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Critical Toxic Concentration of Cadmium in African Marigold Grown in Typic Ustochrept Soil

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ABSTRACT

Heavy metals are potentially toxic to human life and the environment. In a greenhouse pot experiment, Typic Ustochrepts soil order (alluvial soil) with pH 5.7 was used. African marigold variety *Pusa Narangi* was used as a test crop. The soil was artificially spiked with different cadmium (Cd) levels (0, 5, 10, 25, 50 and 100 mg kg^{-1}). Critical toxic concentrations of Cd resulting in 25 per cent reduction in dry matter yield were established for African marigold grown in alluvial soil. The corresponding values for non-inoculated, arbuscular mycorrhiza (*Glomus moseae*) and phosphorus solubilizing fungi (*Aspergillus awamori*) treated soils, respectively, were 28, 24 and 16 mg kg^{-1} Cd applied in soil; 12, 12 and 8 mg kg^{-1} AB-DTPA extractable Cd in soil; 6.4, 6.2 and 6 mg kg^{-1} Cd content in plant tissues.

INTRODUCTION

Heavy metal pollution of soil is one of the major environmental issues worldwide (Kabata-Pendias 1995, Nriagu & Pacyna 1988, Yanai et al. 2006). Among heavy metals, cadmium (Cd) is considered to be an important soil pollutant because it is potentially biotoxic in nature that is readily absorbed by plants and has the potential to enter the human food chain. It may accumulate in agricultural soils through the application of soil additives, such as phosphatic fertilizers and sewage sludges which contain 7.3-170 mg kg^{-1} and <1- 3410 mg kg^{-1} (Alloway 1990) cadmium, respectively. To consider a plant as hyperaccumulator, the minimum threshold tissue concentration is 0.01% for Cd of dry weight of plant (Wang et al. 2007). The technique is environmentally friendly, potentially cheap, visually unobtrusive, and offers the possibility of bio-recovery of the heavy metals (Yang et al. 2002). The study about the critical toxic concentration helps to know the concentration of heavy metals that limit the cultivation of the crop in contaminated soils.

Most previous workers have focused on wild species (non-economic crops) that can tolerate and uptake large amounts of heavy metals to increase the efficiency of phytoremediation. However, in developing countries, like India, it is difficult to convince local people to grow these hyperaccumulators for the sole purpose of removing pollutants from their environment without any financial remuneration. Therefore, marigold is preferred, for this purpose as the flowers produced are non-edible and also income generators (Chintakovid et al. 2007). Against this backdrop, a study was conducted on soils having diverse physico-chemical nature, taking marigold as test crop with the objective to evaluate critical toxic concentration of cadmium in plant and soils.

MATERIALS AND METHODS

Bulk composite surface (0-15 cm) soil samples viz. fine loamy, mixed hyperthermic and Typic Ustochrepts (alluvial soil) were collected from the Agricultural Research Farm, Banaras Hindu University, Varanasi (25°18' N latitude and 83°03'E longitude). The samples were processed, passed through a 2 mm sieve and analysed for pH, EC, organic carbon, clay and $CaCO_3$ using standard analytical methods (Sparks 1996). Cation exchange capacity (CEC) was determined by using 1N sodium acetate solution as proposed by Hesse (1971). Concentration of available Cd in soil samples was determined using DTPA extraction method (Lindsay & Norvell 1978). Pot culture experiments were conducted to find a critical toxic concentration. Soil sample (3 kg dried and processed soil) was placed into a plastic pot after mixing with different Cd concentrations viz. 0, 5, 10, 25, 50 and

100 ppm as $3CdSO_4 . 8H_2O$ and kept for one month incubation. Two seedlings of African Marigold (*Tagetes erecta* L. var. Pusa Narangi Gaenda) were transplanted in each pot and proper moisture was maintained throughout the growing period. Crop was harvested at flowering stage. Two bioinoculants, arbuscular mycorrhiza (*Glomus moseae*) and phosphorus solubilizing fungi (*Aspergillus awamori*) were treated before planting.

A method developed by Bingham et al. (1975) was employed to calculate the critical toxic concentration of Cd in soil for 25 percent yield decrement. Yields expressed relative to that of the control (0 mg Cd kg^{-1} treatment yield = 100%) were calculated. To determine the critical toxic concentration of Cd application in a contaminated soil, percent relative dry matter yields were plotted against the graded levels of soil cadmium application. Similarly, in order to find out the critical concentration of DTPA-extractable Cd in soil, percent relative dry matter yields were plotted against their respective DTPA-extractable Cd concentration in soil after 30 days equilibrium. Critical concentration of Cd in plant tissue was also estimated by plotting its concentration in plant tissue against percent relative dry matter yield.

Statistical analysis: In order to draw reliable conclusions, the experimental data on soil and plant were statistically analysed to draw conclusions of significance by using the method as described by Panse & Sukhatme (1967). The test of significance was carried out at 5% level of significance by referring to 'F' table values. The correlation of relevant data in soils and plants was also statistically calculated. Statistical analysis of data was carried out using the SPSS 12.0 programme designed for factorial CRD. Differences were considered as statistically significant at $p<0.05$ and highly significant at $p<0.01$.

RESULTS AND DISCUSSION

The data on AB-DTPA extractable cadmium in alluvial soil and relative dry matter yield are presented in Table 1. A perusal of the data revealed that in alluvial soil with no bioinoculant treatment, for the soil treatment levels of 0, 5, 10, 25, 50 and 100 mg Cd kg^{-1}, the AB-DTPA extractable Cd in soil before sowing was 0.010, 1.342, 5.756, 12.473, 23.746 and 48.350 mg kg^{-1}, respectively. The dry matter yield varied from 10.82 to 18.51 g pot^{-1}. As the soil Cd level increased, the relative dry matter yield (0 mg Cd kg^{-1} soil treatment yield = absolute) was recorded as 0.08, 3.30, 4.31, 6.23 and 7.69 g pot^{-1} for 5, 10, 25, 50 and 100 mg kg^{-1} treatments. The percent relative dry matter yields (yield expressed relative to that of control i.e. 0 mg Cd kg^{-1} treatment = 100%) were 99.57, 82.17, 76.72, 66.34, and 58.45 for 5, 10, 25, 50 and 100 mg Cd kg^{-1} treatments, respectively.

Table 1: Percent relative dry matter yield in alluvial soil.

Treatments	Cd applied to soil (mg kg^{-1})	AB-DTPA extractable Cd before sowing (mg kg^{-1})	Cd concentration in shoots after harvest (mg kg^{-1})	Dry matter yield (g pot^{-1})	Relative dry matter yield (g pot^{-1})	Percent relative dry matter yield
I_0						
Cd_0	0	0.01	0.03	18.51	-	100.00
Cd_5	5	1.34	0.27	18.43	0.08	99.57
Cd_{10}	10	5.76	0.81	15.21	3.30	82.17
Cd_{25}	25	12.47	6.06	14.20	4.31	76.72
Cd_{50}	50	23.75	8.08	12.28	6.23	66.34
Cd_{100}	100	48.35	12.55	10.82	7.69	58.45
AM						
Cd_0	0	0.01	0.04	20.86	-	100.00
Cd_5	5	1.34	0.35	18.46	2.40	88.49
Cd_{10}	10	5.76	2.01	18.10	2.76	86.77
Cd_{25}	25	12.47	7.25	15.33	5.53	73.49
Cd_{50}	50	23.75	9.66	12.93	7.93	61.98
Cd_{100}	100	48.35	17.20	11.71	9.13	56.14
PSF						
Cd_0	0	0.01	0.04	19.31	-	100.00
Cd_5	5	1.34	0.50	18.09	1.22	93.68
Cd_{10}	10	5.76	4.74	15.20	4.11	78.72
Cd_{25}	25	12.47	9.44	13.21	6.10	68.41
Cd_{50}	50	23.75	11.85	11.95	7.36	61.89
Cd_{100}	100	48.35	21.68	10.20	9.11	52.82

I_0 = No bioinoculant; AM = Arbuscular mycorrhizae; PSF = Phosphorus solubilizing fungi

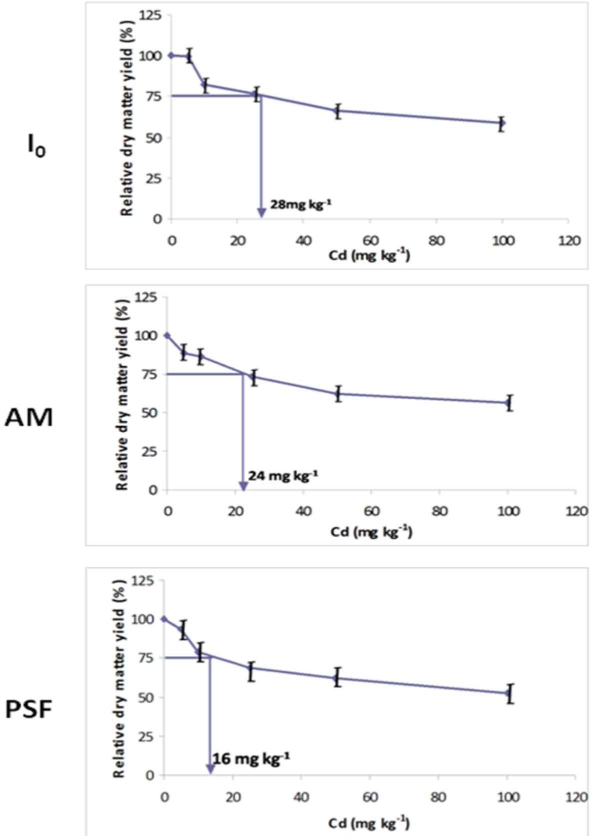

Fig. 1: Critical toxic concentration of Cd applied to soil producing 25% yield decrement in alluvial soil (bar represents the standard error of the mean values).
I_0 = No bioinoculant; AM = Arbuscular mycorrhizae; PSF = Phosphorus solubilizing fungi.

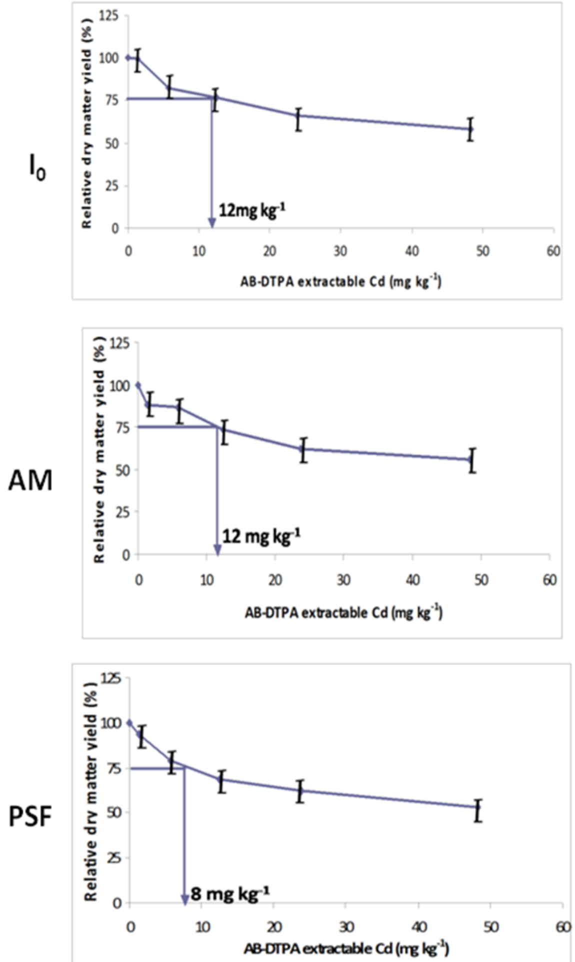

Fig. 2: Critical toxic concentration of AB-DTPA extractable Cd in soil producing 25% yield decrement in alluvial soil(bar represents the standard error of the mean values).
I_0 = No bioinoculant; AM = Arbuscular mycorrhizae; PSF = Phosphorus solubilizing fungi.

In alluvial soil with AM (*Glomus mosseae*) treatment (Table 1), for the soil treatment levels of 0, 5, 10, 25, 50 and 100 mg Cd kg^{-1} the concentration of AB-DTPA extractable Cd in soil before sowing was same as above. Dry matter yield, varied with the increase in Cd application from 11.71 to 20.86 g pot^{-1}. It will be lower in Cd_5 than Cd_{100} because the dry matter yield of Cd_0 is subtracted with the dry matter yield of Cd treated pots and then percent dry matter yield is calculated. Relative yield was recorded as 2.40, 2.76, 5.53, 7.93 and 9.15 g pot^{-1} and the percent relative yield was 100, 88.49, 86.77, 73.49, 61.98 and 56.14 for the levels of 0, 5, 10, 25, 50 and 100 mg Cd kg^{-1}, respectively. It is evident from Table 1 that in alluvial soil with PSF (*Aspergillus awamori*) treatment, the AB-DTPA extractable Cd in soil before sowing was same as above. The dry matter yield varied from 10.20 to 19.31 g pot^{-1}.

As the soil Cd level increased, the dry matter yield progressively decreased and the relative yield was 1.22, 4.11, 6.10, 7.36 and 9.11 g pot^{-1}. The percent relative yields for the above mentioned treatments were 93.68, 78.72, 68.41, 61.89 and 52.82, respectively.

To determine the critical concentrations of cadmium application in soil, percent relative dry matter yields of alluvial soil treated with bioinoculants was plotted against the graded levels of soil cadmium application (Fig. 1). It is evident that from figure that 25 per cent reduction in dry matter yield of control, AM treated and PSF treated alluvial soil was significantly associated with application of approximately 28, 24 and 16 mg Cd kg^{-1}, respectively. In a similar study, Bingham et al. (1975) reported a substrate concentration of 4 to 20 mg Cd kg^{-1} soil for sensitive plants such as spinach, soybean, carrot, curly cress and lettuce. For relatively tolerant plants such as rice, cabbage and wheat, soil Cd concentration for 25 percent yield decrement varied from

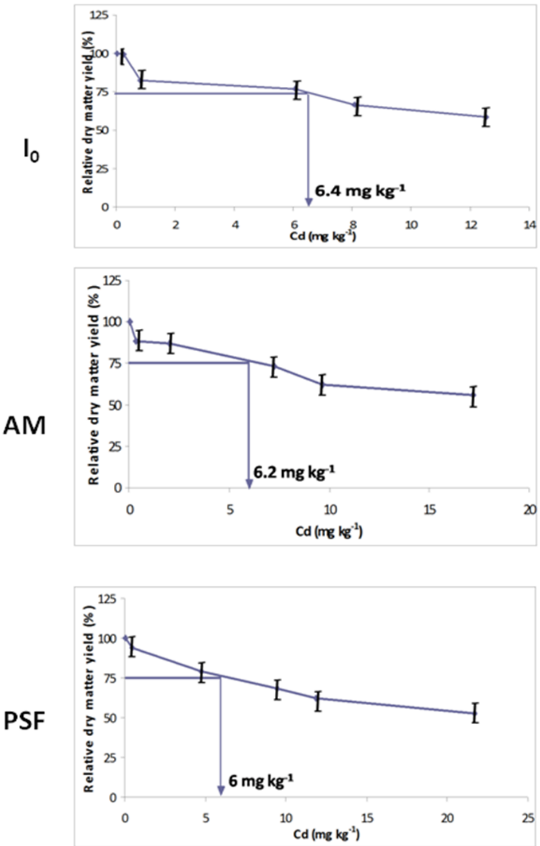

Fig. 3: Critical toxic concentration of Cd in plant tissue producing 25% yield decrement in alluvial soil (bar represents the standard error of the mean values)
I_0 = No bioinoculant; AM = Arbuscular mycorrhizae; PSF = Phosphorus solubilizing fungi

50 mg Cd kg^{-1} for wheat to 170 mg Cd kg^{-1} for cabbage while rice exhibited no ill effect for soil Cd treatment upto 640 mg kg^{-1}.

In order to find out the critical concentrations of AB-DTPA extractable cadmium in soil, percent relative dry matter yields of alluvial soil treated with bioinoculants were plotted against their respective the AB-DTPA extractable cadmium concentrations estimated at the time of sowing i.e. one month after application of graded levels of cadmium in soil (Fig. 2). It is evident from the figure that 25 percent dry matter yield significant decrement was encountered around 12, 12, 8 mg DTPA-extractable Cd kg^{-1} for control, AM treated and PSF treated alluvial soil, respectively. Critical levels of Cd toxicity in plant tissues associated with causing 25% decrease in dry matter production were also computed. In order to find out these values, percent relative dry matter yield of different bioinoculants treated alluvial soil i.e. control, AM and PSF were plotted against their respective cadmium concentration in plant tissues (Fig. 3). It is clearly reflected from the figure that 25% decrease in dry matter yield was recorded approximately around 6.4, 6.2 and 6.0 mg Cd kg^{-1} in the plant tissue of control, AM treated and PSF treated alluvial soil, respectively.

CONCLUSIONS

Critical toxic concentrations of Cd resulting in 25 per cent reduction in dry matter yield were established for African marigold grown in alluvial soil. The corresponding values for non-inoculated, AM and PSF treated soils respectively, were 28, 24 and 16 mg kg^{-1} Cd applied in soil; 12, 12 and 8 mg kg^{-1} AB-DTPA extractable Cd in soil; 6.4, 6.2 and 6 mg kg^{-1} Cd content in plant tissues.

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