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REVIEW ARTICLE

EFFECT OF CADMIUM ON GROWTH, YIELD AND DRY MATTER ACCUMULATION IN *CAJANUS CAJAN* L

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ABSTRACT

The seeds were raised in earthen pots lined with polyethylene bags and filled with washed river sand. Thirty days after sowing (DAS), the plants were treated with 3mM and 6mM Cd^{2+} solution. Sampling of plants was done at 7-8 days intervals starting from 30 DAS of the crop till its maturity. Major morphological changes that occurred in cadmium treatment plants were: Early yellowing of leaves and their subsequent abscission, browning and bending of stem, swelling at the base of stem, increase in secondary branches, early flowering, smaller leaves per plant, fewer pods, fever seeds per pod and smaller seeds. Plant height, leaf area, and dry weight also decreased in Cd^{2+} treated plants and were concentration dependent. The effect of Cd^{2+} was more pronounced during the vegetative phase. Dry matter accumulation was severely affected under cadmium treatment, control plants accumulated dry matter at much faster rate during the vegetative phase, 53.2%, the corresponding values for cadmium treatments were much less i.e. 34.6% and 29.5% for 3mM Cd^{2+} and 6mM Cd^{2+} respectively. Dry matter Harvest Index (HI) were reduced at higher cadmium concentration (6mM Cd^{2+}), however plants treated with 3mM Cd^{2+} exhibit a higher HI than the control. Cd^{2+} accumulation was more at 6mM Cd^{2+} however it was not proportional to concentration, as Cd^{2+} content per plant organ was comparable in 3mM and 6mm treated plants, but Cd^{2+} content per unit dry weight was higher in 6mM Cd^{2+} treated plants. Seeds accumulated 26-40 ug Cd g^{-1} dry weight.

INTRODUCTION

Soils air and water all over the world are slightly to moderately contaminated by cadmium due to both natural sources such as bedrock or transported parent material such as glacial till and alluvium (Tran and Popova, 2013) as well as anthropogenic activities such as extended use of superphosphate fertilizers, sewage discharge,sewage sludge application as well as smelters dust spreading and atmospheric sedimentation (Thaworncahaisit and Polprasert, 2009). Plants easily take up Cd from soil and transport it to aerial parts, and enter food chains. Bio-accumulation in plants can be highly dangerous (Sanita´ and Gabrieli., 1999), since plants are part of the food chains and a risk for man and animals, through the contamination of their food supplies (Fargasova, 1994). The presence of excessive amount of Cd in soil causes many toxic symptoms in plants, such as reduction of growth, especially root growth (Weigel and Jäger, 1980), disturbances in mineral nutrition and carbohydrate metabolism (Moya *et al*., 1993). Taken up in excess by plants, Cd directly or indirectly inhibits physiological processes, such as respiration, photosynthesis, cell elongation, plant–water relationships, nitrogen metabolism and mineral nutrition, resulting in poor growth and low biomass (Sanita´ and Gabrieli 1999). Pigeonpea (*Cajanus cajan* L.) is an important legume crop (Family-*Fabaceae*) of rain fed agriculture in the semiarid tropics. Pigeonpea is cultivated in more than 25 tropical and subtropical countries. The objective of this investigation is to study the accumulation of cadmium and its effect on growth and yield of Pigeonpea

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MATERIALS AND METHODS

Raising of the Crop: The seeds of UPAS-120 variety of Pigeonpea were raised in earthen pots in a naturally lit net house. The pots were lined with polyethylene bags and filled each with washed river sand. Four seeds of Pigeonpea were sown per pot at a uniform depth and distance. Before sowing, the seeds were inoculated with suitable rhizobium culture. Thirty days after sowing (DAS), the plants were thinned to two per pot. The pots were supplied with tap water as and when required. The nitrogen free nutrient solution was supplied to each pot at weekly intervals.

Treatment: 30 days after sowing plants were grouped into three sets. Set 1 was kept as control where as set 2 and set 3 were supplied with 400 ml of 3mM and 6mM $CdCl_2$ respectively.

Sampling: Sampling was done at 7 days intervals starting from 33 days after sowing (DAS) of the crop till its maturity. Eight plants from each treatment were used at each sampling. Two plants constituted one replicate.

Growth observations: After taking plants heights plants were uprooted and different plant parts were separated. Leaf area was taken and parts were than dried at 50^{o}C.

Estimation of cadmium: 100 mg of the dried sample was digested with a mixture of $HClO_4$ and H_2SO_4 (1:4), and the Cd^{2+} concentration was determined using atomic absorption spectrophotometer.

RESULTS AND DISCUSSION

Morphological changes: Cadmium induced morphological changes are shown in Fig.1. The following changes were observed, swelling at the base of stem, Browning and bending of stem, yellowing of leaves and their subsequent abscission increase in secondary branches, smaller leaves per plant, early flowering, fewer pods, fewer seeds per pod and smaller seeds.

Plant height: The plant height was reduced with both the cadmium levels i.e. 3mM and 6mM (Table.1, Fig.1), but the reduction was significant reduction up to 53 days after sowing (DAS). In control and 6mM Cd^{2+} treatments, the maximum height was attained at 97 DAS. Thereafter, there was no significant change. With 3mM Cd^{2+}, the increase in height continued even up to 120 DAS. The differences in plant height were clearly visible at flowering stage.

Table 1. Effect of cadmium on plant height and leaf area at different stages of growth

DAS	Plant height (cm)			Leaf Area (cm^{2}plant^{-1})		
	Control	3mM	6mM	Control	3mM	6mM
33	34.1±3.8	-	-	135±26	135±26	135±26
39	42.1±6.2	38.7±3.8	36.8±3.9	303±60	196±18	154±25
46	51.9±6.2	48.7±4.1	38.5±3.8	554±91	447±85	271±54
53	56.8±4.2	50.2±4.9	4139±4.2	705±75	451±90	304±62
60	62.3±6.9	52.6±5.5	46.3±4.9	927±102	458±96	298±68
68	79.3±6.1	56.1±5.8	50.8±4.8	1175±171	482±98	339±88
75	112.5±9.8	52.3±5.8	58.9±5.2	1361±107	508±96	446±92
90	129.6±10.2	73.6±6.2	68.2±5.8	1584±123	710±97	559±90
97	136.2±11.6	83.2±6.9	73.6±6.1	1826±232	717±103	563±96
111	136.8±11.1	89.9±7.1	73.8±6.8	1089±218	798±101	747±107
120	136.7±10.6	95.8±7.8	74.6±7.0	1071±152	715±161	537±107
129	135.9±11.3	95.6±7.6	74.5±7.1	715±108	527±105	492±98

Leaf Area: With cadmium, the total leaf area was reduced at all the stages of plant growth (Table.1). There was maximum reduction with 6mM Cd^{2+}. In control, there was maximum leaf area at 97 DAS, whereas in Cd^{2+}. In control, there was maximum leaf area at 97 DAS, whereas in Cd^{2+} treated plants it was maximum at 111 DAS. Thereafter, there was a drastic reduction in leaf area due to leaf senescence and abscission.

Dry Weight: The dry weight of all plant parts was reduced by both the levels of cadmium (Table. 2). In control as well as in cadmium treated plants, the dry weight of stem reached its maximum at 111 DAS: thereafter there was a slight reduction in the dry weight. The dry weight of leaves reached its maximum at 97 DAS in control as well as in cadmium treated plants followed by a decrease which was mainly due to heavy leaf fall. The dry weight of abscised leaves in cadmium treated plants was greater at the initial growth stages, but during the later stages, it was less than or equal to that of control plants. The root dry weight in control reached its maximum at 111 DAS, whereas in cadmium treated plants.

(a)

(b)

(c)

(d)

Fig.1. Visual effects of cadmium (a) Yellowing of leaves, (b) Browning and bending of stem, (c) Swelling at the base of stem, (d) Increase in secondary branch, small height, early flowering, smaller leaves per plant

Table 2. Dry weight (g plant^{-1}) of cadmium treated Pigeonpea plant organs at different stages of growth.

DAS	Plant organs											
	Stem			Leaves			Root			Nodule		
	Control	3mM	6mM	Control	3mM	6mM	Control	3mM	6mM	Control	3mM	6mM
33	0.220±0.040	0.220±0.040	0.220±0.040	0.260±0.045	0.260±0.045	0.260±0.045	0.143±0.021	0143±0.021	0.143±0.021	0.030±0.009	0.030±0.009	0.030±0.009
39	0.335±0.057	0.305±0.084	0.265±0.061	0.500±0.080	0.400±0.068	0.357±0.062	0.160±0.048	0.155±0.039	0.145±0.032	0.045±0.011	0.042±0.010	0.034±0.008
46	0.590±0.095	0.565±0.089	0.450±0.050	0.880±0.105	0.170±0.096	0.395±0.066	0.300±0.092	0.240±0.062	0.175±0.038	0.070±0.020	0.079±0.020	0.050±0.012
53	0.875±0.105	0.745±0.092	0.490±0.076	1.235±0.135	0.775±0.099	0.421±0.071	0.470±0.163	0.333±0.073	0.230±0.59	0.131±0.032	0.101±0.028	0.062±0.016
60	1.565±0.260	0.945±0.168	0.504±0.082	1.700±0.240	0.820±0.102	0.535±0.079	1.010±0.234	0.365±0.098	0.245±0.068	0.210±0.046	0.112±0.032	0.069±0.018
68	2.450±0.420	1.320±0.361	0.945±0.149	2.185±0.306	1.105±0.156	0.655±0.110	1.575±0.380	0.700±0.231	0.355±0.082	0.298±0.058	0.141±0.039	0.086±0.021
75	3.825±0.425	2.000±0.405	1.130±0.352	3.765±0.315	1.435±0.268	0.980±0.221	2.050±0.405	0.865±0.132	0.460±0.131	0.388±0.079	0.158±0.042	0.138±0.031
90	5.625±0.638	3.070±0.460	2.380±0.410	4.485±0.417	1.845±0.281	1.390±0.232	2.575±0.515	1.195±0.386	0.600±0.213	0.479±0.097	0.226±0.049	0.154±0.043
97	7.295±0.790	4.940±0.592	3.420±0.431	4.915±0.439	2.125±0.292	1.820±0.316	2.660±1.0490	1.745±0.452	1.115±0.298	0.557±0.116	0.253±0.050	0.172±0.052
111	7.420±0.805	5.550±0.608	4.660±0.439	4.520±0.408	2.255±0.312	1.830±0.320	2.715±0.468	2.215±0.469	1.320±0.316	0.588±0.127	0.360±0.082	0.262±0.056
120	7.500±0.815	5.525±0.686	4.145±0.403	3.850±0.381	1.900±0.376	1.395±0.238	2.690±0.441	2.325±0.498	1.525±0.376	0.572±0.106	0.400±0.087	0.277±0.063
129	7.200±0.789	5.250±0.672	3.995±0.386	3.405±0.323	1.460±0.272	1.250±0.169	2.145±0.408	2.115±0.462	1.490±0.326	0.540±0.101	0.395±0.084	0.302±0.062

Table 2. Continued

DAS	Plant organs											
	Ab. Leaves			Flower			Podwall			Seed		
	Control	3mM	6mM	Control	3mM	6mM	Control	3mM	6mM	Control	3mM	6mM
33												
39												
46		0.068±0.017	0.089±0.018									
53	0.063±0.016	0.079±0.018	0.090±0.019									
60	0.089±0.018	0.099±0.020	0.124±0.022									
68	0.095±0.034	0.135±0.045	0.145±0.052									
75	0.180±0.052	0.334±0.056	0.349±0.076									
90	0.280±0.085	0.618±0.098	0.534±0.092	0.065±0.025	0.150±0.065	0.140±0.060	0.100±0.030	0.160±0.050	0.090±0.032			
97	0.420±0.099	0.847±0.106	0.815±0.112	0.085±0.036	0.210±0.085	0.170±0.052	0.410±0.075	0.605±0.092	0.150±0.042	0.060±0.020	0.100±0.036	
111	0.985±0.195	0.919±0.162	0.840±0.129	0.180±0.064	0.075±0.016	0.080±0.031	0.900±0.110	1.070±0.125	0.226±0.095	0.280±0.055	0.435±0.068	0.220±0.050
120	1.301±0.210	1.273±0.215	0.999±0.156	0.170±0.060	0.055±0.014	0.060±0.024	0.965±0.254	1.162±0.032	0.810±0.210	0.995±0.190	0.041±0.295	0.815±0.186
129	1.489±0.315	1.501±0.369	1.290±0.222	0.110±0.051	0.054±0.021	0.050±0.011	1.186±0.195	1.052±0.270	1.050±0.265	2.650±0.465	2.105±0.405	1.040±0.320

Table 3. Yield characteristics of pigeonpea as influenced by cadmium

Parameters	Yield characteristics		
	Control	3 mM	6mM
Seed wt. plant-1	2.98±0.52	1.88±0.52	0.98±0.28
seed wt. (100)	5.25±0.62	4.76±0.38	3.93±0.49
Number of seed pod-1	3.1	2.96	2.46
Number of pod plant-1	22.04	15.14	10.75

Table 4. Proportion of dry matter accumulation at different stages of growth

Stages	Dry matter increment at different stages of growth		
	Control	3mM Cd^{2+}	6mM Cd^{2+}
	19.13 (100)*	13.84 (100)	10.40 (100)
Vegetative (0-75 DAS)	10.20 (53.2)	4.80 (34.6)	3.10 (29.5)
Flowering and pod setting (75-97 DAS)	6.20 (32.4)	6.03 (43.6)	4.61 (44.3)
Seed filling (97-129 DAS)	2.73 (14.3)	3.11 (22.5)	2.81 (27.0)

*value in parenthesis denotes percentage.

Table 5. Dry matter harvest indices of pigeon pea under control and cadmium treatment

Dry matter harvest indices			
Criteria for calculation	Control	3mM	6mM
Proportion of aerial phytomass			
Excluding abscissed leaves	25	31	20
Including abscissed leaves	22	26	16
Proportion of total phytomass			
Excluding abscissed leaves	19	23	15
Including abscissed leaves	17	20	13

It was at 120 DAS, thereafter there was reduction in dry weight increased up to 111 DAS in both the control and the cadmium treated plants, thereafter there was reduction in the control plants but a slight increase up to 129 DAS in the cadmium treated plants. The dry weight of flowers, pod walls and seeds were also reduced in cadmium treated plants. The maximum dry weight of flowers in control was observed at 111 DAS; thereafter there was a slow decrease. In cadmium treated plants, the maximum dry weight of flowers was attained a little earlier, i.e. at 97 DAS; thereafter there was a decrease in the dry weight. The dry weight of seeds and pod walls increased in both the control and the cadmium treated plants, but at every stage, the dry weight of seeds of the cadmium treated plants was less than that of the control.

***Growth and yield*:** Application of Cd^{2+} caused drastic reduction in seed yield. Deleterious effect of this heavy metal on seed or grain yield has also been reported in dwarf bean, pea and in wheat. In the present investigation, the various parameters responsible for diminished seed yield in Cd^{2+} treated plants are decreased number of pods per plant, lesser number of seeds per pod, higher proportional of empty pods and reduced seed weight (Table 3). The reduction in plant growth as observed in the present study could be due to the adverse effect of the heavy metal cadmium on the various physiological and metabolic processes such as photosynthesis, nitrogen fixation and partitioning of carbon and nitrogen.

***Dry matter accumulation*:** Dry matter accumulation was severely affected by cadmium. In this study, dry matter accumulation was severely affected by $Cd^{2+.}$ Control plants accumulates 19.1 g dry matter through its life span, whereas 3mM and 6mM Cd^{2+} treated plants accumulated only 13.8 gm and 10.4 gm dry matter, respectively (Table 4). The percent accumulation (% of total dry matter accumulated throughout life span) of dry matter at different stages of growth differed between the control and cadmium treated plants. Control plants accumulated dry matter at much faster rate. Control plants during vegetative phage accumulated 53.2%. the corresponding values for cadmium treatments were much less i.e 34.6% and 29.5% for 3mM Cd2+ and 6 mM Cd2+ respectively. But this trend was reversed during flowering and pod setting and seed filling stages.The data clearly indicates that cadmium treatment enhanced the leaf abscission. Thus cadmium affected both the rate of dry matter accumulation and dry matter loss from the plant.

***Harvest index for dry matter*:** Harvest indices for dry matter have been calculated with and without considering the below ground mass and abscised leaves. Dry matter Harvest Index (HI) were reduced at higher cadmium concentration (6 mM Cd^{2+}), however plants treated with 3 mM Cd^{2+} exhibit a higher HI than the control (Table 5). Higher HI under 3mM Cd^{2+} was mainly due to greater decrease in biological yield compared to grain yield as the treatment was given at vegetative stage. Values of HI obtained were higher than those obtained by Rao *et al*., (1984) for the same crop. During seed filling phage, unlike other legumes, the shoot did not exhibit any appreciable decrease in either dry weight, the underground parts showed an even lesser decrease in dry weight. The cadmium treated plants showed a higher mobilization of carbon from the stem than the control plants.

Table 6. Cadmium accumulation (µg $plant^{-1}$) in various plant organs at different stages of growth in Pigeonpea treated with cadmium

DAS	Plant organ							
	Leaf		Stem		Root		Nodule	
	3mM	6mM	3mM	6mM	3mM	6mM	3mM	6mM
39	25.07±3.92	28.19±4.12	28.07±4.18	39.73±3.86	17.00±2.96	28.73±3.98	2.76±0.39	2.73±0.34
46	49.81±5.12	39.65±5.01	59.68±4.62	75.26±6.66	34.76±3.72	37.13±3.11	6.72±0.68	4.93±0.59
53	54.88±5.22	37.42±4.36	76.85±5.92	83.25±6.18	49.95±5.86	50.37±5.14	6.29±0.86	5.77±0.62
60	54.69±5.68	48.05±5.26	96.73±7.88	79.63±7.02	50.74±3.19	52.44±5.62	7.46±0.81	6.07±0.69
68	62.43±6.13	51.00±6.11	129.47±9.16	125.79±8.29	76.38±6.33	60.09±5.19	3.98±0.96	7.58±0.72
75	78.21±6.91	77.91±6.34	193.36±10.14	146.81±9.06	92.48±8.92	60.48±6.05	11.17±0.98	11.18±0.89
90	93.50±7.22	94.84±7.18	22.15±13.21	267.54±11.62	92.54±9.06	63.54±7.99	13.65±1.01	11.44±0.92
97	118.83±7.98	124.51±8.66	361.50±25.08	365.70±28.26	125.86±9.11	112.79±8.62	15.16±1.09	12.88±1.06
111	104.00±3.16	119.72±7.96	376.23±30.19	448.39±38.92	154.12±9.98	131.25±9.18	21.46±1.69	17.70±1.74
120	76.86±6.68	93.97±7.02	346.86±26.09	301.38±32.11	143.89±8.62	145.27±10.16	24.24±1.92	17.71±1.62
129	44.62±3.69	76.89±6.62	282.56±30.11	281.76±19.36	129.59±8.09	142.35±9.97	23.37±2.04	19.26±1.96

Table 6. Continued

DAS	Plant organ								Total per plant	
	Ab leaves		Flowers		Seed		Podwall			
	3mM	6mM	3mM	6mM	3mM	6mM	3mM	6mM	3mM	6mM
39									72.9	99.38
46									150.97	154.97
53									187.97	176.81
60									209.62	186.19
68	11.08±0.66	14.32±0.72							288.34	258.87
75	27.58±1.38	35.09±1.63							402.8	331.67
90	49.69±1.76	56.35±2.14							471.67	493.71
97	64.62±3.96	80.69±3.96	7.73±0.63	8.12±0.61	3.06±0.26		6.12±0.55	2.57±0.32	702.88	707.26
111	72.85±4.68	77.67±4.98	3.21±0.50	3.61±0.56	13.54±0.82	8.98±0.71	9.72±0.79	2.88±0.39	755.13	810.2
120	95.95±7.32	89.47±5.16	2.41±0.42	2.98±0.94	27.17±3.68	32.31±2.96	8.74±0.76	8.59±0.67	726.12	691.68
129	99.25±6.65	114.20±6.90	2.42±0.39	2.53±0.48	58.65±4.49	33.96±4.16	8.26±0.91	10.10±0.96	648.72	611.05

Table 7. Cadmium accumulation (μg g^{-1} dry wt.) in various plant organs at different stages of growth in pigeon pea treated with cadmium

DAS	Plant organ							
	Leaf		Stem		Root		Nodule	
	3mM	6mM	3mM	6mM	3mM	6mM	3mM	6mM
39	62.68±5.26	78.96±5.62	92.03±9.87	119.92±11.92	109.68±10.08	198.16±16.42	65.61±7.76	80.29±9.06
46	70.16±6.19	89.45±5.86	105.62±9.88	167.25±14.62	144.88±14.41	212.16±18.65	74.72±8.16	98.68±9.19
53	70.81±5.11	88.89±5.61	103.15±8.65	169.90±14.98	150.01±13.69	219.02±19.08	62.01±7.29	93.12±3.69
60	66.69±4.85	89.81±5.58	102.36±8.96	158.00±14.42	139.16±11.62	218.16±19.19	66.63±5.98	87.91±8.42
68	56.90±5.02	78.00±5.48	98.09±8.66	133.11±12.68	109.12±9.96	169.27±14.46	63.71±6.12	89.14±7.67
75	54.50±4.32	79.50±5.42	96.68±9.01	129.92±11.92	106.92±9.09	131.92±14.68	70.74±7.26	81.00±7.32
90	50.68±4.68	68.23±3.98	72.36±6.66	112.41±10.94	77.56±8.26	105.88±10.11	60.42±6.24	74.30±7.01
97	55.92±4.92	68.41±4.62	73.18±5.92	106.93±9.68	71.92±7.96	101.16±9.01	59.92±4.99	74.89±6.34
111	46.12±3.61	65.42±4.58	67.79±6.32	96.22±8.86	69.58±7.09	99.43±3.89	59.63±5.05	68.31±6.26
120	40.45±3.21	67.36±4.26	62.78±5.58	72.71±8.05	61.89±5.26	95.26±8.86	62.62±4.69	63.92±5.97
129	30.56±2.68	61.51±4.09	53.82±5.24	70.53±6.98	61.26±5.11	97.49±7.92	59.67±4.82	64.21±4.95

Table 7. Continued

DAS	Plant organ							
	Ab leaves		Flowers		Seed		Podwall	
	3mM	6mM	3mM	6mM	3mM	6mM	3mM	6mM
39-68	82.09±7.98	98.79±8.62						
75	82.58±7.88	100.56±9.16						
90	80.41±8.11	105.52±9.24						
97	76.29±7.62	99.01±8.98	36.80±3.11	47.79±5.42	30.61±2.91		10.11±1.18	17.16±2.19
111	79.27±7.44	92.46±3.42	42.81±3.38	45.09±5.16	31.13±3.62	40.82±3.98	9.08±1.04	12.73±1.68
120	75.38±6.93	85.56±7.92	43.73±4.16	49.68±5.38	26.10±2.11	39.64±4.16	7.56±0.89	10.61±1.14
129	66.12±5.52	88.53±7.76	44.87±4.22	50.67±5.29	27.86±2.16	32.63±3.11	7.85±0.81	9.62±1.06

Cadmium content: The changes in the cadmium contents of the different plant organ (μm plant^{-1} and μg g^{-1} DW basis) are given in Table.6 and 7. The cadmium content in the different plant organs was higher in plants treated with 6mM Cd^{2+}, but the increase was not proportionate to the amount found with 3mM Cd^{2+} treatment. The cadmium content on μm plant^{-1} basis showed an increase in all the plant organs. In stem, leaves and roots the cadmium content increased up to 120 DAS, beyond which there was a slight decrease. However, in nodules, abscised leaves, flower, pod walls, and seeds there was a continuous increase in the cadmium content up to maturity. On μg g^{-1} DW basis the cadmium content of leaves, roots, stem and nodules showed an initial increase, followed by a continuous decrease afterwards. The cadmium content of the abscised leaves, seeds and pod walls decreased with time, whereas in flower it increased.

Cadmium accumulation: The concentration of Cd^{2+} in various plant parts increased with increase in concentration applied and with duration of application. Although there was a positive correlation between the plant Cd^{2+} concentration and soil applied Cd^{2+} concentration, the concentration of the heavy metal in plant was not in direct proportion to the added amount. This was because of retention of Cd^{2+} in the rooting medium as cadmium was present in the sand even at the time of harvest. It has been well documented that various nutrients particularly phosphorus form the cadmium salts which are insoluble in water and hence decreased availability to plants (Williams and David, 1973; 1977; Miller *et al*., 1973).

In pigeonpea, maximum concentration of Cd^{2+} was detected in roots followed by stem, leaves, seeds and pod walls. In general, the order of distribution of the heavy metal in various parts of different species is in the order of roots> stem> leaves (Cunningham *et al*., 1975; Malik *et al*., 1989) followed by pods and seeds (Haghiri, 1973; John, 1972; Jastrow and Koeppe, 1980). Evidently the level to which Cd^{2+} accumulates in the edible part of a plant is of utmost concern from the point of view of human and animal health. Result on distribution of Cd^{2+} in various plant parts reveal that the metal gets accumulation in the seeds only in minute quantities and it ranges from 25 to 40 µg g-1 dry weight of the seed in case of plants supplied with 6mM Cd^{2+}. These values are however, higher than those reported by John (1972), Williams and David (1973) and Chug (1991) in case of pea seeds and in soybean by Haghiri (1973). From the distribution pattern of the heavy metal in Pigeonpea and other plant species, it appears that as compared to leafy vegetable, consumption of Pigeonpea seed raised soil contaminated with low to moderate levels is likely to be less injurious from the point of human health. However, this small accumulation is still of great concern.

Conclusion

- Reduced dry matter production in cadmium – treated plants was mainly due to initial effect on growth at vegetative stage, either due to reduced cell division or cell elongation.
- Effect of Cadmium on the various metabolic processes was short lived and in the long term most of these reactions recover from the initial shock. Reduced rate of the various metabolic processes was mainly due to the reduced growth of the concerned organ. Metabolic activities in nodules were affected more as compared to leaves.
- Cadmium accumulates in significant amount in the seeds and hence unfit for consumption.

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