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Cadmium Uptake by Plants[1]

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ABSTRACT

Absorption of ^{115m}Cd by soybean (*Glycine max* L.) plants via foliar and root systems and translocation into the seed was determined. The uptake of ^{115m}Cd by soybeans via the root system was more efficient than that of the foliar placement.

Growth and Cd concentrations of soybean and wheat (*Triticum aestivum* L.) tops were influenced by soil-applied Cd. In both crops, the Cd concentration of plant tops increased while yield decreased with increasing levels of applied Cd. Cadmium toxicity began to occur in both crops at the lowest level of soil applied Cd (2.5 ppm). With soybean plants, Cd toxicity symptoms resembled Fe chlorosis. For wheat plants there were no visual symptoms other than the stunted growth.

The relative concentration of Cd found in several vegetable crops varied depending on the plant species. The relative Cd concentration in descending order for various vegetables was lettuce (*Lactuca sativa* L.) > radish top (*Raphanus sativus* L.) > celery stalk (*Apium graveolens* L.) > celery leaves ≥ green pepper (*Capsicum frutescens* L.) > radish roots.

Additional Index Words: heavy metal, cadmium toxicity, translocation.

Cadmium toxicity in mammals is well established (15). Poisoning by this element can occur by intake or injection of Cd salts or by inhalation of CdO. A good correlation between cardiovascular death rates and the concentration of Cd in the air as an industrial pollutant was reported by Carrol (2). Experiments with animals have shown that Cd and its compounds can induce malignant tumors in rats (5).

Cadmium in the environment is generated from smelting industries, attrition of automobile tires, and burning of diesel and heating oil. The Cd concentration of four brands of tires ranged from 20–90 ppm; and for diesel and heating oil, it ranged from 0.07 to 0.10 and from 0.42 to 0.54 ppm, respectively (11). Other sources of Cd are sewage sludge and, to some extent, impurities in certain agricultural chemicals. Since Cd is predominately released into the atmosphere, the airborne particulates containing Cd eventually will be deposited on the surface of soils and plants by rain or snow or as dust "fallout." Kitamura (8) reported that over a 3-year period, Cd concentrations in the soil pots which were placed 500 m from the Cd emission source increased from 0.7 to 9.4 ppm while there were no increases in Cd concentrations (0.7 ppm) of those soils which were located in a control area. Lagerwerff and Specht (11) found that the concentration of Cd in soil and vegetation along the highway decreased with distance from traffic. The Cd concentration was related to the composition of motor oil and automobile tires and their residues deposited along the roadside.

Cadmium is present in various quantities in soil, water, air, and foods. In nonpolluted areas, the concentration of Cd in soil is reported to be < 1 ppm (18). In areas of suspected Cd contamination, in rice (*Oryza sativa* L.) fields of Japan, concentrations of 1–50 ppm have been reported (13).

In nonpolluted areas, the normal concentration of Cd in water is < 1 ppb. However, values greater than 10 ppb have been reported for natural waters and water for consumption (4).

Cadmium concentration in air varies with the distance from a Cd-emitting source. Kneip et al. (9) found that the yearly mean concentration of Cd in the air at lower Manhattan was 0.023 $\mu g/m^3$ while at a nonurban site it was 0.003 $\mu g/m^3$. For Stockholm, a weekly mean concentration of 0.005 $\mu g/m^3$ was reported, while for a rural area, a monthly mean of 0.0009 $\mu g/m^3$ was recorded (4).

A comprehensive review of the Cd content of various common foodstuffs in the USA and other countries was made by Friberg et al. (4). They indicated that the "normal" levels of Cd in foodstuffs are below 0.05 ppm. Some seafoods such as shellfish from areas not known to be contaminated contained > 0.05 ppm (14).

According to Pringle et al. (12), concentrations of Cd in oysters from the east coast of the USA varied from 0.1 to 7.8 ppm; and values from the west coast ranged from 0.2 to 2.1 ppm. Rice and wheat (*Triticum aestivum* L.) normally contain < 0.1 ppm, but higher concentrations for both grains have been reported. Meat usually contains < 0.05 ppm Cd; however, values greater than 0.05 ppm have been measured in liver and kidneys (4).

Although the magnitudes of this metal in different matrices are small, man accumulates Cd in his kidney and liver (14). Since most foods in nonpolluted areas contain < 0.05 ppm Cd, the daily intake by man is about 50 μg. Although Cd levels below 10 ppb in water contributes very little to the daily intake, 20 ppb in drinking water would increase the daily intake 20 μg/liter of water taken in per day. Under normal conditions, the contribution of Cd in the air to the daily intake (0.02–0.2 μg/day) via the respiratory system is considered to be very small (4).

The objectives of this study were to determine (i) Cd absorption by plants via foliar and root systems and translocation into the seed, (ii) the effect of soil-applied Cd on yield and Cd concentration of crops, and (iii) the relative uptake of Cd by various vegetable crops.

EXPERIMENTAL PROCEDURE

Experiment 1—Two soybean (*Glycine max* L.) seedlings, germinated in acid-washed white silica sand, were transferred to a 7.6-liter plastic container containing a complete nutrient solution with a pH of 6.4. The concentrations of macronutrients and micronutrients (ppm), in the solution culture were 112N, 117K, 48Mg, 160Ca, 45P, 64S, 0.013Mo, 0.020Cu, 0.250Mn, 0.049Zn, 0.250B, and 15.07Fe. Heavy metals (impurities) in the macronutrient salts were removed by using 1% aqueous solution of ammoniumpyrrolidine dithiocarbamate and methylisobutylketone (4).

The plants were grown in the aerated nutrient solution in the greenhouse under 8 hours of darkness and 16 hours of light. After 4 weeks of growth, 4.909 μCi ^{115m}Cd was applied on the surface

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Table 1—Uptake of ^{115m}Cd by soybean tops over a 2-week period (Exp. 1)

Part treated	Plant tops	Stems	Leaves
	% of applied ^{115m}Cd		
Roots	13.35	7.77	5.28
Foliage	1.76	1.13	0.53
LSD at 1%	4.76		

Table 2—Uptake of ^{115m}Cd by soybean pods and seed (Exp. 1)

Part treated	Pods + seed	Pods	Seed
	% of applied ^{115m}Cd		
Roots	2.73	2.74	0.49
Foliage	0.17	0.11	0.06
LSD at 1%	2.36		

of the first trifoliate leaf above the third branch for foliar absorption; and the same dosage was added to the nutrient solution media for a study of root absorption. Each treatment including the control was replicated six times. Two weeks after the application of ^{115m}Cd, plants from three replications of each treatment were harvested; and leaves and stems were separated for ^{115m}Cd assay. The remaining plants were allowed to grow to maturity at which time the soybean pods and seeds were harvested for radio-assay. The plant parts were dried at 70C, weighed, ground in a micro Wiley mill, and assayed for ^{115m}Cd activity with a Single Channel Analyzer.

Experiment 2—Soybean and winter wheat (*Triticum aestivum* L.) plants were grown in pots lined with polyethylene bags, and containing 750 g of air-dried Marengo silty clay loam soil. The soil had a pH of 6.7, organic matter content of 4%, and a cation exchange capacity of 31.2 meq/100 g of soil. Cadmium in the form of $CdCl_2$ was incorporated into the soil at the rates of 0, 2.5, 5, 10, 15, 20, 30, 40, 50, and 100 ppm. Each treatment was replicated three times. After 5 weeks of growth in the greenhouse, the soybean and wheat tops were harvested, dried at 70C, weighed, ground in a stainless steel Micro-Mill, digested with $HClO_4$ and HNO_3, and the Cd concentrations of plant samples were determined by atomic absorption spectrophotometry.

Experiment 3—Lettuce (*Lactuca sativa* L.), radish (*Raphanus sativus* L.), celery (*Apium graveolens* L.), and green pepper (*Capsicum frutescens* L.) were grown in 3.7-liter pots lined with polyethylene bags, and containing 3.5 kg of Marengo silty clay loam soil. Cadmium ($CdCl_2$ solution) at the rates of 0, 2.5, and 10 ppm was mixed with the soil. Each treatment was replicated three times. Lettuce, radish, celery, and green pepper were sown and the seedlings were thinned to 12, 6, 4, and 3 plants per container, respectively. Radish, lettuce, green pepper, and celery crops were harvested after 26, 37, 112, and 117 days of growth, respectively. Plants were washed with glass-distilled water, blotted dry, and the fresh weights were determined. All samples were freeze-dried,

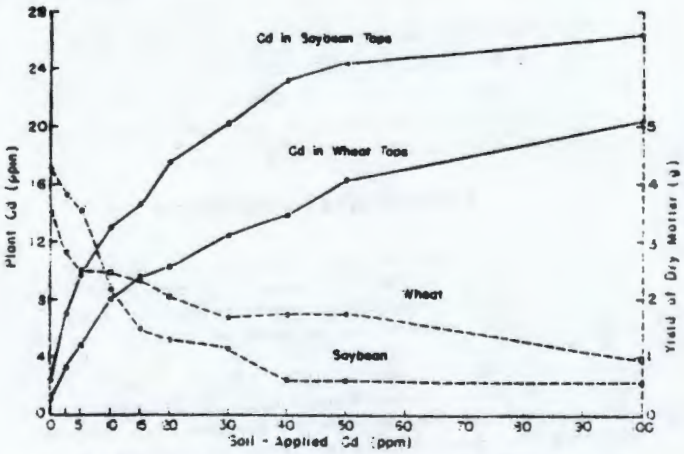

Fig. 1—Yields and Cd uptake by soybean and wheat tops as influenced by soil-applied Cd.

weighed, ground in a stainless steel Micro-Mill, and digested with $HClO_4$ and HNO_3 for Cd analysis by atomic absorption spectrophotometry.

RESULTS AND DISCUSSION

Roots and Foliar Absorption

The translocation of ^{115m}Cd in soybean tops and beans via foliar and root systems is shown in Tables 1 and 2. Irrespective of the method of application, the percent of the applied ^{115m}Cd in various plant parts decreased in the following order: stem > leaves > pods > beans.

Radiocadmium applied to a trifoliate leaf of 4-week-old soybean plants was readily transported and distributed within the plant tops, as measured by subsequent assay of radiocadmium of nontreated plant parts. Similar translocation and distribution of ^{115m}Cd within the plant tops were found with root placement of radiocadmium. Although foliar-applied ^{115m}Cd was readily translocated, the root application resulted in a much higher percentage of the applied radiocadmium found in leaves, stems, pods, and beans. Based on the percentage of applied ^{115m}Cd, the uptake of this isotope by beans via the root system was more than 16 times as efficient as the foliar placement.

Effect of Soil-Applied Cd on Growth and Cd Concentrations of Plants

The dry matter yields and Cd concentrations of wheat and soybean tops with different rates of soil-applied Cd are shown in Fig. 1. In both crops, the Cd concentration of plant tops increased while yields decreased with increasing levels of applied Cd. Cadmium toxicity began to occur in both soybeans and wheat at the lowest level of applied Cd (2.5 ppm) as shown by a sharp decline in the yields of dry matter (Fig. 1). Soybean plants appeared to be more sensitive to excess Cd than wheat. For wheat plants, there were no visual toxicity symptoms other than the stunted growth. For soybean plants however, in addition to growth retardation, definite visual Cd toxicity symptoms were observed. At the 2.5-ppm Cd level, the veins at the lower parts of the younger trifoliates near the petiole became reddish-brown in color. As the Cd level increased, the browning of the veins progressed further throughout the leaves (Fig. 2). Finally at the acute stage of toxicity, younger leaves became chlorotic until the

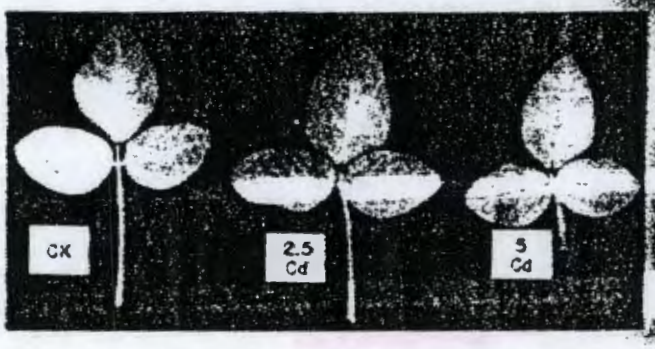

Fig. 2—Effect of Cd excess on soybean leaves. Note the dark veins on the abaxial surface of the leaf at 5 ppm soil-applied Cd.

leaves were devoid of chlorophyll (Fig. 3). Since excessive application of heavy metals such as Zn (3), Cu (13 and 16), Ni (7, 17), and Mn (6) may produce or aggravate Fe deficiency in plants, perhaps excess Cd in plants may have a similar effect as is witnessed by those symptoms which resemble Fe chlorosis.

Although there was a positive correlation between the plant Cd and soil-applied Cd, the concentration of this metal in plants was not in direct proportion to the added amounts. Apparently, the effect of Cd toxicity is such that plant growth is retarded before large quantities of Cd are absorbed and translocated to the top.

Cadmium Uptake by Vegetable Crops

Uptake of Cd and yields of various vegetable crops as influenced by soil-applied Cd are shown in Table 3. The relative concentration of Cd found in vegetable crops varied considerably depending on the plant species. Highest concentration of this metal (dry weight basis) was found in lettuce while the least amounts were detected in green pepper and radish roots. The Cd concentration of radish tops was more than two times greater than that of the roots. Similar results were reported by Lagerwerff (10).

In general, there was a depression in yield due to soil-applied Cd. Such depression was more pronounced for lettuce than for any other vegetable crop. Lagerwerff (10), however, found a significant increase in radish yield which coincided with increase in Cd (from 0.11 to 0.56 ppm) and Zn (from 10.1 to 59.8 ppm) contents of the soil extracted with NH_4Cl. The Cd and Zn concentrations of the above radish tops ranged from 1.6 to 2.9 and from 69.8 to 152 ppm, respectively. Although the yield of radish tops was associated with soil Cd, perhaps the increase in yield was due to the alleviation of Zn deficiency. Preliminary studies by Allaway (1) indicated that plant growth depression due to Cd toxicity tended to occur after plants had accumulated approximately 3 ppm of this metal.

The results presented here show that although foliar-applied Cd was readily translocated into various parts of soybean plants, the uptake of Cd via the root system was significantly higher. This suggests that for grain crops Cd absorption via the foliage from contaminated airborne particulates is not as serious as absorption via the root systems from contaminated soils. However, it is important to consider that those crops directly consumed either by man or animals, are continually exposed to aerial contaminants. During the exposure, dust particles containing Cd will adhere to the plant, and a certain fraction of the metal, depending on the solubility of the contaminant, may be absorbed by leaves. The remaining fraction may or may not be washed by rain depending on the physical nature of the plant surface and the characteristics of the contaminants. In addition to Cd uptake from soil, the above fractions will increase the overall Cd content of plants. According to Lagerwerff (10), aerial contamination accounted for more than 40% of the Cd content of the radish tops in radish plants grown at 200 m from the highway.

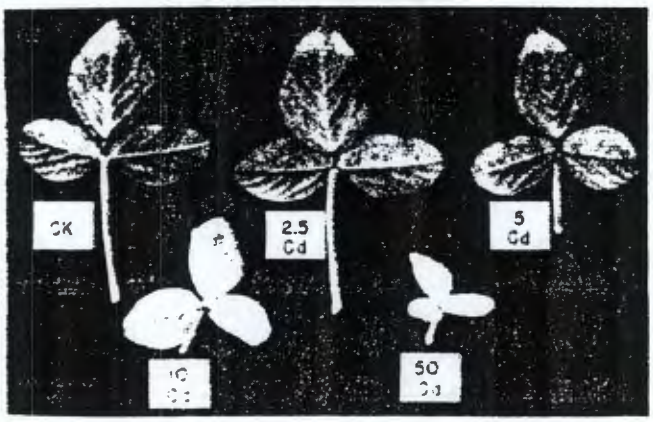

Fig. 3—Effect of soil-applied Cd (0–50 ppm) on soybean leaves.

Table 3—Cadmium uptake and yields of various vegetable crops as a function of soil-applied Cd (Exp. 3)

Cd applied, ppm	Lettuce	Celery, stalk	Celery, leaves	Green pepper	Radish, tops	Radish, roots
			Cd Concentration, ppm			
0	2.30 k*	1.26 m	0.83 n	0.76 n	1.57 l	0.51 o
2.5	11.50 d	5.33 h	3.77 j	3.82 j	10.20 f	4.20 i
10	27.10 a	14.87 c	10.77 e	6.28 g	16.13 b	5.93 h
			Yield, g dry weight			
0	3.16	11.24	16.32	16.91	2.35	2.11
2.5	1.49	10.77	13.92	16.57	2.11	1.28
10	1.35	10.29	14.35	16.74	2.06	1.50
			Yield, g fresh weight			
0	54.3	107.3	102.1	414.2	12.9	10.9
2.5	35.1	109.9	90.7	388.7	10.5	9.5
10	21.9	100.9	90.0	178.9	10.3	7.5

* Means followed by the same letter are not significantly different at the .5% level.

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Microbiological Effects and Persistence of Some Pesticide Combinations in Soil[1]

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ABSTRACT

Zineb, parathion, DDT, and Furadan were applied alone and in combination to field plots, with times and rates of application approximating current agronomic practice for the growth of shade-leaf tobacco in the area of Quincy, Florida. Persistence of the pesticides in the soil and possible effects of the pesticides on relative microbial numbers and nitrification were monitored at 2-week intervals over a period of 16 weeks. Relative numbers of bacteria and actinomycetes in all treatments failed to differ significantly from the untreated control. Fungi increased significantly (5% level) in the parathion + DDT + zineb treatment. There were no other significant differences in microbial numbers. Nitrification, as indicated by levels of NO_3-N, showed no significant difference due to treatments when compared to the control at the 5% level. Parathion applied as a single dose was present in the soil in significantly higher amounts initially when compared with treatments where parathion was applied on a weekly basis. This difference disappeared after 6 weeks. There were no other significant differences in pesticide persistence in the soil.

Additional Index Words: parathion, DDT, zineb, Furadan, nitrification.

The substantial increase in development and use of pesticides in agriculture within recent years has stimulated a corresponding increase in research to determine the effects and fate of these pesticides in nature. To date, most of these studies have been concerned with compounds used singly, whereas in actual practice several different pesticides may be used simultaneously or in sequence. Such practice is common in the cultivation of shade leaf tobacco in the vicinity of Quincy, Florida. As many as 10 different pesticides may be applied at weekly intervals, at rates up to 2.24 kg/ha (1 lbs/acre), throughout the course of the growing season. Much land has been committed to continuous cultivation of this crop for several generations. This amounts to a massive qualitative as well as quantitative pesticide application over a period of a few years. The purpose of this study was to determine the effects of some of these pesticides, alone and in combination, with respect to persistence in soil and possible effects on the relative numbers of microorganisms and their activity.

MATERIALS AND METHODS

Experimental Design—A randomized complete block design with 10 treatments (nine different pesticide treatments plus one untreated control) replicated three times was used in this study. The plots, on a Norfolk loamy fine sand, were 4.8 m by 4.8 m (16 ft by 16 ft), separated by 3.6 m (12 ft) wide alleys. Treatments and application rates are given in Table 1. The pesticides used in this study were: zineb (zinc ethylene bisdithiocarbamate), parathion (*0,0*-diethyl *0-p*-nitrophenyl phosphorothioate), DDT [1,1,1-trichloro-2,2-bis (*p*-chlorophenyl) ethane], and Furadan (2,3-dihydro-2,2-dimethyl benzofuranyl-7-N-methylcarbamate). Duncan's Multiple Range test was used to compare treatments with the control using a significance level of 5%.

Site Preparation—The test site was prepared by harrowing north-south, then east-west in late January, 1970. Ammonium sulfate was applied at the rate of 1,333 kg/ha (1,190 lbs/acre) in late March and the site was again harrowed as before. Pesticides were broadcast by hand over each plot surface on a 7-day schedule beginning on March 27 and ending June 12, a period of 12 weeks. Parathion (Treatment 5) and Furadan (Treatment 9) were applied once during the test, on March 27. Soil samples, 0–15 cm in depth, were taken at nine bi-weekly intervals. Each plot sample consisted of 10 random 1.9-cm cores composited into one sample/plot. The first samples were taken immediately before the first pesticide application. The plots were maintained in a weed fallow condition and the test site was harrowed for weed control on May 20–21, June 18, and July 28. A daily record of rainfall was maintained.

Table 1—Treatments and application rates

No.	Treatment	Active ingredient/application	
		kg/ha	lbs/acre
1.	Zineb (Z)	1.456	1.3
2.	Parathion (P) Zineb	0.224 1.456	0.2 1.3
3.	Parathion DDT (D) Zineb	0.224 2.240 1.456	0.2 2.0 1.3
4.	Parathion	0.224	0.2
5.	Parathion*	2.688	2.4
6.	Parathion DDT	0.224 2.240	0.2 2.0
7.	DDT Zineb	2.240 1.456	2.0 1.3
8.	DDT	2.240	2.0
9.	Furadan*	1.200	1.0
10.	Control (untreated)	—	—

* Pesticides in Treatments 5 and 9 were applied as a single dose at Time 0. All other treatments were applied at weekly intervals.

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