Growth and Cadmium Accumulation of Plants Grown on a Soil Treated with a Cadmium-Enriched Sewage Sludge[1]

F. T. Bingham, A. L. Page, R. J. Mahler, and T. J. Ganje[2]

ABSTRACT

Corn, wheat, rice, field bean, soybean, cabbage, spinach, lettuce, curlycress, carrot, turnip, radish, tomato, and squash plants were grown to commercial harvest stage using as the substrate, soil pretreated with a municipal sewage sludge (1%) containing variable amounts of $CdSO_4$ up to 640 μg Cd/g soil. Observations included injury symptoms, yield decrement, Cd level of diagnostic tissue, and Cd and Zn content of harvested produce. Cadmium-sensitive plants such as spinach, soybean, curlycress, and lettuce were injured by soil Cd levels of 4–13 μg Cd/g soil; whereas, tomato and cabbage tolerated soil levels of approximately 170 μg Cd/g soil without exhibiting injury symptoms. Rice was tolerant at all levels tested. Leafy plants such as lettuce, spinach, and turnip greens (tops) accumulated 175 to 354 μg Cd/g; whereas, fruit and seed tissue of plants under comparable treatment, with the exception of soybean, accumulated no more than 10 to 15 μg Cd/g tissue. The concentration for soybean extended up to 30 μg Cd/g tissue. Paddy rice exhibited no ill effects for soil Cd treatments up to 640 μg Cd/g soil. Grain of plants under the 640 μg Cd/g treatment contained 2 μg Cd/g tissue. DPTA-extractable Cd correlated (r=0.99) with the level of $CdSO_4$ added to the substrate.

Additional Index Words: Cd availability, Cd toxicity for economic plants, DTPA extractable Cd.

During the past decade, there has been an increasing concern over Cd in the environment because of its toxicity to plants and animals. Chronic exposure to low Cd concentrations via intake of Cd-polluted air, water, and foodstuffs has resulted in numerous cases of ill health in humans. Details of Cd pollution and consequences regarding plants and animals are discussed in review papers by Friberg, Piscator, and Nordberg (1), Fulkerson and Goeller (2), and Page and Bingham (12).

Recent research consisting mainly of short term greenhouse experiments has established that plants absorb substantial amounts of Cd from Cd-amended or contaminated substrates and that Cd accumulation by plants depends upon plant species as well as substrate Cd level. In solution culture experiments, Page, Bingham, and Nelson (13) found that leaves of cabbage, tomato, barley, pepper, corn, lettuce, red beet, and turnip plants, cultured on complete nutrient solutions with Cd concentrations of 0.1 to 0.5 μg Cd/ml, contained up to 200 to 300 μg Cd/g tissue. Turner (15) also observed damage and excessive uptake of Cd with assorted vegetable plants in solution cultures containing as little as 0.1 μg Cd/ml. John (4) studied Cd uptake by eight crop species grown on soil pretreated with Cd in amounts varying from 40 to 200 μg Cd/g. He found leaves of lettuce, spinach, broccoli, cauliflower, and oat plants contained Cd ranging from 100 to 900 μg Cd/g. Haghiri (3) presented comparable data for selected vegetables, soybean, and wheat plants. Thus, there is no question that plants absorb and accumulate Cd in their shoots. There is, however, little information on Cd levels in harvested produce from crop plants under Cd treatments.

Municipal sewage sludges differ greatly in their content of trace metals, depending upon the nature and degree of industrial activity. According to Page's review of the fate of trace metals added with sewage sludge to soils (11), Cd concentrations range from 1 to 1,500 μg Cd/g dry sludge. The studies by Jones, Hinsely, and Ziegler (7) and Linnman (10) indicate the possibility of Cd uptake by plants growing on sludge-treated soil. The above questions served as a stimulus for the present research on Cd uptake and accumulation of a variety of crop plants grown to maturity on soil treated with a Cd-enriched sewage sludge. These experiments were also designed to yield sufficient information on plant growth and tissue Cd relations to establish diagnostic criteria for assessing Cd hazards.

MATERIALS AND METHODS

Sufficient soil (Domino silt loam, Xerollic Calciorthid) was collected from a field site for the greenhouse experiments. This soil has a pH_{sp} of 7.5, CEC of 14 meq/100 g, PW_{sp} of 40%, and an EC_e of 1.0 mmho/cm (16). Mica and montmorillonite predominate the clay fraction.

To have sludge low in heavy metals, sewage sludge was obtained from a treatment plant which processes sewage wastes exclusively from a residential community. The sludge was air-dried, ground, and sieved through a 3.2-mm screen. Separate batches of the sludge

Table 1—Crop species and description of leaf sampling technique used in Cd availability experiment

Crop species	Diagnostic tissue
Field bean *Phaseolus vulgaris* L.	Most recently matured leaf at early blossom
Soybean *Glycine max* Merr.	Most recently matured leaf at early blossom
Wheat *Triticum aestivum* L.	Top three leaves at early spike emergence
Rice *Oryza sativa* L.	Top two leaves at early spike emergence
Corn *Zea mays* L.	Third and fourth leaf from top at early tassel
Tomato *Lycopersicon esculentum* Mill.	Most recently matured leaf at early blossom
Zucchini squash *Cucurbita pepo* L. var. *medullosa* Alef.	Most recently matured leaf at early blossom
Cabbage *Brassica oleracea* L. var. *capitata* L.	Most recently enclosed leaf at early heading
Lettuce *Lactuca sativa* L.	Wrapper leaf at early heading
Curlycress *Lepidium sativum* L.	Shoot at normal harvest stage
Spinach *Spinacia oleracea* L.	Shoot at normal harvest stage
Turnip *Brassica rapa* L.	Most recently matured leaf at early root swelling
Radish *Raphanus sativus* L.	Shoot at normal harvest stage
Carrot *Daucus carota* L. var. *Sativa* D. C.	Shoot at normal harvest stage

[1]Contribution of the Department of Soil Science and Agricultural Engineering, University of California, Riverside, CA 92502; presented before Div. A-5 and S-4, Soil Sci. Soc. Amer., Las Vegas, Nev. 13 Nov. 1973. Received 21 June 1974.

[2]The first two authors are Professors of Soil Science and the other are Research Associates.

9187

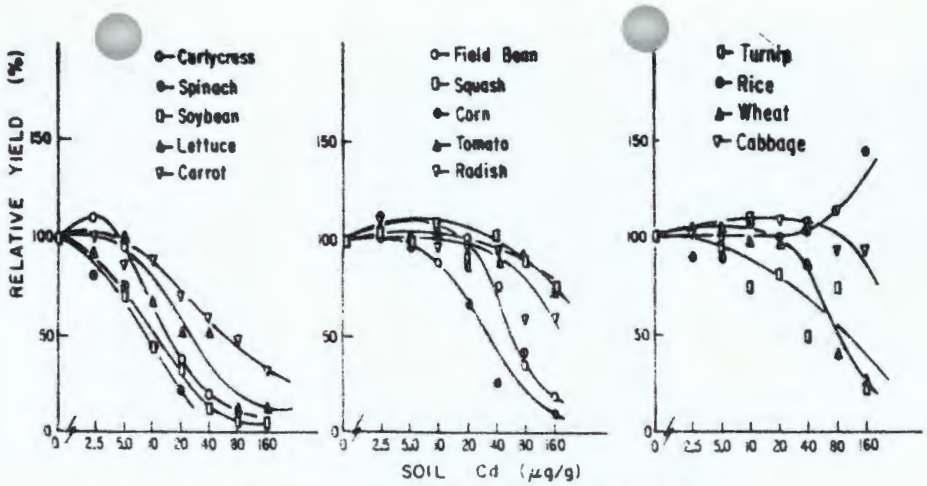

Fig. 1—Relative yield in relation to soil Cd level.

were moistened with $CdSO_4$ solutions to have treatment rates of 0.0, 250, 500, 1,000, 4,000, 8,000, 16,000, 32,000, and 64,000 μg Cd/g dry sludge. Soil Cd treatments of 0, 2.5, 5.0, 10, 20, 40, 80, 160, 320, and 640 μg Cd/g soil were prepared by incroporating 10 g of a given Cd-treated sludge/kg soil. Sufficient 15–30–15 fertilizer was also added to the soil-sludge mix to meet NPK requirements of the test crops. The prepared soil was placed in 7.6-liter plastic pots and arranged on greenhouse benches to have a completely randomized design with 6-fold replication for each Cd treatment level. Freshly prepared soil was used for each crop species. The pH of the soil mixes varied from 7.5 to 7.8.

Crops were established by germinating seed in each soil culture and thinning to two seedlings per pot. All crops were grown to maturity to note treatment effects on yield of edible produce and to have samples of the edible produce for chemical analysis. In addition, leaf samples were collected at early blossom stage for chemical analysis. Deionized water was used for irrigation. A summary of crop species tested and details of sampling the diagnostic tissue (blade, leaf, wrapper leaf, etc.) is given in Table 1.

Chemical analysis of plant tissue for Cd and Zn were carried out by drying the plant samples at 70C, grinding, and mineralizing (digesting) 100 mg of the ground tissue with a perchloric-nitric acid solution, and determining the Cd and Zn concentrations of the perchloric-nitric solution with an atomic absorption instrument equipped with a graphite furnace attachment (the graphite cell was used for low concentrations of Cd).

Available soil Cd was measured according to the technique described by Lindsay (9) for available Fe, Mn, and Zn which, in essence, entails shaking for 2 hours 10 g soil with 20 ml of DTPA-TEA solution adjusted to pH 7.3 and separating the solution phase for determination of Cd.

Table 2—Soil and plant tissue Cd levels associated with a 25% yield decrement

Crop species	Yield component	Soil Cd treatment producing a 25% yield decrement: Cd added	Soil Cd treatment producing a 25% yield decrement: Cd extracted (DTPA)	Tissue Cd level at 25% yield decrement: Diagnostic leaf	Tissue Cd level at 25% yield decrement: Edible
		μg/g			
Spinach	Shoot	4	2.4	75.0	75.0
Soybean	Dry bean	5	3.0	7.0	7.0
Curlycress	Shoot	8	4.8	70.0	80.0
Lettuce	Head	13	7.8	48.0	70.0
Corn	Kernal	18	10.8	35.0	2.0
Carrot	Tuber	20	12.0	32.0	19.0
Turnip	Tuber	28	16.8	121.0	15.0
Field bean	Dry bean	40	24.0	15.0	1.7
Wheat	Grain	50	30.0	33.0	11.5
Radish	Tuber	96	57.6	75.0	21.0
Tomato	Ripe fruit	160	96.0	125.0	7.0
Zucchini squash	Fruit	160	96.0	68.0	10.0
Cabbage	Head	170	102.0	160.0	11.0
Rice	Grain	>640	>384.0	3.0*	2.0*

* Maximum values for 640 μg Cd/g soil treatment -- no yield depression noted up to 640 μg Cd/g addition.

RESULTS AND DISCUSSION

Yield Relations

Yields expressed relative to that of the c[illegible] Cd/g treatment yield = 100%) are plotted in F[illegible] function of the soil Cd level up to 160 μg Cd/g [illegible] er treatment levels (320 and 640 μg Cd/g) w[illegible] cluded for a number of crop species because o[illegible] treme toxicity. This figure is composed of th[illegible] each showing relative yields of crop plants of [illegible] comparable tolerance to Cd. The left-hand gra[illegible] ample, illustrates yield relations of sensiti[illegible] (spinach, soybean, carrot, curlycress, and lett[illegible] strate concentrations of 4 to 20 μg Cd/g soil [illegible] ated with yield reductions of 25% for such cro[illegible] The right-hand graph depicts yields of relatively [illegible] plants such as rice, cabbage, and wheat. Soil C[illegible] trations for a 25% yield decrement varied from [illegible] g for wheat to 170 μg Cd/g for cabbage. Ri[illegible] other hand, was tolerant; actually yields contin[illegible] crease with soil Cd up to the highest level teste[illegible] Cd/g). Increased yields upon adding small amou[illegible] to the substrate were exhibited by most of the cro[illegible] tested in the current investigation. Such increase[illegible] also been observed by Turner (15) and John (4) [illegible] not have an adequate explanation for Cd stim[illegible] yields.

The present study was conducted under highly unifo[illegible] conditions for establishing tolerance to Cd. Ta[illegible] sents a tabulation of crop species listed accordi[illegible] soil Cd level causing a 25% yield decrement. T[illegible] of this ranking (Table 2) are consistent with the [illegible] rankings deduced from short term solution cultur[illegible] ments by Page et al. (13) and from soil culture [illegible] ments by Haghiri (3) and John (4). However, "c[illegible] soil concentrations (μg Cd/g producing a 25% yield [illegible] ment) reported in Table 2, pertain to the specific con[illegible] tions of experiments and, hence, are not necessa[illegible] cable to other soils or soil mixes. Perhaps th[illegible] tracted with DTPA solution is a more realistic [illegible] ment of available soil Cd. Lindsay (9) recommended th[illegible] DTPA technique for available Fe, Mn, and Zn; be[illegible] cause Cd is chemically akin to Zn, this procedure s[illegible]

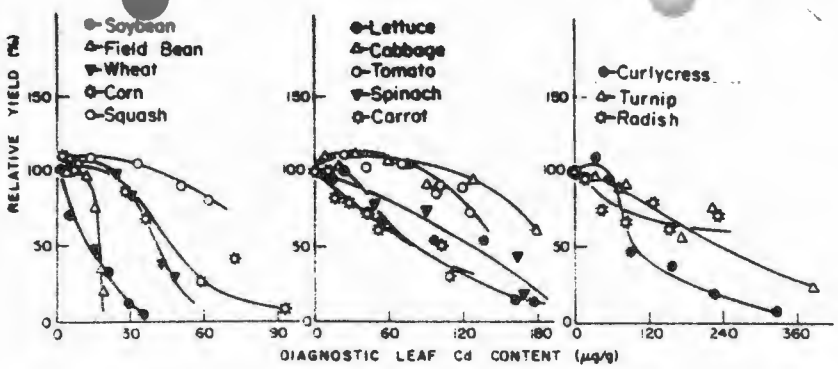

Fig. 2—Relative yield in relation to Cd content of diagnostic tissue.

sufficient for Cd. This technique extracts approximately [illegible] of the Cd added to the sludge-soil mixture ($y = 0.07 + 0.50x$, $r = 0.99$) and thus can be correlated with yields. We recognize that the utility of the DTPA extraction technique for available Cd is still subject to question because (i) our study includes only one soil, and (ii) inclusion of a variety of soils may result in different DTPA-Cd plant relations. Nevertheless, soil chemical tests for available Cd need to be calibrated for specific crop species, as shown in Table 2, as well as for a variety of soil conditions. The reader interested in additional detail on chemical soil tests for Cd is referred to publications by Lagerwerff (8) and John and associates (5, 6).

Leaf Analysis

Another technique frequently employed for assessing nutritional levels or possibilities of a toxicity consists of sampling and chemically analyzing specific plant parts such as the leaf blade or petiole at a given physiological growth stage. In most cases, we sampled the most recently matured leaf at early bloom (see Table 1 for additional details). Figure 2 presents the relationship between leaf Cd and yield for various crop species. These data clearly indicate that leaf analysis may serve as a valuable guide to diagnosing Cd toxicity. Leaf Cd values for 25% yield decrements are listed per respective crop species in Table 2. These values differ from the extremes of 3.0 and 7.0 μg Cd/g leaf for rice and soybean at early flowering to 160 and 125 μg Cd/g leaf for cabbage and tomato. There is no distinct relationship between Cd tolerance with respect to yield and accumulation of Cd in the diagnostic tissue. Leaf analysis for Cd from earlier but less extensive experiments by Page et al. (13), Turner (15), Haghiri (3), and John (4) are consistent with those of the present experiment.

Cd Content of Edible Plant Parts

Figure 3 indicates the range of Cd concentrations for edible parts of mature crop plants under known treatment levels of Cd. In general, the lowest Cd concentrations are found in tuber, seed, and fruit tissue, and the highest in leafy tissue. Moreover, there are marked plant species effects to contend with when discussing uptake and accumulation of Cd in specific plant parts. As an example, seed Cd content for rice, bean, corn, wheat, and soybean

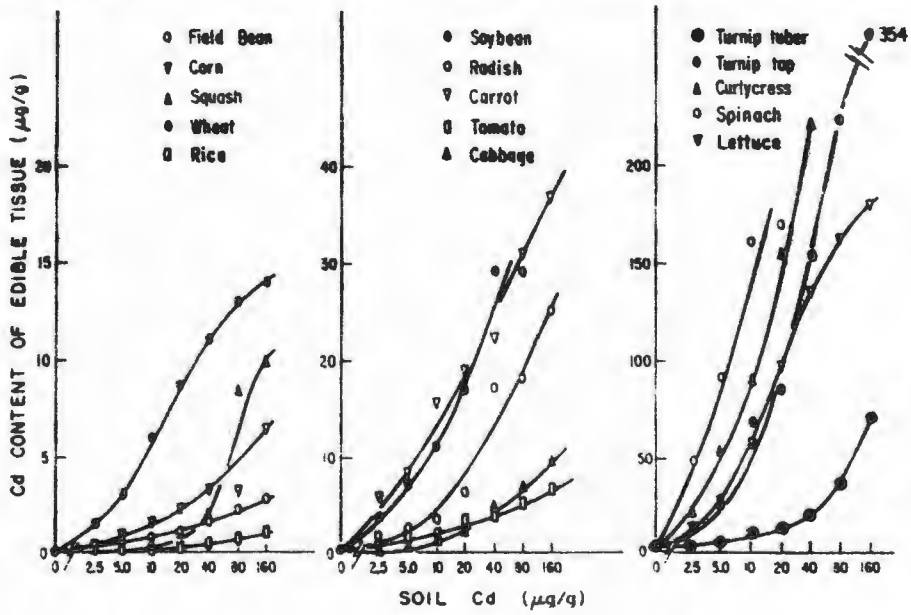

Fig. 3—Cadmium content of edible tissue in relation to soil Cd level.

Table 3—Cadmium and zinc content of diagnostic and edible tissue in relation to soil Cd treatment

	Field bean				Soybean				Corn				Wheat					
	Leaf		Dry bean		Leaf		Seed		Leaf		Grain		Leaf		Grain		Leaf	
Treatment	Cd	Zn	Cd	Zn	Cd	Zn	Cd	Zn	Cd	Zn	Cd	Zn	Cd	Zn	Cd	Zn	Cd	Zn
μg Cd/g soil	μg/g tissue*																	
0.0	0.6a	47c	0.05a	23cd	0.4ab	57fg	0.6a	61def	3.9a	38bcd	0.05a	32a	0.1a	44d	0.1a	45c	0.1a	13ab
2.5	1.8a	44c	0.2ab	25d	3.7ab	58g	3.9bc	72g	11.0b	42d	0.05a	38ab	2.7a	38bcd	1.5ab	47c	0.1a	16ab
5.0	4.3b	39de	0.4ab	21c	5.5b	49defg	6.8c	63ef	23.0b	39cd	0.5ab	47ab	6.4ab	35bc	2.8b	42c	0.1a	17bc
10.0	10.0c	31cd	0.7bc	21c	16.0c	53efg	11.0d	68fg	27.0bc	33abcd	1.4bc	47ab	12.0b	41cd	5.8c	48c	0.1a	16ab
20.0	12.0d	29abc	1.0c	20c	22.0d	48cdefg	17.0e	55cde	40.0c	26ab	2.4cd	45ab	24.0c	34bc	8.7d	41bc	0.1a	14ab
40.0	14.0e	29abc	1.7d	15b	29.0e	38bcd	29.0g	54bc	58.0d	27abc	3.4d	54b	31.0	37bcd	10.0d	44c	0.1a	16ab
80.0	19.0f	21ab	2.3e	13ab	36.0f	36abcd	29.0g	54bc	71.0d	24a	3.2d	41ab	41.0d	31ab	13.0e	32ab	0.3b	20c
160.0	19.0f	24abc	3.0f	12a	35.0ef	28ab	21.0f	37a	94.0e	22a	6.6e	53b	48.0d	24a	14.0e	29a	0.7c	13a

* Values followed by same letter within column are not significantly different by Duncan multiple range test at the 5% level.

plants under a uniform Cd treatment of 10 μg Cd/g soil were found to be, respectively, 0.2, 0.7, 1.4, 5.8, and 10.7 μg Cd/g tissue. Under the comparable treatment, 0.2 and 1.2 μg Cd/g tissue were noted for squash and tomato fruit. The leafy tissue from lettuce, curlycress, and spinach had markedly higher concentrations, namely 60, 90, and 160 μg Cd/g tissue. Moreover, comparison of shoot and tuber content of Cd reveals large differences dependent upon plant tissue. As examples, turnip tops under the 10 μg Cd/g soil treatment accumulated 70 μg Cd/tissue, whereas the tuber accumulated 9.3 μg Cd/g tissue. Table 3 gives additional data on Cd content of leaf and seed tissue of corn, wheat, rice, soybean, and field bean plants under soil Cd treatments ranging up to 160 μg Cd/g soil. Zinc analyses are also included. Other than the publications by Haghiri (3), John (4), and Jones et al. (7), there is a paucity of data pertaining to Cd content of edible plant parts to compare with those of the present investigation. As mentioned earlier, investigations on Cd accumulation by plants have consisted, in general, of short term experiments.

Although yield relations are of utmost importance to agronomists, entry of Cd into the food chain through consumption of produce with elevated Cd concentrations is of greater importance because of the unusually high toxicity of Cd to animals. Health and welfare workers in Japan, as a result of associating Cd with the "Itai-Itai" disease epidemic in the Jintsu basin (14, 17), consider a daily intake of 300 μg Cd/person the maximum acceptable rate. Their upper limit for Cd in unhulled rice is set at 0.4 μg Cd/g. The locally produced rice in this epidemic area was identified as a major dietary source of Cd for the diseased residents. The Cd concentrations of this rice averaged over 1.0 μg Cd/g and ranged up to 3.4 μg Cd/g. The reader is referred to the discussions of the "Itai-Itai" disease by Yamagata and Shigematsu (17) and Tsuchiya (14) for specific details. Thus, the observation of elevated levels of Cd in the edible portion of crop plants subjected to relatively low additions of substrate Cd, viz. plant Cd analysis corresponding to the 2.5, 5, and 10 μg Cd/g soil treatments (Fig. 3 and Table 3) merits serious attention from a public health consideration. The Cd data for the basic staple crops such as soybean, field bean, corn, wheat, and rice are particularly relevant (Table 3). Of this group, wheat and soybean seed reflect the greatest Cd concentrations. The hazard depends on the accumulative intake of Cd; thus, dietary customs as well as Cd content of foodstuffs are important parameters to include in setting "threshold" limits which is beyond the scope of this paper. We have pointed out some of the growing conditions exerting influences upon the Cd concentration of plant parts.

Cd-Zn Relations

Table 3 lists Cd and Zn analyses for the diagnostic leaf and edible plant part from five crop species under soil Cd treatments. According to Duncan's multiple range criterion the Zn concentrations of plant tissues are significantly reduced at the higher Cd treatment rates. The data for beans are illustrative: leaf Zn, for example, dropped from 47 μg/g tissue for control plants to 24 μg/g tissue for plants under the 160 μg Cd/g soil treatment. Similarly, seed Zn concentrations decreased about 50%. Although the higher treatment levels of Cd curtailed yields and Zn concentrations markedly, none of these crops developed Zn deficiency symptoms. Some plants at the highest Cd treatment rates did exhibit chlorosis; however, chlorosis is commonly associated with a variety of deficiency and/or toxicity conditions and is not specific for Cd toxicity. Turner (15) likewise concluded from solution culture experiments with a variety of vegetable plants under Cd treatments that the observed yield reductions were caused by Cd directly rather than through an induced deficiency.

SUMMARY AND CONCLUSIONS

The present series of experiments demonstrate that Cd is accumulated by a wide variety of crop species in response to Cd concentrations of the substrate. Moreover, the Cd content of plants varies according to plant species and plant tissue. Cereals and legumes accumulate more Cd in the shoot than leafy plants such as lettuce, curlycress, and spinach. Extremes in the accumulation characteristics are noted upon comparing rice with lettuce or spinach. Regarding Cd distribution, the least amount is found in the tuber, seed, and fruit tissue, while the greatest in leaf tissue. Analyses of Cd and Zn in leaf and edible tissue reveal a significant negative effect of Cd on Zn accumulation, especially with plants under relatively high treatments of $CdSO_4$; however, no deficiency symptoms were exhibited by any of the crop species. This suggests the possibility of Cd interference with plant Zn through restricting Zn uptake to induce Zn deficiency. The resultant Zn concentrations were not low enough, nor were symptoms noted to cause Zn deficiency. We do not have an adequate explanation to account for the reduced Zn levels. Chemical analysis for both DTPA-Cd and

agnostic leaf-Cd may be used as agnostic criteria for assessing Cd toxicity.

ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support for research leading to this publication by the University of California Water Resources Center (Grant UCAL-WRC-W-420).

LITERATURE CITED

1. Friberg, L., M. Piscator, and G. Nordberg. 1971. Cadmium in the environment. Chemical Rubber Co. Press, Cleveland, Ohio. 166 p.
2. Fulkerson, W., and H. E. Goeller (ed.). 1973. Cadmium, the dissipated element. Oak Ridge National Laboratory Report NSF-EP-21.
3. Haghiri, F. 1973. Cadmium uptake by plants. J. Environ. Qual. 2:93–96.
4. John, M. K. 1973. Cadmium uptake by eight food crops as influenced by various soil levels of cadmium. Environ. Pollut. 4(1):7–15.
5. John, M. K., H. H. Chuah, and C. J. VanLaerhoven. 1973. Cadmium contamination of soil and its uptake by oats. Environ. Sci. Tech. 6:555–557.
6. John, M. K., C. J. VanLaerhoven, and H. H. Chuah. 1972. Factors affecting plant uptake and phytotoxicity of cadmium added to soils. Environ. Sci. Tech. 6:1005–1009.
7. Jones, R. L., T. L. Hinsely, and E. L. Ziegler. 1973. Cadmium content of soybeans grown in sewage-sludge amended soil. J. Environ. Qual. 2:351–353.
8. Lagerwerff, J. V. 1971. Uptake of cadmium, lead, and zinc by radish from soil and air. Soil Sci. 111:129–133.
9. Lindsay, W. L. 1972. Zinc in soils and plant nutrition. Advan. Agron. 24:147–186.
10. Linnman, L. 1973. Cadmium uptake by wheat from sewage sludge used as a plant nutrient source. Arch. Environ. Health 27:45–47.
11. Page, A. L. 1974. Fate and effects of trace elements in sewage sludge when applied to agricultural lands. EPA Report No. 670/2-74-005, Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, Ohio.
12. Page, A. L., and F. T. Bingham. 1973. Cadmium residues in the environment. Residue Rev. 48:1–44.
13. Page, A. L., F. T. Bingham, and C. Nelson. 1972. Cadmium adsorption and growth of various plant species as influenced by solution cadmium concentration. J. Environ. Qual. 1:288–291.
14. Tsuchiya, K. 1969. Causation of Ouch-Ouch disease. An introductory review. Kei J. Med. 18:181–211.
15. Turner, M. A. 1973. Effect of cadmium treatment on cadmium and zinc uptake by selected vegetable species. J. Environ. Qual. 2:118–119.
16. U. S. Salinity Laboratory. 1954. USDA Handbook No. 60.
17. Yamegata, N., and I. Shigematsu. 1970. Cadmium pollution in perspective. Inst. of Public Health 19(1):1–27. Tokyo, Japan.

The Responses of Soils and Soil Microorganisms to Silver Iodide Weather Modification Agents[1]

R. A. Sokol and D. A. Klein[2]

ABSTRACT

To determine the consequences of AgI weather modification agent accumulation to the soil microbial environment, the effects of added silver compounds on microbial growth, anaerobic cellulose degradation, and the soil environment adjacent to a cloud seeding generator were investigated. Silver ion from $AgNO_3$ inhibited microbial growth in cultures at concentrations as low as 6×10^{-9} g ml^{-1} and cultures saturated with AgI displayed an inhibition of growth initiation approximately equivalent to 35×10^{-9} g ml^{-1} silver ion. Muds containing AgI exhibited significantly decreased anaerobic cellulose degradation rates in long term experiments, when concentrations of 100 μg AgI/g were present. An analysis of the soil surrounding a seeding generator site in Steamboat Springs, Colorado indicated that deposited silver tends to remain near the soil surface (0–2 cm). Alterations in the soil environment due to high silver concentrations were indicated by consistently higher organic matter levels, water contents, microbial populations, and rates of soil respiration. These results suggest that high concentrations of seeding agent potentially can alter the soil microbial environment by inhibiting organic matter decomposition, but that the silver levels which accumulate in seeded target areas should have no short effects on the soil environment.

Additional Index Words: cloud seeding, silver accumulation, microbial decomposition, anaerobic cellulose decomposition, organic matter decomposition, *Arthrobacter* sp.

[1]Contributed by the Department of Microbiology, Colorado State University, Fort Collins, CO 80523. This investigation was supported in part by funds from the Bureau of Reclamation under Project 14-06-7052. Received 6 August 1974.

[2]Ph.D. Candidate and Associate Professor, respectively, Dep. of Microbiology.

The environmental consequences of weather modification must be considered in assessing the ramification of these operations for land use. One aspect of weather modification which has not been adequately investigated is the residual effect of the most commonly used cloud seeding agent, silver iodide, on the soil and the micro-organisms present in this environment.

Present weather modification operations produce seeding nuclei by burning a mixture of silver iodide and an iodide salt dissolved in acetone. Burning rates vary with the type of storm being seeded and the method of application, but amounts as high as 10 Kg AgI $hour^{-1}$ $storm^{-1}$ have been used (14). Silver concentrations as high as 45×10^{-10}g ml^{-1} (17) have been measured in seeded precipitation compared to levels of 20×10^{-12}g ml^{-1} in unseeded precipitation (5, 13).

The amount of nucleating agent deposited in the soil from any one seeding event would appear to be negligible. Long term weather modification operations; however, in conjunction with recent evidence (3) that silver iodide deposited on the soil tends to be retained predominantly in the surface 2 cm would indicate that residual seeding agent could eventually be deposited in soils to biologically significant levels. In addition, wind and water erosion of soil may be capable of concentrating silver in the sediments of streams and lakes resulting in silver levels higher than predicted by overall area accumulation calculations.

Cooper and Jolly (4) have postulated that it is unlikely that silver from weather modification will adversely effect