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The Effect of Soil-added Cadmium on Several Plant Species[1]

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ABSTRACT

Several species (*Andropogon scoparius, Rhus radicans, Rudbeckia hirta, Anemone cylindrica, Monarda fistulosa, Poa pratensis,* and *Carex spicata*) native to northwestern Indiana were grown from seed in the greenhouse for 6 weeks. An uncontaminated sandy soil was utilized as the substrate with four levels of soil-added Cd. The concentrations added ranged from 0 to 100 μg Cd/g soil and were comparable to surface soil Cd concentration levels found in the urban-industrial region of northwestern Indiana.

Data on germination, survival, height, and dry weight were collected. Germination, survival, and weight were found to exhibit a negative response to increasing soil Cd concentration over all species. Height, however, was not found to be a consistently good indicator of Cd response. While overall species' differences were noted, no differences could be conclusively shown among the species for Cd tolerance, although there were indications that this was the case. All effects noted were of a low level for the soil-added Cd concentrations utilized.

Additional Index Words: urban ecosystems, germination, seedling growth, dry weight.

Increasing Cd concentrations have been associated with reduction in plant growth, measured as dry weight yield (Haghiri, 1973; Inst. Environ. Stud., 1972; Turner, 1973; Bingham et al., 1976; Bingham et al., 1975), and with root damage (Turner, 1973). These effects are, in turn, species-dependent (Turner, 1973; Bingham et al., 1975; Bingham et al., 1976; Page et al., 1972), some species being more tolerant of Cd than others.

The above effects have, for the most part, been determined from controlled experiments using culture solution (Haghiri, 1973; Inst. Environ. Stud., 1972; Turner, 1973; Jarvis et al., 1976; Page et al., 1972). Almost exclusively they have utilized vegetable or other plant species of economic importance (Haghiri, 1973; Turner, 1973; Jarvis et al., 1976; Bingham et al., 1975; Page et al., 1972), rather than the native species of importance in terrestrial ecosystems.

Most field studies on heavy metals to date have dealt with plant communities adjacent to ore smelters (Buchauer, 1973; USEPA, 1972; Burkitt et al., 1972)[3] where heavy metal concentrations are quite high. Many greenhouse experiments also have utilized high heavy metal concentrations. These high concentrations do show dramatic results but they are not representative of the more moderate environmental concentrations to be found in most urban-industrial regions.

The urban-industrial region of northwestern Indiana has been subjected to atmospheric contamination of heavy metals for about 80 years. The concentrations of Cd, Zn, Pb, and Cu averaged 10, 2,456, 463, and 119 μg/g soil, respectively, in the top 2.5 cm of soil, in a relatively undisturbed urban ecosystem approximately 5.3 km south of Lake Michigan (Parker et al., 1978). These levels compare to 0.2, 29, 20, and 4 μg/g for the same metals, respectively, in the top 2.5 cm of soil, at a similar, although uncontaminated, site 67.2 km to the south.

The major emphasis of this research was on the potential effects of Cd on native plant species, and, by implication, on native plant communities. An experiment was performed to determine if Cd in moderate concentrations can affect germination, survival, height, and yield of several ground-cover species native to the urban-industrial region of northwestern Indiana.

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METHODS

Seven plant species native to the urban-industrial region of northwestern Indiana were chosen: *Rudbeckia hirta* (black-eyed Susan), *Andropogon scoparius* (little bluestem), *Monarda fistulosa* (wild bergamot), *Rhus radicans* (Poison-ivy), *Anemone cylindrica* (long-fruited thimbleweed), *Liatris spicata* (rough blazing-star), and *Poa pratensis* (Kentucky bluegrass). These species, hereafter referred to by genus, comprise a wide range of Cd accumulation characteristics and represent about 10% of the species composition and 50% of the June biomass for ground-cover species for an urban ecosystem (Chaney et al., 1975).

Seed for *Liatris* and *Rhus* were collected for use in these experiments. Seed for the other species were purchased from seed supply companies. All seed were stratified in moist sand before planting (Andersen, 1968; USDA, 1948).[4]

The upper 14 cm of the soil profile (i.e., A horizon) were collected from an uncontaminated site at the Willow Slough Fish and Game Area 67.2 km south of Lake Michigan. The soil [Plainfield sand (sandy mesic typic Udipsamment)] is similar to those found in the northwestern Indiana urban-industrial region with 0.33 μg Cd/g soil, 1.93% O.M., 6.28 meq CEC/100 g soil, 4.8 pH, 56.6 kg exchangeable P/ha soil, 88.0 kg exchangeable K/ha soil, 17.0 kg total N/ha soil, and 24.3% base saturation.

Soil was air dried and passed through a 0.64-cm (0.25-inch) stainless steel wire mesh sieve to remove organic residue before placing in 11.4-cm (4.5-inch) standard plastic pots. The pots, containing equal weights of soil (800 g/pot), were placed in 13.3-cm (5.25-inch) square plastic trays which were used to subirrigate the pots. This watering strategy was used to prevent splash contamination of adjacent pots, washout of seedlings, and leaching loss of Cd, as well as to provide a faster, more uniform watering regime.

The pots were amended with 0, 10, 30, and 100 μg Cd/g of air dry soil. Cadmium chloride solution was added to the tops of each pot in amounts sufficient to bring each pot to its respective Cd concentration. The soils were watered to field capacity and incubated in the greenhouse for 7 to 10 days to allow the soil chemical reactions to equilibrate before seeding. No nutrient solutions or other additions were made.

Forty seeds were planted in each pot for all species except *Poa*, for which 10 seeds were planted. Germination was recorded for each pot every 2 to 3 days. When germination appeared to be complete, the "0 day" was calculated. This was taken to be the day midway between the day the initial germination was recorded and the day the final germination was recorded. This was done separately for each pot and was used to represent the beginning of vegetative growth for each pot. Plants were thinned to a maximum of five per pot 1 week after vegetative growth started. Two to three days later the plants were thinned to a maximum of three per pot and for identification each plant was labeled.

Two weeks after growth initiation, at weekly intervals, plant numbers and heights were measured. Height was taken to be: length from the soil surface to the tip of the longest blade for an individual of *Andropogon*, *Liatris*, or *Poa*; to the apex for *Monarda* and *Rhus*; or the maximum width (circumference) from leaf tip to leaf tip across a basal rosette for *Rudbeckia* or *Anemone*. The experiment was terminated after 6 weeks of growth. The plants were harvested, separated into tops and roots, dried at 80°C, and weighed (g).

Samples were collected from the top 2.5 cm and base 2.5 cm (9 to 11.5 cm) of soil and oven dried at 80°C. Metals were extracted from 5- to 10-g soil samples by adding 5 ml of 16*N* HNO_3, and allowing the mixture to stand for 10 min. After NO_2 fumes disappeared, an additional 20 ml of 16*N* HNO_3 were added. This suspension was heated for 2 hours and allowed to stand overnight. The filtrate was evaporated to 15 ml, then brought to volume with double-distilled H_2O. Samples were analyzed for Cd using atomic absorption spectroscopy.

The experiment was a completely random design with two factors: species and soil-added Cd treatments with seven and four levels, respectively (the 100-μg Cd/g soil treatment, however, was dropped from most statistical analyses since it incurred almost total [illegible]. Statistical techniques used to analyze the data included [illegible] homogeneity, analysis of variance, analysis of covariance, [illegible] regression.

[4] R. Clinebell. 1975. Personal communication. Prairie Sunshine Seed Co., Wyoming, Ill.

Table 1—Average germination proportions and (standard [illegible] for three replicates of seven species at four levels of Cd [illegible]

Species	Significance**	Soil-added Cd, μg/g 0	10	30	[illegible]
Poa pratensis	a	1.0000† (0.0)	0.8000† (0.1000)	[illegible]	[illegible]
Rudbeckia hirta	ab	0.8333 (0.3417)	0.6583 (0.0546)	[illegible]	[illegible]
Andropogon scoparius	bc	0.4000 (0.0144)	0.3500 (0.0250)	[illegible]	[illegible]
Liatris spicata	bc	0.3417 (0.0083)	0.4000‡ (0.1250)	[illegible] (0.0)	[illegible]
Anemone cylindrica	bc	0.3667 (0.1481)	0.4000 (0.0500)	[illegible] (0.0607)	[illegible]
Monarda fistulosa	c	0.2417 (0.0601)	0.2250 (0.0946)	0.1250 (0.0382)	[illegible]
Rhus radicans	d	0.0250 (0.0)	0.0250 (0.0144)	0.0583 (0.0167)	[illegible]
Average overall species		0.4583	0.4083	0.2833	[illegible]
Significance, α = 0.01		a	ab	b	[illegible]

** Significant difference, α = 0.01, for species average excluding [illegible] treatment. Species with the same letter are not significantly [illegible]

† Weed seed in soil gave results > 1 in some cases. These were [illegible]

‡ Only two replicates for this cell.

RESULTS

Germination

Germination results (Table 1) show significant [illegible] ences among species and treatments. *Rudbeckia* [illegible] *Poa* had the highest germination rates and *Rhus* [illegible] lowest. Such results are to be expected and reg[illegible] innate species germination rate differences.

An examination of the analysis of variance [illegible] (over the 0- to 30-μg Cd/g soil range) does not [illegible] validity for the hypothesis of species differences in [illegible] nitude of response to Cd. Thus, the null hypothesis [illegible] common response to Cd among the various species [illegible] not be rejected here.

At 100 μg Cd/g soil germination was almost [illegible] existent. No germination was recorded at this tre[illegible] level for *Anemone* and *Poa*. Two of the species, [illegible] and *Liatris*, which did germinate at this level were started from seed collected within the urban-indus[illegible] region of northwestern Indiana. Only two [illegible] species, *Andropogon* and *Liatris*, which did germi[illegible] at this level produced seedlings which survived [illegible] than 1 or 2 weeks past germination.

Results were also affected by the method of Cd additions. The Cd added in aqueous solution to the pot soil surface did not disperse evenly throughout the pot [illegible] instead was bound by the top 2.5 cm soil layer (Table 2). Thus, the actual soil concentration at the surface, [illegible] germination takes place, is approximately twice the [illegible] ported concentration. A common linear germination response coefficient (slope) for Cd, adjusted for the uneven Cd dispersion, is estimated to be: $g = go - 0.0026$ [illegible] Cd applied (μg/g).

Table 2—Average and (standard error) of Cd recovered from pot soil samples.

Section depth	Soil-added Cd, μg/g			
	0	10	30	100
cm	μg/g			
> 2.5	0.34 (0.06)	20.67 (2.03)	55.87 (6.12)	173.33 (27.28)
> 1.5	0.32 (0.12)	0.20 (0.05)	0.52 (0.11)	0.76 (0.19)

Survival

There was no significant difference in plant survival between the 0- and 10-μg Cd/g soil treatments (Table 3). The 30-μg Cd/g treatment, however, caused decreased survival not only with respect to the control treatment but also over time. No differences among the species were found in the experiment for survival. The test, however, was conservative and, therefore, may accept the null hypothesis when it should be rejected.

Dry Weight

Growth data were collected on dry weight at the termination of the experiment. The data were analyzed using a subsample of the original data. *Anemone* was dropped from consideration because it grew very little over the course of the experiments and was close to the limit of accuracy of the measurement.

The species' weights (top and root dry weight) exhibited a significant response to soil-added Cd (Table 4). Recorded weight decreased with increasing Cd concentration. The weights for the 10- and 30-μg Cd/g soil treatments were not significantly different and lower than the control, respectively.

The root/shoot ratio was not significantly affected by Cd treatment. For this variable, species was the only effect that did show significance.

For the other variables (shoot, root, and total weight) a weight response to Cd was indicated. A reasonable estimate of this response for top, root, and total weight was: log weight (*g*) = log *Wo* − 0.025 Cd applied (μg/g).

Height

Height was not considered as good an indication of growth as was weight, because it measures only one aspect of growth and is quite variable. Height, however, does give a nondestructive estimate of growth over time.

It was noted for several species, especially *Andropogon*, that regression on soil-added Cd at each time produced parallel regression lines. It was hypothesized that the effect of Cd upon height was an initial effect which was merely sustained over time and not intensified or abated.

To test this hypothesis, an analysis of covariance was run with the initial height measurement used as the covariate. This analysis negated all the treatment effects (i.e., no effect for treatment when the data had been adjusted for initial height) for *Poa, Rudbeckia, Monarda, Rhus,* and *Andropogon*.

Table 3—Average proportion of plants surviving for all species at the initial (week 2) and final (week 6) measurement periods, the number of plants (*n* at week 6) that these results are based on, and the potential number of plants (*n'*) that could have been present.

Time	Soil-added Cd, μg/g			
	0	10	30	100
Initial	1.00	1.00	0.96	0.50
Final	0.99	1.00	0.77	0.28
n	83	55	58	9
n'	69	56	69	69

Table 4—Average ($\bar{y}$) shoot weight and root weight per individual plant (standard error, $s_{\bar{y}}$), and number of samples (*n*) for each species at each treatment level.

Species	Significance*		Soil-added Cd, μg/g		
			0	10	30
			g		
			Shoot weight		
Poa pratensis	a	$\bar{y}$	0.1189	0.0967	0.0118
		$s_{\bar{y}}$	(0.0356)	(0.0169)	(0.0036)
		n	3	3	3
Andropogon scoparius	a	$\bar{y}$	0.1107	0.0873	0.0907
		$s_{\bar{y}}$	(0.0246)	(0.0123)	(0.0527)
		n	3	3	3
Liatris spicata	a	$\bar{y}$	0.1032	0.0727	0.0201
		$s_{\bar{y}}$	(0.0120)	(0.0123)	(0.0025)
		n	3	2	3
Rhus radicans	a	$\bar{y}$	0.0463	0.0597	0.0170
		$s_{\bar{y}}$	(0.0063)	(0.0053)	(0.0038)
		n	3	2	3
Rudbeckia hirta	b	$\bar{y}$	0.0531	0.0114	0.0008
		$s_{\bar{y}}$	(0.0241)	(0.0041)	(0.0002)
		n	3	3	2
Monarda fistulosa	c	$\bar{y}$	0.0296	0.0227	0.0095
		$s_{\bar{y}}$	(0.0014)	(0.0017)	(0.0073)
		n	3	2	3
Anemone cylindrica	d	$\bar{y}$	0.0023	0.0021	0.0016
		$s_{\bar{y}}$	(0.0005)	(0.0002)	(0.0003)
		n	3	3	3
Average over six species†			0.0770	0.0584	0.0250
Significant difference, α = 0.01			a	a	b
			Root weight		
Poa pratensis	a	$\bar{y}$	0.1569	0.1371	0.0159
		$s_{\bar{y}}$	(0.0529)	(0.0532)	(0.0040)
		n	3	3	3
Andropogon scoparius	a	$\bar{y}$	0.1416	0.0582	0.0401
		$s_{\bar{y}}$	(0.0451)	(0.0092)	(0.0170)
		n	3	3	3
Liatris spicata	a	$\bar{y}$	0.1192	0.0890	0.0212
		$s_{\bar{y}}$	(0.0478)	(0.0190)	(0.0028)
		n	3	2	3
Rhus radicans	a	$\bar{y}$	0.0417	0.0453	0.0107
		$s_{\bar{y}}$	(0.0151)	(0.0070)	(0.0028)
		n	3	2	3
Rudbeckia hirta	b	$\bar{y}$	0.0599	0.0056	0.0004
		$s_{\bar{y}}$	(0.0407)	(0.0027)	(0.0001)
		n	3	3	2
Monarda fistulosa	c	$\bar{y}$	0.0186	0.0172	0.0070
		$s_{\bar{y}}$	(0.0014)	(0.0062)	(0.0046)
		n	3	2	3
Anemone cylindrica	d	$\bar{y}$	0.0012	0.0010	0.0008
		$s_{\bar{y}}$	(0.0001)	(0.0002)	(0.0002)
		n	3	3	3
Average over six species†			0.0897	0.0587	0.0159
Significant difference, α = 0.01			a	a	b

* Species with the same letter are not significantly different, α = 0.05.
† *Anemone cylindrica* is not included.

DISCUSSION

While the design and setup used for this experiment was as much to generate a data base for native species, which is absent from the literature, as it was an attempt to determine actual effects upon these species, differences among species for magnitude of response to Cd could not be conclusively determined. Species differences have, however, been reported by several investigators (Page et al., 1972; Turner, 1973; Bingham et al., 1976; Bingham et al., 1975; Pettersson, 1976).

The results presented here indicate that soil-added Cd at moderate concentration levels (10 to 30 μg Cd/g soil) can adversely affect the germination, survival, and yield of native species. Yield reductions have been concluded to be caused by Cd directly (Bingham et al., 1975; Turner, 1973) and not indirectly through an induced deficiency. For economic species Cd toxicity has been shown to occur at 2.5 μg Cd/g soil for soybean and wheat (Haghiri, 1973) and 25% yield reductions have been reported for spinach, soybean, curleycress, lettuce, corn, carrot, turnip (Bingham et al., 1975), sudangrass, and alfalfa (Bingham et al., 1976) at Cd addition levels of 4, 5, 8, 13, 18, 20, 28, 15, and 30 ppm, respectively. These are all within the soil Cd addition range utilized for this experiment and found to cause adverse effects on native species.

Some species (or ecotypes), such as *Andropogon* and *Liatris*, are more tolerant of Cd than other species. While we did find innate species differences for germination rate and yield, we could not conclude that species differ in rate of response to Cd. There are, however, indications in the data that this is so.

Only *Andropogon* and *Liatris* germination at 100 μg/g could be considered as significantly greater than 0. Germination for some species such as *Andropogon* and *Liatris*, therefore, may not be as sensitive to Cd as for other species, such as *Rudbeckia* and *Poa*. This provides circumstantial evidence that the hypothesis of species-dependent germination response to Cd is still a viable hypothesis.

Germination and survival effects are quite similar. They can be grouped as a single type of effect—viability. Cadmium can affect a species' viability and certain species, such as *Rudbeckia*, *Monarda*, and *Poa*, may be more susceptiable to this type of effect, while other species, such as *Andropogon* and *Liatris*, which were the only species that had individuals at 100 μg Cd/g soil survive to the end of the experiment, may be less susceptible.

The ecological consequences of viability effects may be quite different from the consequence of growth effects. growth effects are continuous data and would be exhibited as differences in magnitude rather than by the presence or absence of an event (germination or mortality).

It can be hypothesized that Cd may affect two conceptually different types of response—viability and growth. As species may differ in tolerance to soil-added Cd for yield (growth), they may also differ in tolerance to soil-added Cd for germination (viability). In addition, for any given species the growth tolerance and the viability tolerance to soil Cd may be different. If viability response is more tolerant of Cd than is growth, the main Cd effect may be seen in the growth data. If viability is more sensitive to Cd than is growth, there little or no effect noted for soil-added Cd on gro sensitive individuals being culled out at the germ and seedling establishment stage.

Almost exclusively Cd research has dealt with effects. Viability effects may also be quite im ecologically. After all, if a species can't survive ity) it cannot reproduce. Ecologically, the main e Cd upon a plant community may, in fact, be on ty. Germination takes place at the soil surface where Cd concentrations are highest (Antonovics et al., Bachauer, 1973; John et al., 1972).[3] If a seedling survive and become established, it may be able to cover a normal growth rate by root penetration subsurface soil layers with lower Cd concentration This ability will vary with species (Hemphill, 1972).

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