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# CADMIUM UPTAKE BY EIGHT FOOD CROPS AS INFLUENCED BY VARIOUS SOIL LEVELS OF CADMIUM

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*ABSTRACT*

*Since cadmium accumulation in man has been implicated as the cause of several health problems, reduced dietary intake of this non-essential metal is desirable. A method for minimisation of cadmium content of food crops is needed since potentially hazardous levels in plants may result from cadmium uptake from contaminated soils. Study towards that objective involved the comparison of cadmium in various parts of eight food crops when grown under three soil cadmium regimes. Cadmium concentrations in some plants were influenced more dramatically by soil cadmium treatments than other plant sections. For particular crops and regimes of soil cadmium, accumulation of cadmium in root portions was noted. Among the edible plant parts, highest cadmium levels were found in lettuce and spinach leaves, and were followed by levels in brassica tops, radish and carrot tubers, pea seeds, and oat grains. Cadmium phytotoxicity significantly diminished yields of some parts.*

## INTRODUCTION

Increased investigation of environmental cadmium concentrations has been undertaken since numerous reports within the past decade have shown that excessive accumulation of this heavy metal adversely affects human health.

Schroeder (1965) reported increased concentrations of cadmium or increased ratios of cadmium to zinc in the kidneys of humans dying from hypertensive diseases when compared with renal concentrations from subjects dying from other major diseases. The excessive dietary intake of cadmium was cited, by Tsuchiya (1969*a*, 1969*b*), as the major factor in causation of 'ouch-ouch' disease which was restricted to a limited area near Toyama city in Japan. Fischer & Thind (1971) reported that cadmium concentrations in different sized blood vessels, kidney,



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liver and heart of cadmium hypertensive rabbits were significantly higher than levels for tissues from control rabbits. Experiments wherein 5 ppm Cd in water supply was fed to mice (Schroeder *et al.*, 1964) and rats (Schroeder *et al.*, 1965) showed that the dosage enhanced cadmium levels in tissues and was toxic to the animals in terms of life span and longevity. Significantly greater cadmium concentrations were found in water-soluble protein extracts prepared from human liver specimens of patients dying from emphysema and/or chronic bronchitis (Lewis *et al.* 1969). Prompted by the reported association of chronic inhalation of cadmium fumes with pulmonary emphysema, Nandi *et al.* (1969) investigated the distribution of cadmium in whole cigarettes, filters, and ash. They concluded that inhalation of cigarette smoke and absorption of as little as 10–20% of the cadmium in the smoke, by an individual smoking more than 20 cigarettes each day, could lead to a substantially enhanced cadmium intake. A positive correlation between cadmium in the air in US cities and incidence of cardiovascular disease was reported by Carroll (1966).

Subsequent study provided information about the origin and extent of cadmium pollution. In several reports, the natural geochemical partnership of cadmium and zinc (Vinogradov, 1959) accounted for the pollutants' entry into the environment. Cadmium in roadside plants and soils, decreasing with distance from the traffic, was attributed to cadmium as an impurity in zinc-containing additives in motor oils and zinc compounds used in vulcanisation of rubber tyres (Lagerwerff & Specht, 1970). Cadmium in the atmosphere, and the subsequent settling of the airborne particles on vegetation and soils, predominantly originates from smelting and electroplating of metals (Lagerwerff, 1967). Particulate fallout from such metallurgical processes was cited as a source of excessive amounts of the heavy metals in soils near a battery smelter (John *et al.*, 1972). Tsuchiya (1969*b*) postulated that the cadmium, zinc and lead mining operations and the run-off from waste piles at the upstream site were responsible for contamination of water and rice. Apart from its association with zinc, cadmium compounds used as fungicides (Ross & Stewart, 1969) and cadmium present in superphosphate fertiliser (Kropf & Geldmacher-v. Mallinckrodt, 1968; Schroeder & Balassa, 1963) also resulted in the entry of the heavy metal into soil.

Reports concerned with amounts of cadmium present in plants, animals, foods and the human body (Essing *et al.*, 1969; Kropf & Geldmacher-v. Mallinckrodt, 1968; Kubota *et al.*, 1968; Miller *et al.*, 1969; Murthy & Rhea, 1968; Schroeder *et al.*, 1961, 1967) have emphasised the need for intensive research towards a scheme for limiting the cadmium content of food crops (Allaway, 1968). To attain that objective, conditions influencing cadmium uptake by plants must first be determined and then studied. In a study involving a variety of food crops, Schroeder *et al.* (1967) confirmed that markedly higher cadmium concentrations occurred in grains, as noted in an earlier report by Schroeder *et al.* (1961), but, contrary to the results of that report, indicated that vegetables were low in cadmium content. In the

more recent study, although the differences from the control were not impressive, application of superphosphate fertiliser enhanced the cadmium content of three grains, two legumes, three root and four leafy vegetables. However, it is not clear whether the increased concentrations were due to cadmium associated with the treatment as an impurity in the fertiliser or to the influence of enhanced soil phosphate. When grown on roadside soil (pH 5·9) which contained 0·56 ppm N HCl-extractable cadmium, and away from possible aerial contamination, 1·7 and 2·9 ppm Cd in radish roots and tops were reported by Lagerwerff (1971). However, liming to pH 7·2 decreased levels to 1·1 and 2·8 ppm Cd, respectively. In a study at this laboratory, conducted with 30 different soils, John (1972) found that, when 50 mg Cd were added to 500 g soil, the cadmium concentrations in edible portions of radishes and lettuce averaged 387·0 and 138·0 ppm Cd, respectively. Levels in plant materials harvested from the treated soils were significantly influenced by ammonium acetate extractable cadmium in the soils, the capacity of the soils to adsorb cadmium, soil reaction, and organic matter content. Since adsorption of cadmium limited plant uptake, John (1971) studied the adsorption and desorption of cadmium in relation to soil properties. Although aerial contamination of plants has been indicated (Lagerwerff, 1971; Lagerwerff & Specht, 1970), the uptake of the heavy metal from contaminated soils may cause potentially hazardous accumulation of cadmium in food crops, even if airborne cadmium pollution were eliminated.

As part of our study towards minimising cadmium uptake by plants, and thereby limiting dietary cadmium intake, the present investigation was undertaken to compare the cadmium content of different food crops grown on a soil treated with various amounts of cadmium. The influence of differing soil properties and degrees of atmospheric cadmium pollution were eliminated by growing plants on a single soil in a controlled environmental chamber. To permit study of the distribution of cadmium within the plants, crops were separated in to various parts before determination of cadmium concentration by atomic absorption spectrophotometry. In addition, dry weight yields were measured, since cadmium phytotoxicity has been reported to decrease yields of radish plants (John, 1972).

## MATERIALS AND METHODS

The soil chosen for this study was the Ap horizon of Hazelwood silt loam collected from a site in the Lower Fraser Valley of British Columbia, Canada. The soil had 11·8% oxidisable organic matter, 38·3 me/100 g of cation exchange capacity and was 31·8% base saturated. The soil, initially at pH 4·9, was limed to pH 5·1 by mixing 5 g $CaCO_3$/1000 g soil, adding deionised distilled water to field capacity, and incubating at 25 ± 3°C in darkness for 2 weeks. Two rates of cadmium contamination, 40 mg Cd/1000 g soil and 200 mg Cd/1000 g soil (air-dry basis), were

TABLE 1

THE INFLUENCE OF CADMIUM CONTAMINATION OF SOIL ON CADMIUM CONTENT OF VARIOUS PARTS OF THE EIGHT CROPS

| *Description of crop and plant part* | | | | | *Plant cadmium (ppm)* | |
|---|---|---|---|---|---|---|
| | *Crop* | *Variety* | *Plant part* | *control* | 40 mg Cd / 1000 *g soil* | 200 mg Cd / 1000 *g soil* |
| I. *Leafy vegetables:* | | | | | | |
| Leaf lettuce | *Lactuca sativa* L., cv. *crispa* | Salad Bowl | leaves | 4·8 a | 51·1 a | 667·7 b |
| | | | roots | 2·3 a | 294·7 a | 1628·2 b |
| Spinach | *Spinacia oleracea* L. | King of Denmark | leaves | 12·2 a | 207·5 b | 239·3 b |
| | | | roots | 8·5 a | 213·9 b | 490·5 c |
| II. *Brassicas:* | | | | | | |
| Broccoli | *Brassica oleracea* L., cv. *italica* | Waltham No. 29 | leaves | 2·7 a | 36·0 a | 268·5 a |
| | | | roots | 6·5 a | 153·0 a | 1647·4 b |
| Cauliflower | *Brassica oleracea* L., cv. *botrytis* | Snowball Y | leaves | 4·8 a | 18·5 a | 198·6 b |
| | | | roots | 1·8 a | 202·5 a | 1356·7 b |
| III. *Legume:* | | | | | | |
| Peas | *Pisum sativum* L. | Dark Skin Perfection | seeds | 5·4 a | 10·1 b | 19·7 c |
| | | | pods | 5·7 a | 9·5 a | 28·2 b |
| | | | vines | 7·4 a | 37·2 a | 116·9 b |
| | | | roots | 8·6 a | 409·7 b | 1571·2 c |
| IV. *Grain:* | | | | | | |
| Oats | *Avena sativa* L. | Fraser | grains | 3·9 a | 20·8 b | 33·6 c |
| | | | husks | 4·5 a | 37·8 b | 96·0 c |
| | | | leaves | 3·9 a | 45·4 b | 177·0 c |
| | | | stalks | 3·9 a | 47·4 b | 116·5 c |
| | | | roots | 3·6 a | 144·8 a | 663·2 b |
| V. *Tuberous vegetables* | | | | | | |
| Radish | *Raphanus sativus* L. | Early Scarlet Globe | tops | 9·8 a | 264·7 b | 398·0 b |
| | | | tubers | 3·6 a | 54·6 b | 123·3 c |
| Carrot | *Daucus carota* L., cv. *sativa* | Chantenay Red Cored | tops | 6·6 a | 79·3 b | 294·4 c |
| | | | tubers | 2·4 a | 26·8 b | 29·8 c |
| | | | roots | 8·5 a | 1737·5 b | 6121·5 c |

TABLE 2

THE INFLUENCE OF CADMIUM CONTAMINATION OF SOIL ON YIELD OF VARIOUS PARTS OF THE EIGHT CROPS

| Crop | Description of crops harvested: Plants/pot | Growth period (days) | Plant part | Dry weight (g/pot): Control | 40 mg Cd / 1000 g soil | 200 mg Cd / 1000 g soil |
|---|---|---|---|---|---|---|
| I. *Leafy vegetables:* | | | | | | |
| Lettuce | 6 | 35 | leaves | 17·50 a | 18·82 a | 1·55 b |
| | | | roots | 0·91 a | 0·99 a | 0·36 a |
| Spinach | 8 | 55 | leaves | 10·96 a | 0·39 b | 0·16 b |
| | | | roots | 0·51 a | 0·02 b | 0·02 b |
| II. *Brassicas:* | | | | | | |
| Broccoli | 3 | 60 | leaves | 95·93 a | 122·50 a | 35·20 b |
| | | | roots | 2·46 a | 4·08 a | 2·09 a |
| Cauliflower | 3 | 70 | leaves | 103·67 a | 100·83 a | 3·17 b |
| | | | roots | 1·78 a | 1·47 a | 0·17 b |
| III. *Legume:* | | | | | | |
| Peas | 3 | 95 | seeds | 27·45 a | 16·98 ab | 0·21 b |
| | | | pods | 10·59 a | 7·45 a | 0·84 b |
| | | | vines | 19·64 a | 14·43 a | 2·47 b |
| | | | roots | 1·98 a | 1·80 a | 0·56 b |
| IV. *Grain:* | | | | | | |
| Oats | 12 | 100 | grains | 42·57 a | 27·28 b | 18·37 b |
| | | | husks | 5·56 b | 8·31 a | 6·85 ab |
| | | | leaves | 20·84 a | 21·50 a | 18·72 a |
| | | | stalks | 29·90 a | 39·17 a | 23·28 a |
| | | | roots | 3·75 a | 3·18 a | 2·88 a |
| V. *Tuberous vegetables:* | | | | | | |
| Radish | 8 | 45 | tops | 8·24 a | 6·25 b | 1·47 c |
| | | | tubers | 7·10 a | 5·12 a | 0·48 b |
| Carrot | 10 | 130 | tops | 18·95 a | 16·92 a | 1·50 b |
| | | | tubers | 41·72 a | 38·27 a | 1·52 b |
| | | | roots | 0·96 a | 0·81 a | 0·13 b |

obtained by thoroughly mixing appropriate amounts of $CdCl_2$ salt with incubated soil, while some soil remained uncontaminated for the control treatment. The experiments were factorial with 8 crops × 3 rates of cadmium contamination arranged in randomised blocks with 3 replications. The crops (Table 1) were grown in a controlled chamber in 4-litre plastic pots containing the equivalent of 3000 g soil on air-dry basis. Except for lettuce, cauliflower, and broccoli plants, which were transplanted to pots of soil after germination from seed in quartz sand, seeds were placed in the soil and plants were thinned to obtain an equal number of plants in each pot for the particular crop (Table 2). Sufficient N, P, K, S, Ca, Mg, Zn, Cu, Fe, Mo and B were added to ensure optimum growth. Cool fluorescent and incandescent lamps provided a daily 16 h photoperiod. Day and night temperature regimes were 20 ± 2°C and 15 ± 2°C.

Plants were harvested at maturity, and the number of days of growth on the soils recorded. After drying and separating the samples into various parts (Table 1), the dry weight of each part was recorded. The plant materials were ground and digested with a nitric–perchloric acid mixture for the determination of cadmium content by atomic absorption. Acquisition, reduction, and statistical analyses of the data followed the computer methods described previously by John (1970).

## RESULTS AND DISCUSSION

From analyses of variance and Duncan's multiple range tests performed for each of the 22 plant parts, treatment means for cadmium concentrations (Table 1), followed by the same letter, did not differ significantly at the 5% level. At the high rate of soil contamination, mean cadmium concentrations for all plant parts, except broccoli leaves, were significantly greater than the corresponding means for the control pots. Although much greater than the corresponding mean content for the control pots (2·7 ppm Cd), the concentration in broccoli leaves (268·5 ppm) for the high rate was not significantly different at the 5% level, according to the analysis of variance, due to extreme variations between replicates. Cadmium concentrations in some plant portions were more dramatically affected than others. When the soil was contaminated at the lower rate, mean cadmium concentrations in the lettuce leaves and roots, the four brassica materials, the pod and vine sections of pea plants, and oat roots were not significantly different ($P = 0{\cdot}05$) from levels in those grown on untreated soil. The other thirteen plant materials contained significantly incremented levels at the lower contamination rate, and all of those, except spinach leaves and radish tops, grown on the soil contaminated at the high rate contained concentrations which were, again, significantly increased.

Differences between cadmium levels in various sections of particular crops could also be assessed from the results shown in Table 1. Leaf portions of lettuce, spinach,

cauliflower, and oat plants grown on the untreated soil contained greater concentrations of cadmium than the root portions of those plants. However, the other crops, harvested from the control pots, accumulated more cadmium in the root portion of the plants. When either the low or high rate of cadmium had been added to the soil, plant cadmium levels were substantially higher in the root sections than other parts of all crops except spinach. In the instance of spinach grown on soil treated with 40 mg Cd/1000 g soil, the leaf cadmium level (207·5 ppm Cd, which, for the edible plant portions, was the highest concentration at the low treatment rate) was nearly equal to that in the roots (213·9 ppm Cd). However, as generally found, accumulation in the root portion of spinach was evident at the high treatment rate. At the high rate, the highest cadmium concentration in an edible plant part was that of 667·7 ppm Cd in lettuce leaves. The pea seeds and oat grains accumulated less cadmium from the treated soils than other parts of those plants. Although the husk, leaf and stalk sections of the oat plants contained similar amounts of cadmium at the low treatment rate, differences were apparent at the high treatment rate. The tuber portions of radishes and carrots were not zones of high cadmium accumulation. Perhaps this observation can be explained by the fact that these portions are not responsible for adsorption of soil nutrients, whereas the carrot roots contained the highest cadmium concentrations.

Another analysis of variance for a 3 factor experiment (3 replicates, 3 treatments, 22 plant parts) was performed in order to compare cadmium concentrations in different plant parts. The total variance (with degrees of freedom ($df$) = 197) was partitioned among 6 sources of variation as follows: replication ($df = 2$), treatment ($df = 2$), replication × treatment interaction ($df = 4$ used to calculate $F$-ratios for first 2 sources of variation), plant part ($df = 21$), plant part × treatment interaction ($df = 42$), and residual error ($df = 126$, used to calculate $F$-ratios for previous 3 sources of variation). Since calculated $F$-ratios for 'treatment', 'plant part', and 'plant part × treatment interaction' were highly significant ($P < 0{\cdot}01$), Duncan's multiple range tests for these sources of variation were conducted at the 5% significance level. Over 3 replicates and 22 plant parts, levels of 5·4, 186·5, and 742·1 ppm Cd for the control, low and high treatments, respectively, were significantly different from one another. To remain concise, results for the mean plant cadmium concentrations, associated with the 'plant part × treatment interaction' portion of the variance, were not presented even though means differed significantly. However, results for Duncan's test of 'plant part' means are presented graphically (Fig. 1). The letters 'a' to 'g' group the means into seven homogeneous subsets wherein means did not differ significantly. The accumulation of cadmium in the root portion of plants, the site of absorption between plant and soil, was dramatically shown (Fig. 1) since all root portions were placed in the last subsets. Among the edible plant parts, subset 'c' included the mean cadmium concentrations for spinach and lettuce leaves, and the latter was included in subset 'd'. Means for cadmium levels in all other edible portions were present in the first subset 'a' and

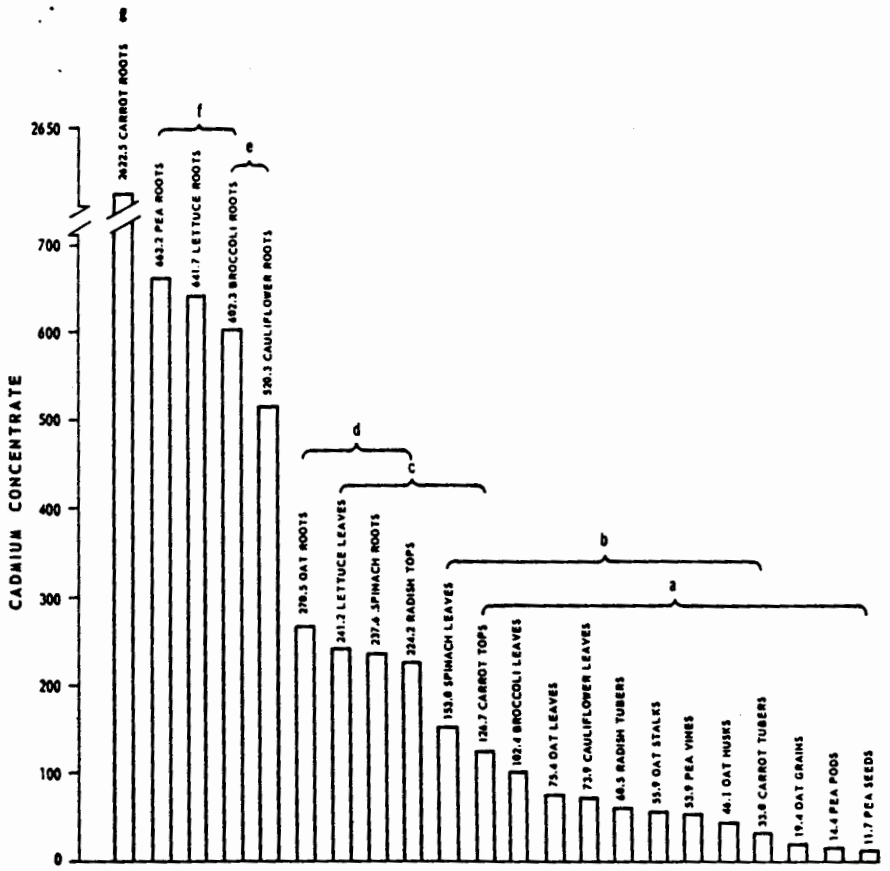


Fig. 1. Cadmium in various plant parts.

none was included beyond subset 'd'. Contrary to the findings of Schroeder *et al.* (1967), the grain contained less cadmium than several vegetables.

Besides increasing cadmium levels in various plant parts, cadmium treatment applied to the soil resulted in significant yield depression for most plant parts (Table 2). Only the dry weight yields of spinach leaves and roots, oat grains, and radish tops were significantly decreased when the low rate of cadmium was applied. At the high rate, however, yields of most plant materials, except root portions of lettuce, broccoli, and oat plants, and the husks, leaves, and stalks of oat plants, were drastically depressed. The yields of marketable portions, notably oat grain, were generally more affected than root parts of the crops. Perhaps, in practice, with the high phytotoxicity, so little of the crop would be produced that the grower's produce might not be marketed and there would be little chance of anyone consuming it. However, the results would also indicate that the cadmium content

of crops grown under conditions of intermediate toxicity, such that saleable yields are still obtained, can be a source of dietary cadmium intake which constitutes a potential hazard to health.

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