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Yield and uptake of Cadmium, Lead and Zinc by wheat grown in a soil polluted with heavy metals

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A pot culture experiment was conducted with wheat (*Triticum aestivum* L. var. WL 711) grown in a loamy sand (Ustipsamment) soil to which cadmium, lead and zinc were applied at the rate of 0, 10, 20, 40 and 80 mg kg^{-1} soil. Effect of increasing levels of these was studied in respect of yield of grain and straw. Also levels of their incorporation into these structures were ascertained. Application of lower doses of Zn significantly increased the yield of wheat while increasing levels of Cd drastically reduced it. The application of Pb, even at higher doses, excercised little influence on yield. While Cd and Pb content of wheat straw was much higher than that of wheat grain, opposite was true in case of Zn.

KEY WORDS : Cadmium; Lead; Zinc; Wheat; soil pollution.

INTRODUCTION

Due to rapid industrialization and urbanization, disposal of solid and liquid wastes on agricultural lands in the outskirts of cities has increased tremendously in the recent past. One of the serious problems arising from this mode of waste disposal is the absorption of some toxic heavy metals by crop plants which ultimately leads to the entry of these pollutants into the food chain. Cadmium has been recognized as one of the most toxic heavy metals in this regard. Due to their geochemical kinship, environmental presence of Cd is normally linked to that of Zn. For example, a high correlation has been found between per capita consumption of Zn in 14 different countries and death due to hypertension (Barrett and Franke, 1970), an illness oftenly associated with Cd (Schroeder, 1965). However, Zn has been found to compete with Cd for uptake by plants (Haghiri, 1974). No doubt, Zn is an essential plant nutrient, yet its application to the soil beyond a certain level may also prove toxic to the growing plants. Lead has been considered relatively less toxic than Cd, but its toxicity level in a particular soil-plant system is not clearly understood. For example, low cation exchange capacity and little organic matter in a soil are conducive to higher absorption of Pb by plants (Miller *et al.* 1975a; Liebhardt and Koske, 1974).

In the present investigation, attempt has been made to study the influence of increasing levels of Cd, Pb and Zn on both the yield and uptake of these heavy metals by wheat crop. Partitioning of the absorbed metals between edible and non-edible plant parts has also been studied so as to have an idea of the proportion of the soil applied heavy metals entering into the food chain.

MATERIALS AND METHODS

A surface (0-15 cm) sample of an ustipsamment loamy sand soil was collected from the Punjab Agricultural University farm at Ludhiana. Before filling in 5-kg capcity polyethylene lined pots, it was air-dried and ground to pass through a 2 mm sieve. The experimental soil tested pH 8.4, electrical conductance 0. 0 dSm^{-1} (1 : 2 soil/water suspension), calcium carbonate 0.40%, organic carbon 0.45%, 1N HCl-extractable Zn 0.5 mg kg^{-1}, Cd 0.09 mg kg^{-1} and Pb 0.08 mg kg^{-1}. A basal dose of 120 mg N kg^{-1} as urea, 12 mg P kg^{-1} as KH_2PO_4 and 25 mg K kg^{-1} as KCl and KH_2PO_4 was applied to all the pots. The 13 treatments included four levels (10, 20, 40 and 80 mg kg^{-1}) each of Cd, Pb and Zn and a control. Each treatment was replicated thrice. Wheat (*Triticum aestivum* L. var. WL 711) was raised to maturity in all the pots. Deionized distilled water was used for irrigating the pots.

At maturity, grain and straw yields were recorded. Plant samples were successively washed with 0.1 N HCl, distilled water and deionized water, dried at 60°C and ground in a Wiley Mill. Dried samples were digested in triple acid mixture (HNO_3 : $HClO_4$: H_2SO_4 :: 9 : 3 : 1). Cadmium, Pb and Zn were estimated in the digests on an atomic absorption spectrophotometer.

RESULTS AND DISCUSSION

Cadmium

Phytotoxicity due to Cd was apparent from a continuous decrease of both grain and straw yield of wheat upto 80 mg Cd kg^{-1} soil (Fig. 1). Compared to no-Cd control, the extent

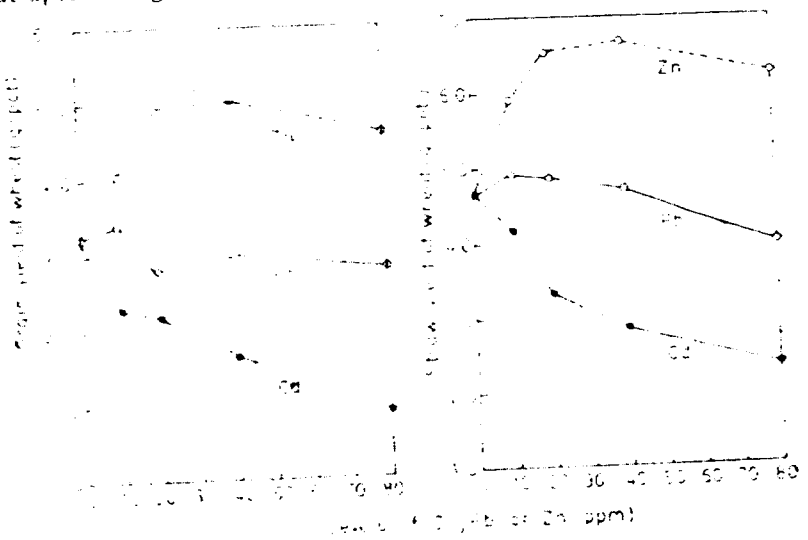

Fig. 1. Effect of Cd, Pb and Zn on grain and straw yield of wheat.

of reduction in the grain yield of wheat at the highest level of Cd application was 72%. Similar adverse effects of Cd on the yield of wheat have been reported by Page *et al.* (1972) and Mahler *et al.* (1978). Cadmium, even at relatively low concentration, results in respiratory, photosynthetic (Lee *et al.*, 1976) and structural disorders (Lamoreavy and Chaney, 1977) which ultimately lead to reducted crop yields. The basic cause of Cd toxicity in plants probably lies in much higher affinity of Cd for thiol groupings (—SH) in enzymes and other proteins.

As compared to 72% in the present investigation, Juwarkar and Shende (1986) have reported only a 32% reduction in the grain yield of wheat at a level as high as 400 mg Cd kg^{-1} soil applied through Cd-enriched sewage sludge. It seems that Cd when applied through a watersoluble salt is more toxic and retards plant growth at relatively lower levels. Work of Dijkshoorn and Lamp (1975) has clearly shown that uptake of Cd from sewage sludge is considerably lower than that from an equal level of Cd-salt added to the soil.

Compared with no-Cd control, a more than 10-fold increase in the uptake of Cd by wheat was recorded by applying 10 mg Cd kg^{-1} soil (Table 1). It suggests that applied Cd is readily absorbed by wheat and is easily translocated from roots to above ground plant parts. Schroeder and Balassa (1961) and Lagerwerff (1971) also found it true in case of radish and some other food crops including wheat. Raising the soil Cd level to 20 mg kg^{-1} did not increase the Cd uptake by wheat to an extent similar to that observed with initial 10 mg Cd kg^{-}soil. Infact, by applying 40 mg Cd kg^{-1} soil, no further increase in Cd intake was observed over that recorded at 20 mg kg^{-1} soil. This kind of Cd-uptake

Table 1. Effect of heavy metals on Cd, Pb and Zn uptake by wheat crop.

Heavy metal	Level (mg kg^{-1})	Uptake (μg per pod)			Percentage in grain		
		Cd	Pb	Zn	Cd	Pb	Zn
Cd	10	64	4.5	100	27	22	43
	20	88	3.9	85	25	20	46
	40	88	2.7	67	19	20	40
	80	74	1.7	39	19	18	37
Pb	10	5.0	3.7	137	29	22	49
	20	3.2	12.4	119	24	19	44
	40	3.0	17.5	108	26	16	48
	80	2.4	14.6	94	27	18	51
Zn	10	5.4	9.6	298	29	23	47
	20	5.4	7.3	420	28	26	52
	40	5.8	7.6	705	24	24	48
	80	4.9	6.6	777	23	21	45
Control		5.0	4.0	123	29	24	48
CD(P−0.05)		15.0	1.0	25	—	—	—

pattern is a consequence of both reduction in yield due to Cd toxicity and increased uptake of Cd at higher application levels. A drastic reduction in yield was compensated by higher Cd absorption so that only at 80 mg Cd kg^{-1} soil, a slight reduction in total Cd uptake by wheat could be observed.

Content of Cd in both grain and straw of wheat increased significantly by applying Cd to the soil (Table 2). Inspite of the fact that total Cd uptake decreased by applying 40 mg or more Cd kg^{-1} soil (Table 1), a continuous rise in the Cd content of wheat grain and straw was a direct consequence of the reduction in yield due to Cd-poisoning. At all levels of application, Cd content in straw was 2 to 2.6 times higher than in grains. Juwarkar and Shende (1986) also observed this ratio to be 2.3 to 3.1 in their studies with wheat. Partitioning of the total amount of Cd absorbed in the above ground protein of the wheat into grain and straw (Table 1) shows that only 19 to 29% of the total Cd was in the grains. At low Cd levels in the plants, a relatively higher percentage of Cd could be recovered in the grains. As higher amounts of Cd were applied to the soil, percentage of total amount of Cd absorbed increased in wheat straw. These data suggest that translocation of Cd from straw to grains was adversely affected due to Cd-poisoning in the wheat plants.

As a result of Cd application to the soil, uptake of Pb and Zn by wheat plants registered a significant decrease (Table 1). Although, as discussed earlier, both grain and straw yield of wheat were also adversely influenced by Cd, yet decreas in the content of both Pb and Zn (Table 2) was observed. These data indicate a negative interaction of Cd

Table 2. Effect of heavy metals on Cd, Pb and Zn content of wheat straw and grain.

Heavy Metal	Level (mg kg^{-1})	Content (mg kg^{-1}) Cd Grain	Cd Straw	Pb Grain	Pb Straw	Zn Grain	Zn Straw
Cd	10	5.4	12.2	0.54	0.78	18.7	13.5
	20	8.2	21.0	0.48	0.86	18.3	13.7
	40	10.2	24.9	0.34	0.76	16.9	14.0
	80	13.8	26.2	0.39	0.59	15.6	10.4
Pb	10	0.45	0.72	0.57	1.38	20.2	14.0
	20	0.28	0.50	0.86	2.06	18.4	13.8
	40	0.27	0.48	0.98	3.18	17.3	12.3
	80	0.22	0.44	0.96	2.97	17.0	11.5
Zn	10	0.40	0.65	0.40	0.90	34.4	27.0
	20	0.30	0.60	0.38	0.83	44.2	31.1
	40	0.28	0.66	0.38	0.86	66.9	55.2
	80	0.25	0.60	0.38	0.78	76.1	69.1
Control		0.45	0.77	0.32	0.65	18.5	13.8
CD (P=0.05)		1.21	1.04	0.22	0.41	8.0	7.5

with both Pb and Zn in the absorption of latter by wheat plants. While working with radish plants, Khan and Frankland (1983) could attribute the phytotoxicity of Cd to the reduction of Zn in the plant tissues to below critical level of deficiency. Somewhat similar observations for wheat were recorded by Koshino (1973).

Lead

As shown in Fig. 1, application of Pb up to a level of 80 mg kg^{-1} soil did not significantly reduce the grain yield of wheat. However, a reduction in the straw yield of wheat could be observed at 80 mg kg^{-1} soil. This is in accord with Miller and Koeppe (1971) who observed that with soil-grown plants high concentrations of Pb in the soil were necessary before sufficient accumulation occurred to cause an observable toxic response. In their study, Pb acetate at over 1000 mg kg^{-1} soil did not affect height or morphology of maize grown in a silt loam soil, while in sand culture, levels as 240 mg kg^{-1} soil severely retarded the growth of maize. The difference was probably due to the capacity of soil to adsorb Pb and/or the formation of relatively insoluble salts (Hassett, 1974; Miller *et al.* 1975 a. b). Since the soil under investigation was loamy sand in texture, adverse effects due to increasing Pb concentration in the soil started becoming visible in the wheat straw only at 80 mg kg^{-1} soil. Toxicity of Pb is due to its affect on mitochondrial membrane permeability (Bittel *et al.* 1974).

Although uptake of Pb by wheat plants increased significantly by applying 10 mg or more Pb kg^{-1} soil, yet the extent of increase was several fold less than that observed for Cd (Table 1). By applying 40 mg Pb kg^{-1} soil, only 4-fold increase in Pb intake by wheat plants could be recorded. By supplying a similar amount of Cd, rise in Cd uptake was more than 15-fold. These data suggest that either Pb is not readily absorbed by roots or it has a restricted translocation from roots to shoots and grains. Although as stated earlier, substantial evidence exists that Pb is strongly bound to the soil and its availability to plants is low, yet Lagerwerff *et al.* (1973) could also observe restricted translocation of Pb within the plants. As shown in Table 1, amongest the three heavy metals included in the present investigation, percentage of total amount of metal absorbed by the plants translocated to the wheat grains was the least in the case of Pb. A significant reduction in the uptake of Pb at the highest level of application (80 mg^{-1}) is a consequence of the adverse effect of Pb on the straw yield of wheat.

Content of Pb in both straw and grain increased by applying Pb to the soil upto a level of 40 mg kg^{-1} (Table 2). When 80 mg Pb kg^{-1} soil was applied, while there was no further increase in Pb content of grains, slight reduction in Pb content of straw was observed. These observations are in line with Lagerwerff *et al.* (1973) who could conclude that there was lack of clearer relationship between Pb uptake and its content in soil. As shown in Table 2, by applying increasing amounts of Pb to soil, a reduction, though much less in extent when compared with application of Cd, in the uptake of Zn and Cd was

observed. In fact, it does not seem that adverse effects of Pb pollution were in any way linked with reduced intake of Zn by wheat.

Zinc

Zinc being physiologically essential element for plants, and the soil under test being deficient in Zn, a substantial response of wheat Zn was observed upto 20 mg kg^{-1} soil. Increasing the application rate from 20 to 40 mg kg^{-1} soil did not influence the dry matter production of wheat. However, at 80 mg Zn kg^{-1} soil, a slight decrease in wheat grain and straw yield was observed. Takkar and Mann (1978) have reported a reduction in the yield of wheat when DTPA-extractable Zn in the soil exceeded 7 mg kg^{-1} soil.

Zinc uptake by wheat continued to increase upto 80 mg Zn kg^{-1} soil (Table 1). Although wheat yield did not increase beyond 20 mg Zn kg^{-1} soil (Fig. 1), yet a substantial rise in Zn uptake indicated that wheat could indiscriminately absorb Zn when it available in the soil. In the study of Takkar and Mann (1978) also, while wheat yield started declining at soil DTPA level of 7 mg kg^{-1}, Zn uptake continued to rise even beyond 80 mg Zn kg^{-1} soil.

Zinc content of wheat grain as well as in the straw significantly increased by applying Zn upto 80 mg kg^{-1} soil (Table 2). Contents of Zn in straw and grain were comparable so that total amount of Zn absorbed by wheat was distributed almost equally between grain and straw (Table 1). Compared with Cd and Pb, higher percentage of Zn in grains is desirable because intake requirements of humans and stock are both such that a fully vegetarian grain based diet is close to the minimum acceptable level for Zn (Tinker, 1986).

Unlike pollutant heavy metals Cd and Pb, application of increasing levels of Zn did not suppress the uptake of other metals by wheat (Table 1). Perhaps, due to higher dry matter production, uptake of Cd and Pb by wheat was more than even in control treatment and it was almost similar at all the levels of Zn. However, when content of Cd and Pb in different plant parts was considered, a Zn × Cd interaction could be observed in wheat grains (Table 2). Lead content of wheat grain and straw was slightly enhanced over the control at all the levels of Zn. These data bring out that Cd which is generally present as a impurity in Zn fertilizers, will not be preferentially translocated into edible parts of wheat in the presence of Zn.

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