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 Cd²⁺ 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, fewer seeds per pod and smaller seeds. Plant height, leaf area, and dry weight also decreased in Cd²⁺ treated plants and were concentration dependent. The effect of Cd²⁺ 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 Cd²⁺ and 6mM Cd²⁺ respectively. Dry matter Harvest Index (HI) were reduced at higher cadmium concentration (6mM Cd²⁺), however plants treated with 3mM Cd²⁺ exhibit a higher HI than the control. Cd²⁺ accumulation was more at 6mM Cd²⁺ however it was not proportional to concentration, as Cd²⁺ content per plant organ was comparable in 3mM and 6mM treated plants, but Cd²⁺ content per unit dry weight was higher in 6mM Cd²⁺ 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 superfosphate 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 semi-arid 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.

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 CdCl₂ 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 then dried at 50°C.

**Estimation of cadmium:** 100 mg of the dried sample was digested with a mixture of HClO₄ and H₂SO₄ (1:4), and the Cd²⁺ 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 Cd²⁺ treatments, the maximum height was attained at 97 DAS. Thereafter, there was no significant change. With 3mM Cd²⁺, the increase in height continued even up to 120 DAS. The differences in plant height were clearly visible at flowering stage.

**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 Cd²⁺. In control, there was maximum leaf area at 97 DAS, whereas in Cd²⁺ 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.
### Table 2. Dry weight (g plant\(^{-1}\)) of cadmium treated Pigeonpea plant organs at different stages of growth.

<table>
<thead>
<tr>
<th>DAS</th>
<th>Plant organs</th>
<th>Stem</th>
<th>Leaves</th>
<th>Root</th>
<th>Nodule</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>3mM</td>
<td>6mM</td>
<td>3mM</td>
<td>6mM</td>
</tr>
<tr>
<td>33</td>
<td>0.220±0.040</td>
<td>0.220±0.040</td>
<td>0.260±0.045</td>
<td>0.260±0.045</td>
<td>0.143±0.021</td>
</tr>
<tr>
<td>39</td>
<td>0.335±0.057</td>
<td>0.305±0.084</td>
<td>0.400±0.068</td>
<td>0.357±0.062</td>
<td>0.160±0.048</td>
</tr>
<tr>
<td>46</td>
<td>0.590±0.095</td>
<td>0.565±0.089</td>
<td>0.450±0.050</td>
<td>0.395±0.066</td>
<td>0.300±0.092</td>
</tr>
<tr>
<td>53</td>
<td>0.875±0.105</td>
<td>0.745±0.092</td>
<td>0.490±0.076</td>
<td>0.775±0.099</td>
<td>0.421±0.071</td>
</tr>
<tr>
<td>60</td>
<td>1.565±0.260</td>
<td>0.945±0.168</td>
<td>0.504±0.082</td>
<td>1.700±0.240</td>
<td>0.820±0.102</td>
</tr>
<tr>
<td>68</td>
<td>2.450±0.420</td>
<td>1.320±0.361</td>
<td>0.945±0.149</td>
<td>2.185±0.306</td>
<td>1.105±0.156</td>
</tr>
<tr>
<td>75</td>
<td>3.825±0.425</td>
<td>2.600±0.405</td>
<td>1.130±0.352</td>
<td>3.765±0.315</td>
<td>1.435±0.268</td>
</tr>
<tr>
<td>90</td>
<td>5.625±0.638</td>
<td>3.070±0.460</td>
<td>2.380±0.410</td>
<td>4.885±0.417</td>
<td>1.845±0.281</td>
</tr>
<tr>
<td>97</td>
<td>7.295±0.790</td>
<td>4.940±0.592</td>
<td>3.420±0.431</td>
<td>4.915±0.439</td>
<td>2.125±0.292</td>
</tr>
<tr>
<td>111</td>
<td>7.420±0.805</td>
<td>5.550±0.608</td>
<td>4.660±0.439</td>
<td>4.520±0.408</td>
<td>2.255±0.312</td>
</tr>
<tr>
<td>120</td>
<td>7.500±0.815</td>
<td>5.250±0.686</td>
<td>4.145±0.403</td>
<td>3.850±0.381</td>
<td>1.900±0.376</td>
</tr>
<tr>
<td>129</td>
<td>7.200±0.789</td>
<td>5.250±0.672</td>
<td>3.995±0.386</td>
<td>3.405±0.323</td>
<td>1.460±0.272</td>
</tr>
</tbody>
</table>

### Table 2. Continued

<table>
<thead>
<tr>
<th>DAS</th>
<th>Plant organs</th>
<th>Ab. Leaves</th>
<th>Flower</th>
<th>Podwall</th>
<th>Seed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>3mM</td>
<td>6mM</td>
<td>3mM</td>
<td>6mM</td>
</tr>
<tr>
<td>33</td>
<td>0.068±0.017</td>
<td>0.089±0.018</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>0.063±0.016</td>
<td>0.079±0.018</td>
<td>0.090±0.019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>53</td>
<td>0.089±0.018</td>
<td>0.099±0.020</td>
<td>0.124±0.022</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>0.095±0.034</td>
<td>0.135±0.045</td>
<td>0.145±0.052</td>
<td></td>
<td></td>
</tr>
<tr>
<td>68</td>
<td>0.180±0.052</td>
<td>0.334±0.056</td>
<td>0.349±0.076</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>0.200±0.085</td>
<td>0.618±0.098</td>
<td>0.534±0.092</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>0.420±0.099</td>
<td>0.847±0.106</td>
<td>0.815±0.112</td>
<td></td>
<td></td>
</tr>
<tr>
<td>97</td>
<td>0.985±0.195</td>
<td>0.919±0.162</td>
<td>0.840±0.129</td>
<td></td>
<td></td>
</tr>
<tr>
<td>111</td>
<td>1.301±0.210</td>
<td>1.273±0.215</td>
<td>0.999±0.156</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>1.483±0.315</td>
<td>1.501±0.369</td>
<td>1.290±0.222</td>
<td></td>
<td></td>
</tr>
<tr>
<td>129</td>
<td>1.052±0.320</td>
<td>1.050±0.265</td>
<td>2.650±0.465</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Yield characteristics of pigeonpea as influenced by cadmium

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Yield characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
</tr>
<tr>
<td>Seed wt. plant-1 and seed wt. (100)</td>
<td>2.98±0.52</td>
</tr>
<tr>
<td>Number of seed pod-1</td>
<td>2.96</td>
</tr>
<tr>
<td>Number of pod plant-1</td>
<td>15.14</td>
</tr>
</tbody>
</table>

Growth and yield: Application of Cd²⁺ caused drastic reduction in seed yield. Detrimental 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 Cd²⁺ 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.

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

<table>
<thead>
<tr>
<th>Stages</th>
<th>Dry matter increment at different stages of growth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
</tr>
<tr>
<td>(0-75 DAS) Vegetative</td>
<td>10.20</td>
</tr>
<tr>
<td>(75-97 DAS) Flowering and pod setting</td>
<td>6.20</td>
</tr>
<tr>
<td>(97-129 DAS) Seed filling</td>
<td>2.73</td>
</tr>
</tbody>
</table>

Dry matter accumulation: Dry matter accumulation was severely affected by cadmium. In this study, dry matter accumulation was severely affected by Cd²⁺. Control plants accumulated 19.1 g dry matter through its life span, whereas 3mM and 6mM Cd²⁺ treated plants accumulated only 13.8 g and 10.4 g 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 phase 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.

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

<table>
<thead>
<tr>
<th>Criteria for calculation</th>
<th>Dry matter harvest indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of aerial phytomass</td>
<td>Control</td>
</tr>
<tr>
<td>Excluding abscissed leaves</td>
<td>25</td>
</tr>
<tr>
<td>Including abscissed leaves</td>
<td>22</td>
</tr>
<tr>
<td>Proportion of total phytomass</td>
<td>19</td>
</tr>
<tr>
<td>Excluding abscissed leaves</td>
<td>17</td>
</tr>
</tbody>
</table>

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 Cd²⁺), however plants treated with 3 mM Cd²⁺ exhibited a higher HI than the control (Table 5). Higher HI under 3mM Cd²⁺ 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 phase, 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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Leaf</th>
<th>Plant organ</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAS</td>
<td>3mM</td>
<td>6mM</td>
</tr>
<tr>
<td>46</td>
<td>49.81±5.12</td>
<td>39.65±5.11</td>
</tr>
<tr>
<td>53</td>
<td>54.88±5.22</td>
<td>76.85±5.92</td>
</tr>
<tr>
<td>60</td>
<td>54.69±5.68</td>
<td>87.57±5.92</td>
</tr>
<tr>
<td>68</td>
<td>62.43±6.13</td>
<td>129.47±9.16</td>
</tr>
<tr>
<td>75</td>
<td>78.21±6.91</td>
<td>193.36±10.14</td>
</tr>
<tr>
<td>90</td>
<td>93.50±7.22</td>
<td>22.15±13.21</td>
</tr>
<tr>
<td>97</td>
<td>118.83±7.98</td>
<td>267.54±11.62</td>
</tr>
<tr>
<td>110</td>
<td>104.00±3.16</td>
<td>112.79±8.62</td>
</tr>
<tr>
<td>120</td>
<td>76.86±6.68</td>
<td>28.17±6.62</td>
</tr>
<tr>
<td>129</td>
<td>44.62±3.69</td>
<td>28.12±6.62</td>
</tr>
</tbody>
</table>

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.
### Table 6. Continued

<table>
<thead>
<tr>
<th>DAS</th>
<th>Plant organ</th>
<th>Total per plant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ab leaves</td>
<td>Flowers</td>
</tr>
<tr>
<td></td>
<td>3mM</td>
<td>6mM</td>
</tr>
<tr>
<td>39</td>
<td>59.62±5.84</td>
<td>181.45±12.45</td>
</tr>
<tr>
<td>46</td>
<td>78.96±6.53</td>
<td>192.78±12.95</td>
</tr>
<tr>
<td>53</td>
<td>89.45±5.78</td>
<td>192.97±12.95</td>
</tr>
<tr>
<td>60</td>
<td>98.42±6.34</td>
<td>192.97±12.95</td>
</tr>
<tr>
<td>75</td>
<td>117.45±7.65</td>
<td>192.97±12.95</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>DAS</th>
<th>Leaf</th>
<th>Stem</th>
<th>Root</th>
<th>Nodule</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3mM</td>
<td>6mM</td>
<td>3mM</td>
<td>6mM</td>
</tr>
<tr>
<td>39</td>
<td>119.92±11.92</td>
<td>109.68±10.08</td>
<td>198.16±16.42</td>
<td>65.61±7.76</td>
</tr>
<tr>
<td>46</td>
<td>109.68±10.08</td>
<td>141.62±14.62</td>
<td>121.65±18.65</td>
<td>74.72±8.16</td>
</tr>
<tr>
<td>53</td>
<td>117.45±7.65</td>
<td>141.62±14.62</td>
<td>212.15±18.65</td>
<td>98.60±9.19</td>
</tr>
<tr>
<td>60</td>
<td>127.56±8.26</td>
<td>141.62±14.62</td>
<td>223.16±18.65</td>
<td>117.45±7.65</td>
</tr>
<tr>
<td>68</td>
<td>133.11±12.68</td>
<td>141.62±14.62</td>
<td>234.16±18.65</td>
<td>133.11±12.68</td>
</tr>
</tbody>
</table>

### 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 Cd²⁺, but the increase was not proportionate to the amount found with 3mM Cd²⁺ 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, flowers, 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 Cd²⁺ in various plant parts increased with increase in concentration applied and with duration of application. Although there was a positive correlation between the plant Cd²⁺ concentration and soil applied Cd²⁺ concentration, the concentration of the heavy metal in plant was not in direct proportion to the added amount. This was because of retention of Cd²⁺ 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 Cd²⁺ 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 > roots and leaves (Cunningham et al., 1975; Malik et al., 1989) followed by pods and seeds (Haghighi, 1973; John, 1972; Iastrow and Koepp, 1980). Evidently the level to which Cd²⁺ accumulates in the edible part of a plant is of utmost concern from the point of view of human welfare.
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.

REFERENCES


******