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Influence of cadmium on dry matter yield, micronutrient content and its uptake in some crops

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Abstract

The study was conducted to evaluate the accumulation pattern of cadmium (Cd) and its tolerance in different crops grown on sewage irrigated soils with differentCd levels. Growth, yield, uptake and tolerance of maize, raya, berseem and spinach were assessed to different levels of Cd ranging from 0-40 mg kg^{-1} soil. Significant reduction in dry matter yield in raya was observed at 20 mg Cd kg^{-1} soil where as for other crops it was 10 mg Cd kg^{-1} soil. The quadratic models seem to give the best description of variation in dry matter yield with Cd levels as revealed by significant coefficient of determination ($R^2 \geq 90$). Cadmium content and uptake varied in the following order : raya > spinach> maize> berseem. Raya could tolerate high levels of Cd as compared to other crops. Conversely, berseem and maize which showed reduced ability to absorb or translocate Cd for genetic reasons compared to raya and spinach be preferred for growing on sewage irrigated soils or area having increased Cd-levels. The relationship of Cd with other micronutrients was variable.

Key words

Berseem, Cadmium, Maize, Raya, Spinach, Uptake

Introduction

Disposal of untreated industrial/municipal waste water results in a serious problem of metal loading in the soil environment. This important aspect of pollution has emerged as a potent weapon causing health hazards. Contamination of agricultural land with heavy metals has implications to the marketability of crops in highly competitive international market. Among heavy metals, cadmium has received considerable attention due to its easy absorption by plants and serious health risks to animals and human beings by entering into food chain. Anthropogenic sources, including smelter emissions and application of fertilizers and sewage sludge to land, may lead to contamination of both soils and crops with Cd (Lagriffoul *et al*., 1998). The presence of excessive amount of Cd in soil causes many toxic symptoms in plants, such as reduction of growth, inhibition of chlorophyll synthesis and photosynthesis and other morpho-physiological characteristics in various crops (Jhanji *et al*., 2012).

Vegetables are an important part of human diet but are generally grown on soils receiving sewage irrigation. These soils have been reported to contain high amount of heavy metals compared to normal soils (Khurana *et al*., 2003). Therefore, there is a need to minimize uptake of heavy metals by plants. One such approach of discouraging plant uptake is by applying range of inorganic and organic materials like lime, phosphate, organic manures, and zeolites (Datta *et al*., 2007; Ghafoor *et al*., 2008). But influence of such practice may create imbalance by interfering with the absorption of essential micronutrients like Cu, Zn, Mn and Fe. An alternative approach is to identify crops which have reduced ability to absorb or translocate such metals for genetic reasons. Khurana *et al*. (2006) reported that several varieties of maize differed in their susceptibility to Cd phytotoxicity when grown under identical conditions. Thus, Cd uptake might be minimized through the choice of appropriate plant species. In view of this hypothesis, the objective of the present study was to investigate the accumulation pattern of Cd in different crops and its tolerance when grown on sewage irrigated soils with increased Cd levels. The influence of Cd application on the absorption of other micronutrients was also evaluated.

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Materials and Methods

Four plant species namely maize (*Zea mays*), raya (*Brassica juncea*), berseem (*Trifolium alexendrium*) and spinach (*Spinacia oleracea*) belonging to different botanical families, Gramineae, Cruciferae, Chenopodiaceae and Leguminosae respectively, were grown in pots in green house. The plants were grown at four levels of Cd 0, 10, 20 and 40 mg kg^{-1} soil to study accumulation pattern of Cd and comparative performance of these plants. The polythene lined pots were filled with 5 kg of thoroughly mixed air dried soil. Cadmium was applied as cadmium chloride at above rates in the solution form. Organic carbon, pH, electrical conductivity and available N, P, K and total Cd content in the experimental soil were determined by standard methods (Page, 1982) and are presented in Table 1. DTPA extractable micronutrients were determined by employing the method of Lindsay and Norvell (1978). The soils were watered to field capacity and kept in green house for 30 days and allowed to equilibrate with subsequent wetting and drying cycles. Thereafter, representative soil samples from each pot were taken with the help of stainless steel tube auger. The samples were dried, ground, sieved and stored in polythene bags and analyzed for DTPA extractable cadmium. Basal doses of nitrogen, phosphorus and potassium were applied @ 100, 24 and 24 mg kg^{-1} soil; 100, 12 ,25 and 30 and 87.5 and 30 mg kg^{-1} soil respectively to maize, raya, beseem and spinach through their analytical grade chemicals *i.e.*, urea, dihydrogen potassium phosphate and potassium chloride respectively, at the time of sowing The crops were harvested 45 days after sowing. After harvest, shoot samples were taken from each pot and washed with tap water, dipped in 0.01 N HCl taken in a plastic tub for few seconds and then again washed with distilled and deionised water. Samples were first dried in air and then at a temperature of 60°C in hot air oven. The dried samples were weighed and ground in willey mill. The samples were digested in a di-acid mixture of HNO_3 and $HClO_4$ in 4:1 ratio and the digests were analyzed for total Cd and micronutrients using an atomic absorption spectrophotometer.

Survey studies : Soils and plant samples of the above crops were collected from the sites receiving sewage water and tube-well water irrigation which is mostly encountered in agricultural production to study the accumulation pattern of Cd vis a vis responses to high Cd exposure.

ANOVA was used to calculate LSD using CPCS-1 software (developed at PAU Ludhiana). Regression analysis was performed using Minitab 15 software.

Table 1 : Physico-chemical properties of experimental soil

Properties	Values	
pH*	7.98	
EC(dSm^{-1})*	0.71	
Organic carbon (percent)	0.52	
$CaCO_3$ (percent)	0.75	
CEC(C mol (P+) kg^{-1}	6.12	
Sand (%)	80.40	
Silt (%)	11.80	
Clay (%)	7.80	
Texture	Loamy sand	
Available N (kg ha^{-1})	325	
Available P (kg ha^{-1})	15.2	
Available K (kg ha^{-1})	210	
	DTPA	Total
Zinc (mg kg^{-1} soil)	0.98	32.92
Iron (mg kg^{-1} soil)	10.2	151.40
Manganese (mg kg^{-1} soil)	5.80	310
Copper (mg kg^{-1} soil)	0.67	12.38
Cadmium (mg kg^{-1} soil)	0.21	1.74

Results and Discussion

Different crops showed considerable variation in dry matter yield of shoot even in the absence of Cd application. The dry matter yield of the shoots was highest in maize followed in succession by spinach, berseem and raya respectively, in the control pots indicating their different yield potential. In all the crops, the mean dry matter yield of maize, raya, berseem and spinach significantly decreased from 17.44, 8.13, 10.41 and 13.24 g pot^{-1} to 9.13, 5.58, 3.98 and 7.78 g pot^{-1} when the rate of cadmium was increased to 40 mg kg^{-1} soil (Table 2). The rate of Cd at which significant reduction in dry matter yield observed was 20 mg Cd kg^{-1} soil for raya, and 10 mg Cd kg^{-1} soil for other crops. The yield reduction at 20 mg Cd kg^{-1} soil was 24, 15, 39 and 20 % in maize, raya, berseem and spinach respectively, indicating the extent and magnitude of decrease varied with crop species. The result indicated that raya was the most tolerant crop and berseem was most susceptible to Cd toxicity.

The detrimental effect of Cd on yield was consistent with the results of others in different crops like wheat (Zhang *et al*., 2002) and raya and spinach (Sidhu and Khurana, 2011). Panwar *et al*. (1999) found that the increasing levels of Cd application resulted in significant decrease in dry matter yield of cowpea and mung bean. Reduction in yield of various crops is attributed to Cd phytotoxicity on metabolic processes such as inhibition of various enzymes activities, induction of oxidative stress and alterations in enzymes of antioxidant defense system in plants (Sandalio *et al*., 2001; Romero–Puertess *et al*., 2002).

Different mathematical and regression models such as linear, quadratic and exponential functions were tested to find out the best fit for the dry matter yield when its value was regressed with cadmium levels (Table 3). It was found that response curve was well described by all the models but the quadratic and exponential models in maize seem to give better description of the process compared to linear models in all other crops as revealed by their higher coefficient of determination($R^2 = 0.93$).

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Table 2 : Effect of rates of applied cadmium on dry matter (g pot^{-1}) yield of crops and DTPA-Cd in soil

Cd rates (mg kg^{-1} soil)	DTPACd	Maize	Percent reduction	Raya	Percent reduction	Berseem	Percent reduction	Spinach	Percent reduction
0	0.08	17.44		8.13		10.41		13.24	
10	5.79	15.37	11.9	7.75	4.7	8.54	18.0	11.92	10.0
20	12.28	13.34	23.5	6.88	15.4	6.32	39.3	10.55	20.3
40	24.71	9.13	47.6	5.58	31.4	3.98	61.8	8.07	39.0
CD (5%)	0.52	0.66		0.42		0.45		0.50	

Table3: Comparison among different models on dry matter yield (g pot^{-1}) of crops

Linear equation	R^2	Quadartic equation	R^2	Exponential equation	R^2
		Maize			
Y=16.308-0.1968X	0.90	Y_2=16.882-.3114X_2+0.0028X^2	0.93	Y_2=16.538$e^{-0.016x}$	0.93
		Raya			
Y=7.512-0.0513X	0.89	Y_2=7.688-0.0877X_2+0.0009X^2	0.93	Y_2=7.5338$e^{-0.0079x}$	0.91
		Berseem			
Y=8.672-0.1361X	0.83	Y_2=9.199 -0.2452X_2+0.0025X^2	0.87	Y_2=8.944$e^{-0.0242x}$	0.85
		Spinach			
Y=11.797-0.1029 X	0.84	Y_2=12.115-01767X_2+0.0018 X^2	0.88	Y_2=11.851$e^{-.016X}$	0.85

Y represents dry matter yield of a crop and X is the rate of Cd applied

Khurana and Kansal (2014) also obtained best fit with exponential model corresponding to Mitscherlich curve.

The mean Cd concentration in the shoots of different crops increased successively with increasing rates of Cd application. The mean Cd concentration increased from 1.71, 3.5, 0.73 and 0.1.25 µg g^{-1} dry matter in maize, raya, berseem and spinach in control to 16.42, 60.17, 10.81 and 39.92 µg g^{-1} dry matter at 20 mg Cd kg^{-1} soil. This was probably due to the fact that Cd concentration in each crop increased with increasing Cd level (Table 4) *i.e.* increase in soil available Cd (DTPA extractable) resulted in marked and significant increase in amount of metal being absorbed by the plants. Sidhu and Khurana (2011) and Moustakas *et al*. (2011) also reported high Cd content in plants due to Cd application.

Cd concentration in shoots of maize, raya, berseem and spinach ranged between 1.71 to 31.5, 3.5 to 75.33, 0.73 to 21.29 and 1.25 to 58.77 µg g^{-1} dry matter. However, Cd accumulation by plants from the soil varied with plant species. For example, raya accumulated about 3.22, 4.77 and 1.53 times more Cd than maize, berseem and spinach (Table 4).

In spite of higher concentration of Cd in raya, no visual symptoms of Cd toxicity were noticed except for yield differences, illustrating that Cd accumulated in this crop without producing any visual symptoms. However, toxicity symptoms in the form of interveinal chlorosis of the leaf lamina, followed by necrosis and leaf rolling, were clearly evident in the case of other crops 40mg Cd kg^{-1}soil. Cadmium is readily bio-available and its accumulation has been reported to cause leaf chlorosis (Baryla *et al*., 2001; Smeets *et al.,* 2005). Cd tolerance in plants involves some factors such as oligopeptide ligands known as phytochelatins (PCs) and metallothioneins (MTs) in response to heavy metals (Stiffens,1990). Peptides bind and form stable complex with heavy metal and thus neutralize the toxicity of heavy metal ions (Ghosh and Singh, 2005).

The toxic or upper critical level of Cd is defined as its lowest concentration in tissue or soil at which its presence leads to reduction in yield. The critical concentration can be calculated by interpolating the concentration at which yield is reduced by some arbitrary amount usually 10 to 30 %. For finding the upper critical level, the regression equations were worked out where the value of per cent reduction in dry matter yield was regressed with corresponding plant Cd concentration. Regression models were employed using MS excel (Windows 2007) to find out the best fit for establishing the critical level. Linear/ Quadratic models seem to give the best description of the process as revealed by significant coefficient of determination (R^2). The toxic levels of Cd in 45 days old shoots of maize, raya, berseem and spinach at 45 days growth stage at 20% reduction in dry matter yield were estimated to be 13.7, 66.8, 7.8 and 33.7µg g^{-1} dry matter.

Work done by various workers on heavy metals suggested that critical limit of an element for a particular plant developed through soil analysis or total plant analysis was not to be taken for guaranteed. Soil analysis is often ambiguous, as the relation between availability of an element in soil to plants and quantities of that extracted by chemical reagent would vary with

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soil type. Earlier studies have reported marked differences for Cd tolerance of various plant species, including wheat (Zhang et al., 2002), cotton (Wu *et al*., 2004) and pea (Metwally *et al*., 2005). Since data in the present study was limited, therefore above calculated values could only be suggestive.

The mean Cd uptake in the shoots of all the crops increased significantly with increasing Cd level. The Cd uptake in raya increased from 28.5µg pot^{-1} in control to 339.1, 414 and 420 µg pot^{-1} with 10, 20 and 40 mg Cd kg^{-1} in soil respectively (Table5). The uptake increased by 11.9 times of control in raya with application of 20 mg Cd kg^{-1}soil suggesting that applied Cd was readily absorbed by raya and easily translocated from roots to above ground plant parts. Raising Cd level to 40 mg kg^{-1} soil did not increase Cd uptake in raya to an extent similar to that observed with 20 mg Cd kg^{-1} soil. In fact applying 40 mg Cd kg^{-1} soil, only 1.3 times increase in Cd uptake was observed over that recorded at 20 mg Cd kg^{-1} soil. (Table5). This kind of Cd uptake pattern was consequence of both reduction in yield due to Cd toxicity and increased concentration of Cd at higher application rate. In general, the rate of increase in shoot Cd uptake with applied Cd declined at the higher levels. Berseem, maize and spinach absorbed about 0.17, 0.54 and 0.95 times Cd from the soil compared to raya. Raya consistently takes up most Cd and berseem the least and the crops can be marked in the order raya> spinach> maize> berseem. can thus be concluded that plant species differ widely in their ability to absorb, accumulate and tolerate Cd toxicity (Ni *et al*., 2002). High concentrations of Cd have been reported in leafy vegetables (Yang *et al*., 2011)

In the present study, berseem belonging to family leguminosae showed maximum reduction in dry matter yield, followed by maize (Gramineae), spinach (Chenopodiaceae) and raya (Cruciferae).

There was a consistent increase in the mean Zn concentration with increase in Cd level in raya while higher rates (20 and 40 mg kg^{-1}soil) depressed Zn concentration in shoots of berseem. This showed that low levels of Cd had synergistic effect on Zn concentration in shoots, while high levels had antagonistic effect in case of berseem. Increase in shoot Zn concentration with Cd application up to 20 mg kg^{-1}soil may be due to the

Table 4. Effect of rates of applied cadmium on Cd content (µg g^{-1} dry matter) of crops

Cd level (mg kg^{-1} soil)	Maize	Raya	Berseem	Spinach
0	1.71	3.5	0.73	1.25
10	7.11	43.75	5.48	19.17
20	16.42	60.17	10.81	39.92
40	31.5	75.33	21.29	58.75
Range	1.71-16.42	3.5-75.33	0.73-21.29	1.25-58.77
Mean	14.19	45.69	9.58	29.77
CD (5%)	1.11	1.71	1.56	2.21

Table 5 : Effect of rates of applied cadmium on Cd uptake (µg pot^{-1}) of crops

Cd level (mg kg^{-1} soil)	Maize	Raya	Berseem	Spinach
0	29.8	28.5	7.60	16.5
10	109.4	339.1	46.80	228.4
20	219.1	414.0	68.30	421.2
40	287.3	420.4	84.90	474.2
Range	29.8-287.3	28.5-420.4	7.60-84.90	16.5-474.2
Mean	161.40	300.50	51.90	285.08
CD (5%)	21.47	16.00	10.54	26.23

Table 6: Effect of Cd on Zn, Cu, Mn and Fe content (µg g^{-1} dry matter) raya and berseem

Cd level (mg kg^{-1}soil)	Raya	Berseem	Raya	Bersem	Raya	Berseem	Raya	Berseem
	Zinc		Copper		Manganese		Iron	
0	48.4	21.4	11	9	65	58.4	155	76
10	53.2	25.9	8.9	8.2	64.6	48.1	152	70
20	56.8	20.8	10.5	8.7	59.4	43.4	162	64
40	59.4	19.4	9.7	8.5	58.4	41.2	156	60
CD(p =0.05)	3.7	4.0	NS	NS	3.4	3.5	NS	5.3

Table 7 : Cd concentration (µg g^{-1}) in shoots of crops receiving sewage and tube well water irrigation

Plant species	Sewage	Tubewell
Berseem	0.16	0.08
Spinach	1.4	0.24
Raya	3.0	0.28
Maize	0.11	0.01

concentration effect, because the dry matter yield was reduced due to Cd application. Decrease in Zn concentration in plants at higher levels of Cd might be due to competition of these metals for the same absorption sites on the plant root surface, resulting in low uptake of Zn, as Cd and Zn ions have similar charges and possibly use the same carrier sites (Table 6).

Copper concentration showed inconsistent trend with increasing levels of Cd in shoots of both the crops, thereby showing no relationship between the two cations (Table 6). This was further supported by weak correlation between Cd and Cu in shoots(r = -0.48 for raya and r = -0.33 for berseem).

Manganese concentration in shoots of both the crops declined with Cd application indicating an inverse relationship which was further supported by high negative correlation (r = -0.8 for raya and r = -0.87 for berseem) between these two cations (Table 6).This might be due to the fact that Cd competitively inhibited Mn absorption, suggesting a common transport site or process.

Cd concentration did not influence. Fe concentration showed inconsistencies with in raya thereby showing no relationship between the two cations (Table 6). This is further supported by weak correlation between Cd and Fe concentration in shoot (r = 0.34 for raya). On the contrary, mean Fe concentration in the shoots of berseem showed decreasing trend which was further supported by high correlation between Cd and Fe concentration in shoots (r = -0.960 for berseem).

Wang *et al.* (2009) reported that Cu and Zn uptake in *Ceratophyllum demersum* was promoted when exposed to lower concentrations of Cd, whereas Mn uptake was inhibited. Unlike Cu, Zn and Mn, Fe content was unaffected by Cd uptake. Studies with different crops revealed different interaction between Cd and micronutrients (Skrebsky *et al*., 2008; Safarzadeh *et al*., 2013).

In sewage irrigated soils, Cd content in plants varied from as low as 0.04 µg g^{-1} dry matter in maize to as high as 3.0µg g^{-1} dry matter in the shoot of raya. The increase in Cd content in waste water irrigation was 2.3, 5.8, 10.7 and 2.8 times higher in the shoots of berseem, spinach, raya and maize respectively in soils (Table 7). These results are in line with result of other workers (Dheri *et al*., 2007; Demirezen and Ahmet 2006). Cd accumulation in plants showed the following order : raya.> spinach> breseem > maize > which was more or less similar to that found in the pot study. Thus the results of pot study may be safely applied under natural conditions (Table 7).

Thus, the results indicated that different crops varied in their ability to respond to different levels of Cd application. Raya was most tolerant and berseem was found to be most sensitive to high levels of Cd. Thus, for consumption purposes raya should not be grown on sewage irrigated soils or soil with high Cd levels, but for phytoremedation this crop should be preferred.

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