enhanced Cd concentration in wheat shoot appeared to be largely as a result of use of saline irrigation water and high Cd content of P fertilizers used

from very long duration. Application of Zn had a positive effect on plant growth regardless of the degree of irrigation water salinity. Zn application further more increased Zn and decreased Cd concentration in plant shoot.

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