Cadmium in Plants

GEOLOGICAL SURVEY BULLETIN 1314-G

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By HANSFORD T. SHACKLETTE

CONTRIBUTIONS TO GEOCHEMISTRY

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An account of the concentrations of cadmium in plants from areas that have normal or anomalous amounts of this element in the air or soil

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CADMIUM IN PLANTS

By Hansford T. Shacklette

ABSTRACT

Cadmium in low concentrations most likely is a normal constituent of all plant tissues. The concentration in the tissue is determined by the inherent ability of a plant species to absorb cadmium and by the cadmium concentration in the environment. Differences in cadmium content among plants of different species growing in low-cadmium soils commonly are greater than differences in amounts of cadmium in the soils. The cadmium content of plant tissue tends to increase with increase of concentrations of soil cadmium above certain background amounts. Airborne cadmium, originating in emissions from the combustion of hydrocarbons or from certain industrial processes, may enter the soil and be absorbed by plants or may be deposited on the surface of plants in particulate matter until very high levels of cadmium are accumulated by the plants. Spanish moss, a plant with no connection to the soil, seems to be a useful indicator of the relative extent of airborne cadmium pollution, in that it contains much more cadmium if growing in areas where aerial pollution is likely than if growing in areas remote from sources of pollution. There seems to be no natural means by which cadmium is eliminated from plant tissue, and no cultural practice has been found to be effective in reducing or preventing the absorption of cadmium by plants.

INTRODUCTION

Cadmium has been found in many plant species and plant organs, although it is not usually considered to be an essential micronutrient. However, it has been reported to increase the sugar content and yield of grapes when applied in a foliar spray (Dobrolyubskii, 1957; Dobrolyubskii and Slavvo, 1958) and to increase the yield of red clover when applied in combination with boron (Dmitriev, 1939). Bertrand and de Wolf (1959) stated that in the fungus *Aspergillus niger*, cadmium may substitute for zinc in the synthesis of tryptophane, an amino acid necessary for the elaboration of indoleacetic acid hormone.

The concentrations of cadmium that are toxic to plants are largely unknown. High levels of zinc often accompany anomalous amounts of cadmium in the environment, and both elements may simultaneously exert a toxic effect at the same time. Ulrychová-

Zelinková (1959, p. 139) stated that "All authors agree that cadmium ions are definitely more poisonous [to plants] than zinc ions." She (1959) reported further that doses greater than 160 milligrams cadmium per plant nearly halved the inorganic phosphorus content of tobacco plants (*Nicotiana tabacum* Samsun) and produced necrotic spots on the leaves, and she suggested that cadmium disturbs phosphorus metabolism.

Soon after McMurtrey and Robinson (1938, p. 817) had stated that "It [cadmium] is one of the very few elements that have not been reported in plants," Clemente and Mendez (1940) detected cadmium in cabbage (*Brassica oleracea* L.), potato (*Solanum tuberosum* L.), sweet potato (*Ipomea batatas* L.), lettuce (*Lactuca sativa* L.), green pepper (*Capsicum frutescens* L.), and tomato (*Lycopersicum esculentum* Mill.), but they did not report the concentrations. Later analyses of plant materials by more sensitive methods have indicated that this element is present in measurable concentrations in all plant tissues.

EXPERIMENTS IN CADMIUM ABSORPTION BY PLANTS

Cadmium is readily absorbed by soil-rooted plants from solutions of cadmium compounds applied to the soil. Autoradiographic studies by Gordee, Porter, and Langston (1960) indicated that exposure of peppermint (*Mentha piperita* L.) plants to radioactive cadmium in soil resulted in the uptake of the element after 24 hours and in its gradual movement through the vascular system to all parts of the plant, with the greatest accumulation occurring in the lower leaves. They reported that cadmium was not eliminated by the plant following leaching of the soil.

In experiments with radish (*Raphanus sativus* L.) designed to test the possibility of preventing or impeding cadmium accumulation in food plants by the interactive effect of zinc, Lagerwerff and Biersdorf (1972) combined 2, 20, and 100 ppb (parts per billion) cadmium and 20, 100, and 400 ppb zinc in culture solutions. At the lowest concentration of cadmium, increasing the concentrations of zinc suppressed cadmium uptake; but at the 100-ppb level of cadmium, increasing amounts of zinc increased cadmium uptake. The great reduction in crop yield caused by levels of zinc that were effective in suppressing cadmium absorption, together with the failure of zinc to inhibit cadmium uptake at high levels of both elements, limits the practical possibilities of reducing cadmium levels in plants by applying zinc to the soil.

Dr. W. H. Alloway, of the U.S. Plant, Soil, and Nutrition Laboratory, reported (written commun., 1971) that in experiments conducted at this laboratory increasing the levels of zinc in culture solutions did not depress the uptake of cadmium by plants.

Schroeder and Balassa (1963) conducted field-plot experiments to determine if the cadmium in superphosphate fertilizers could be absorbed in detectable amounts by food and feed plants. They reported that adding 20-percent superphosphate containing 7.25 ppm (parts per million) cadmium to soil increased the cadmium content of 10 garden vegetables from nondetectable levels in control plots to 0.3–4.0 ppm (wet-weight basis) in the treated plots. Parsnip (*Pastinaca sativa* L.) appeared to be a cadmium accumulator that in the control plot contained 3 ppm cadmium, and in the superphosphate-treated plot, 14.0 ppm.

In a study of the influence of soil type on the mineral composition of corn (*Zea mays* L.), Prince (1957) found the cadmium content of dry material of mature plants from four different types of soil to range from 0.81 to 2.43 ppm, but he did not give the cadmium concentrations in the soils. He reported average values of 1 ppm cadmium in mature corn leaves, 0.96 ppm in the dry grains, and 0.67 ppm in the husks. Ragweed (*Ambrosia artemisiifolia* L.) that grew with the corn averaged 0.46 ppm cadmium.

Schroeder, Nason, Tipton, and Balassa (1967, p. 195) stated:

> Because superphosphate fertilizers contain cadmium, experiments designed to ascertain the uptakes by growing vegetables heavily fertilized with 20 percent superphosphate were repeated. The grains so fertilized had more cadmium than did their controls, as did two legumes, three root vegetables, four leafy vegetables, three fruits, and one squash. Mean differences were not impressive.

In experiments designed to determine if cadmium was translocated from tree leaves to the fruit, Ross and Steward (1969) sprayed apple trees with an aqueous solution of cadmium chloride containing 43 ppm cadmium. They reported (1969, p. 52):

> The results presented here show that following cover sprays of cadmium chloride, cadmium accumulates in apple fruit as it matures. The form in which cadmium is translocated is not known. Cadmium residues persist in the foliage throughout the growing season * * * the cadmium may be translocated from the foliage to the fruit.

CADMIUM CONCENTRATIONS IN PLANTS

STANDARD PLANT SAMPLES

For use in the comparison of the accuracy and precision of analytical methods used for plant analysis, several laboratories have prepared "standard plant samples" for distribution to other laboratories. In 1963, U.S. Geological Survey personnel collected four "standard alfalfa" (*Medicago sativa* L.) samples in Arizona and one in Utah that have been widely used for comparing analytical methods. The cadmium concentrations, in parts per million of ash, the ash yield, as a percentage of dry weight, and the calculated cadmium concentrations, in parts per million, of the dry material are given in the table below (analyses by T. F. Harms, using an atomic-absorption method).

Analyses of standard samples

Sample No.	Variety	Location	Cadmium in ash (ppm)	Ash yield (percent)	Calculated cadmium in dry plants (ppm)
A–1	Common mixed	Graham County, Ariz., near Safford.	0.3	11.5	0.035
A–2	Hairy Peruvian and Chilean mixed.	Pima County, Ariz., near Tucson.	.3	11.2	.034
A–3	"919"	do	.2	10.7	.021
A–4	(Unknown).	Pinal County, Ariz., 15 miles south of Mesa.	.3	10.5	.032
A–5	(Unknown)	Millard County, Utah, near Delta.	.3	8.5	.026

A "standard kale" sample, consisting of dried pulverized leaves of kale (*Brassica oleracea* var. *acephala* DC.), was prepared by Bowen (1967a) and distributed for analysis to 29 cooperating laboratories. Analyses by polarographic methods indicated a mean value of 1.0±0.1 ppm in the dry material (Bowen, 1967a), and analyses by neutron-activation methods gave a mean value of 0.384 ppm (Bowen, 1967b).

The U.S. National Bureau of Standards recently issued a series of Biological Standard Reference Materials (Becker and LaFleur, 1972). The plant sample in the series consists of dried pulverized "orchard leaves" from several kinds of fruit-bearing plants. Analyses by atomic-absorption spectroscopy and polarography by the Analytical Chemistry Division of the Bureau of Standards indicated 0.11±0.02 ppm cadmium in the dry leaves.

ENVIRONMENTS THAT HAVE COMMON LEVELS OF CADMIUM

The mean cadmium concentration in the ash of "surface" plants was reported by Malyuga (1964, p. 15) to be $1\cdot10^{-6}$ percent (0.01 ppm). This value seems to be much too low for cadmium in plant ash but would be a reasonable value (although still low) for the concentration of cadmium in the dry plant material. Earlier, Malyuga (1941) gave cadmium concentrations in dry weight of plant material that seem entirely possible (see the paragraph that follows); therefore, his average value of 0.01 ppm in plant ash is believed to be erroneous. No other investigator is known to have attempted to give an "average" value for cadmium concentration in plants.

The average cadmium concentration in sea water was stated by Goldberg (1965, p. 164) to be 0.00011 μg/l (micrograms per liter) (about 0.11 ppb). Malyuga (1941) reported cadmium concentrations, as parts per million of dry weight, in marine algae, a marine flowering plant, and aspen bark, as follows:

Marine algae: *Allaria esculenta*, 1 ppm; *Ascophyllum nodosum*, 0.29 ppm; *Fucus inflatus*, 0.16 ppm; *Fucus serratus*, 0.34 ppm; *Laminaria saccharina,* 0.14 ppm; and *Phyllaria dermatodea,* 0.1 ppm.

Marine flowering plant: *Zostera marina,* 0.23 ppm.

Tree (aspen) bark: *Populus tremula,* 1.6 ppm.

Ishibashi, Fujinaga, Morii, Kanchiku, and Kamiyama (1964) analyzed samples of marine algae by the dithizone extraction and polarographic method and reported the cadmium concentrations, in parts per million, of the dried samples as follows: *Acanthopeltis japonica,* 0.1; *Desmarestia viridis,* 0.1; *Eisenia bicyclis,* 0.3; *Gelidium* sp., 0.2; and *Ulva* sp., 0.2.

The range of concentrations, in parts per million, of cadmium in some dry plant materials that presumably were produced on soil of normal cadmium content was given by Shirley, Benne, and Miller (1949, p. 303) as follows: Dried spinach, 0.6–1.2; dried lettuce, 0.3–0.5; and alfalfa-leaf meal, 0.1–0.2.

Analyses of the cadmium concentrations in a wide variety of plants and plant products were given by Schroeder, Nason, Tipton, and Balassa (1967). The values were reported in micrograms per gram (μg/g=ppm), based on the "wet" weight of the materials. The losses in weight in drying and ashing the samples were not given; therefore, the reported values cannot be converted to dry-weight or ash-weight bases. These authors reported the following ranges in cadmium concentrations in "wet" plant material (μg/g): Leaves of trees and shrubs, 0.04–0.49; fern leaves, 0.04–0.33; fungi, 0.10–1.95; grains, 0.04–0.49; and nuts, 0.04–0.07.

Kropf and Geldmacher-von Mallinckrodt (1968) reported the cadmium concentrations that they found in samples of fruits, vegetables, and grains, as well as in many other kinds of foods. Cadmium concentrations in samples of the edible parts of the food plants averaged 0.075 ppm, with a low value of 0.004 and a high value of 282 ppm. These values cannot be compared in any way with the data in table 3 of the present report because they are based on the wet weights of the foods. These foods are known to differ greatly in water content, but this content was not given for the samples. Average wet-weight cadmium values derived from analyses of foods as different in water content as fresh tomatoes (probably 95 percent water) and dried beans (probably about 5 percent water) may be useful in estimating dietary intake of cadmium, but they have little usefulness in characterizing the cadmium concentrations in different foods because of the widely fluctuating water content of the foods.

The leaves of 12 species of trees and shrubs were analyzed for cadmium and other elements by Hanna and Grant (1962). These plants grew in Nixon sandy loam or in Quakertown silt loam, and the cadmium concentrations are presumed to be normal, although

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cadmium levels in the soils were not given. The dried leaf samples were digested with nitric and perchloric acids, then analyzed by a spectrochemical method. The cadmium concentrations in the samples, in parts per million of dry weight, are summarized as follows: *Acer rubrum* (red maple), 1.7 (average of four samples); *Acer saccharinum* (silver maple), 0.10; *Acer saccharum* (sugar maple), 0.21; *Ilex opaca* (American holly), 5.2 (average of four samples); *Kalmia latifolia* (mountain laurel), 0.43 (average of two samples); *Pieris japonica,* 1.2 (average of five samples); *Pinus strobus* (white pine), 0.9 (average of three samples); *Quercus palustris* (pin oak), 2.4 (average of four samples); and *Tsuga canadensis* (Canadian hemlock), 0.6 (average of two samples). Hanna and Grant (1962, p. 293) wrote: "Statistical analyses of these data [for 23 elements] indicate more differences in composition between species growing in the same soil than between plants of the same species growing in different soils."

A U.S. Geological Survey study of geochemical environments in Missouri included sampling of plants and soils in six vegetation-type areas (as mapped by Küchler, 1964, but somewhat modified). The specific sampling sites were selected to avoid areas of major industrial and vehicular pollution. All samples of soils at 300 sites in these areas contained less than 1 ppm cadmium. These sites were, therefore, considered to have only the typically low concentrations of cadmium in the soils and the atmosphere. The terminal 6- to 8-inch part of stems (branches) of trees and shrubs that are characteristic species of the vegetation types at the sites, plus a species of grass at three sites, were sampled and analyzed for ash yield (C. S. E. Papp, analyst) and for concentrations of various elements. Results of the cadmium analyses (T. F. Harms, analyst) are given in table 1.

Concentrations of cadmium were determined by analysis of the ash of plant samples, as given in table 1, and they were also converted to approximate concentrations in the dry samples as needed for comparisons with the literature which uses dry weight as the basis for reporting concentrations by the following equation:

$$\text{Cadmium (ppm) in dry plant} = \text{cadmium (ppm) in ash} \times \frac{\text{ash content (percent)}}{100}$$

The geometric means and geometric deviations given in table 1 are antilogs, respectively, of the arithmetic means and standard deviations of the logarithms of the analytical values. The geometric mean is a measure of central tendency of the frequency distribution and, as such, is an estimate of the typical or most common concentration for the element. The arithmetic means of

TABLE 1. — *Mean cadmium concentrations in tree, shrub, and grass samples from six vegetation-type areas in Missouri*

[n, number of samples; AM, arithmetic mean; GM, geometric mean; GD, geometric deviation; ...., no data available]

Common and scientific name	Plant part	n	Plant constituent						
			Cadmium in ash (ppm)			Percent ash			Arithmetic mean (ppm) cadmium converted to units of dry weight (ppm)
			AM	GM	GD	AM	GM	GD	
Big bluestem grass (*Andropogon gerardii* Vitman).	Stem and leaf.	3	0.5	0.5	......	6.0	5.6	1.45	0.03
Buckbush (*Symphoricarpos orbiculatus* Moench).	Stem	149	15	12	2.05	2.7	2.6	1.21	.41
Post oak (*Quercus stellata* Wang.)	do	30	2.6	2.3	1.57	4.4	4.3	1.27	.11
Red Cedar (*Juniperus virginiana* L.)	Stem and leaf.	32	1.6	1.4	1.47	6.2	6.1	1.13	.10
Shagbark hickory (*Carya ovata* (Mill.) K. Koch).	Stem	16	24	19	1.96	5.3	5.1	1.29	1.27
Short-leaf pine (*Pinus echinata* Mill.)	Stem and leaf.	35	15	14	1.48	2.8	2.8	1.20	.42
Smooth sumac (*Rhus glabra* L.)	Stem	184	3.9	3.2	1.90	3.7	3.7	1.20	.14
Sweet gum (*Liquidambar styraciflua* L.)	do	26	8.4	6.2	2.17	4.9	4.6	1.37	.41
White oak (*Quercus alba* L.)	do	65	4.3	4.0	1.43	3.6	3.5	1.24	.16
Willow oak (*Quercus phellos* L.)	do	30	11	9.0	1.97	2.5	2.4	1.33	.28
Winged sumac (*Rhus copallina* L.)	do	29	3.3	2.7	1.84	3.3	3.2	1.22	.11

the analytical data given in this table were derived from the estimated geometric means and geometric deviations by using a technique developed by Sichel (1952) and described by Miesch (1967). The arithmetic means in table 1, unlike the geometric means, are estimates of geochemical abundance (Miesch, 1967) and are directly comparable to arithmetic means commonly employed in presentations of geochemical averages in the literature. Arithmetic means are always larger than corresponding geometric means (Miesch, 1967, p. B1) and are estimates of the fractional part of the population that consists of the element of concern rather than of the typical concentration of the element in a population of samples.

The data in table 1 indicate that the cadmium contents of these plants that grew in environments low in cadmium are determined largely by the abilities of the different species to absorb cadmium, for there seem to be greater differences in cadmium concentration among species than probably exist among the soils in which the plants were rooted. For example, samples of shagbark hickory contained an average of 5 times as much cadmium as was found in white oak, yet both species were collected in pairs from the same soils and, presumably, were exposed to the same quantities of environmental cadmium.

ENVIRONMENTS THAT HAVE UNCOMMONLY HIGH LEVELS OF CADMIUM

NATURALLY OCCURRING CADMIUM CONCENTRATIONS

For those plants growing in soils that contain more than certain background amounts (as yet not defined) of cadmium, the cadmium content of the plant tissues tends to increase with increasing soil concentrations, at least in some environments. Lounamaa (1956), in his studies of trace elements in plants growing wild on different rocks in Finland, reported that the cadmium content of bryophytes (mosses) ranged from 1 ppm in ash of samples from nonmineralized rock to 100 ppm in ash of two samples from sphalerite-enriched substrates.

Certain peat bogs in Orleans County, N.Y., are enriched in zinc, lead, and cadmium by the entrance of ground water from dolomite beds that contain concentrations of these elements (Cannon, 1955). Thirty years after many of these bogs had been drained, Cannon (1970) reported the cadmium concentrations in certain vegetables and native plants that grew on the soils of the drained bogs as follows: Carrots (*Daucus carota* L.), roots washed and peeled, 8 ppm in ash, or 0.36 in dry material; potatoes (*Solanum tuberosum* L.), 7 ppm in ash, or 0.36 ppm in dry material; 15 vegetable samples, median 0.12 ppm in dry material, range 0.05 to 0.96; and seven samples of native vegetation, median 0.18 ppm in dry material, range less than 0.09 to 0.67 ppm. These median cadmium concentrations, however, are lower than the concentrations reported by Bowen (1967a, b) for his "standard kale" sample.

In a U.S. Geological Survey study of trace elements in plants as applied to prospecting for mineral deposits in the Rocky Mountains, several species of trees and shrubs were sampled and analyzed for cadmium and other elements (G. C. Curtin and H. D. King, written commun., 1971). The areas sampled were either mining areas or areas that might contain undiscovered mineral deposits, as indicated by anomalous levels of some metals in the soils—for example, cadmium in the soil humus ranged from less than 1 to 10 ppm. Ash of leaves and stems (branches) were analyzed separately for cadmium by a modified semiquantitative spectrographic method that results in a lower detection limit of 1 ppm in plant ash (Mosier, 1972). Mean cadmium concentrations found in these samples are given in table 2.

Data in table 2 show that the stem ash generally contains about twice as much cadmium as leaf ash. This difference in concentration indicates that the cadmium in the samples was largely taken up from soil by the roots and was transported to stems and leaves, rather than having been directly accumulated by the plants from atmospheric fallout. Because of their relative configurations, stems have a much lower surface-to-volume ratio than leaves; therefore, if the source of cadmium had been airborne particles, stems would be expected to contain the lesser amount of cadmium. Moreover, the fact that the area where the samples were collected was far removed from significant industrial or vehicular pollution suggests that airborne cadmium would account for only a very small part of the total cadmium in the plant tissues.

The cadmium contents given in table 2 suggest that species of trees differ greatly in their ability to concentrate cadmium in their tissues. For example, in analyses of coniferous trees, ash of limber pine leaves and stems contained an average of 3.4 and 5.5 ppm cadmium, respectively, whereas lodgepole pine contained 10.5 ppm cadmium in leaves and 16.6 ppm in stems. Contrasts among deciduous trees are provided by mountain maple, whose leaves contained 1.6 ppm cadmium and whose stems contained 4.9 ppm, and willow, whose leaves and stems contained 15.7 and 37.6 ppm, respectively. However, without information on the abundance of cadmium in the environments where these different species grew, differences in average cadmium content in tissues among species cannot be attributed with certainty to differences in the inherent ability of species to accumulate cadmium. The usefulness of the species listed in table 2 as indicators of anomalous cadmium con-

TABLE 2. — *Mean cadmium concentrations and ash yields in*

[n, number of samples; GM, geometric mean; GD,

Common and scientific name	Leaves				
		Cadmium in ash (ppm)		Percent ash	
	n	GM	GD	GM	GD
Colorado blue spruce (*Picea pungens* Engelm.)	1	<1.0	......	3.3	......
Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)	15	2.0	1.77	3.6	1.28
Engelman's spruce (*Picea engelmannii* (Parry) Engelm.)	5	1.1	1.36	4.9	1.30
Juniper (*Juniperus communis* ssp. *nana* Syme)	14	2.5	2.17	4.4	1.16
Kinnikinnik (*Arctostaphylos uva-ursi* (L.) Spreng.)	1	5.0	......	4.1	......
Limber pine (*Pinus flexilis* James)	6	3.4	2.30	2.8	1.22
Lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.)	24	10.5	1.36	2.0	1.25
Mountain maple (*Acer glabrum* Torr.)	5	1.6	3.06	5.3	1.12
Ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.)	12	5.7	1.45	2.0	1.27
Snowberry (*Symphoricarpus occidentalis* Hook.)	1	2.0	......	5.8	......
Sticky laurel (*Ceanothus velutinus* Dougl.)	1	<2.0	......	4.4	......
Quaking aspen (*Populus tremuloides* Michx.)	22	7.7	1.60	5.9	1.16
Wild gooseberry (*Ribes* sp.)	2	1.2	......	5.9	......
Willow (*Salix* sp.)	4	15.7	1.72	6.2	1.13

centrations in soils cannot be evaluated without data on the same species in environments similar in all characteristics except the cadmium levels in the soils.

A possibly valid comparison of cadmium concentrations in ash of uncultivated plants growing in mineralized areas with those of plants from areas that have only background levels of cadmium is provided by juniper from mineralized areas of Colorado (table 2) that had an average cadmium content of 5.5 ppm in stems and 2.5 ppm in leaves, and red cedar from areas of presumably normal cadmium levels in Missouri that had an average cadmium content of 1.6 ppm in composite samples of stems and leaves. However, these differences in average cadmium concentration may only reflect species differences in ability to absorb cadmium. If the cadmium content (1.6 ppm) of Missouri red cedar samples from areas of normal cadmium is compared with the cadmium content (9.3 ppm) of Missouri roadside samples of the same species that had been contaminated by lead ore (Connor, Shacklette, and Erdman, 1971), the ability of this species to respond to different environmental levels of cadmium is apparent.

CADMIUM FROM VEHICULAR, INDUSTRIAL, AND URBAN POLLUTION

The cadmium concentration in mosses (principally *Hypnum cupressiforme* L.) has been used as an index to airborne cadmium pollution in Sweden. The normal cadmium content of this moss was reported to range from 0.7 to 1.2 ppm on a dry-weight basis. In the center of the Greater Stockholm area, this plant contained as much as 7.5 ppm cadmium (Rühling, 1971, p. 2) and in the cen-

tree and shrub samples from mineralized areas in Colorado

geometric deviation; ......, no data available]

Plant part							
Leaves—Con.	Stems (branches)						
Geometric mean (ppm) cadmium converted to units of dry weight (ppm)	n	Cadmium in ash (ppm) GM	Cadmium in ash (ppm) GD	Percent ash GM	Percent ash GD	Geometric mean (ppm) cadmium converted to units of dry weight (ppm)
......	1	2.0	......	1.5	......	0.03
0.07	15	7.3	2.47	2.7	1.36	.20
.05	5	6.4	1.56	3.5	1.25	.22
.11	14	5.5	1.66	4.7	1.13	.26
.21	1	7.0	......	3.3	......	.23
.10	6	5.5	2.30	2.5	1.15	.14
.21	24	16.6	1.54	2.3	1.12	.38
.09	5	4.9	2.00	3.5	1.26	.17
.11	12	9.8	1.63	2.2	1.42	.22
.12	1	5.0	......	1.8	......	.09
......	1	1.0	......	3.0	......	.03
.45	22	13.7	1.45	5.6	1.21	.77
.07	2	1.7	......	4.7	......	.08
.97	4	37.6	2.19	4.0	1.37	1.50

ter of Oskarshamn, 81.7 ppm (Rühling, 1969, p. 2). Oskarshamn, a city of about 25,000 population, has two important centers of heavy-metal emissions—a sulfuric acid plant that emits copper, cobalt, and zinc, and a storage-battery factory that releases cadmium, chromium, nickel, and lead into the atmosphere (Åke Rühling, written commun., 1969).

Mosses and their underlying soils were sampled by the author at 10 pairs of sites along highways in south-central Missouri. One site of each pair was 15–20 feet from the highway pavement; the other, 100–600 feet from the highway. All soil samples contained less than 1 ppm cadmium. The difference in average cadmium concentrations of the paired moss samples was not significant: cadmium in ash of samples from sites near the road averaged 5.6 ppm (range, 2.2–22.0 ppm), and in samples more distant from the road, 5.2 ppm (range, 1.8–12.0). The moss species sampled were *Anomodon rostratus* (Hedw.) Schimp., *Atrichum angustifolium* (Brid.) B.S.G., *Cirriphyllum illecebrum* (Hedw.) L. Koch, *Dicranum scoparium* Hedw., *Hedwigia ciliata* (Hedw.) P. Beauv., *Leucobryum glaucum* (Hedw.) Ångstr. ex Fr., *Mnium affine* Bland. ex Funck, and *Polytrichum commune* Hedw. The dust contamination of some samples, which could not be removed completely by washing, may have obscured the difference in cadmium content, if present, between the two lots of samples.

The effect of roadside contamination by motor vehicles on the cadmium content of grass was reported by Lagerwerff and Specht (1971) to diminish with distance from the road; dry grass samples 8 m (meters) from the road contained 0.63–1.25 ppm cadmium, whereas those 32 m from the road contained 0.25–0.58 ppm. These authors attributed the cadmium in the grass samples to both soil and aerial sources.

In a U.S. Geological Survey study of element concentrations in sampling media on roadsides in Missouri, Connor, Erdman, Sims, and Ebens (1971) found no significant difference between the cadmium content in roadside cedar trees (*Juniperus virginiana* L.) exposed to presumably normal amounts of cadmium from vehicular traffic and that in trees growing at sites more distant from the roads. Connor, Shacklette, and Erdman (1971) reported that cedar-tree samples from a roadside in Missouri that was believed to be contaminated with lead ore blowing from passing ore trucks had an average cadmium content of 9.3 ppm in the ash of leaves and branches. Similar samples from trees that grew at the same site but at greater distances from the road averaged 2.8 ppm cadmium. A sample of a pine (*Pinus echinata* Mill.) that grew with the cedars at this contaminated site contained 20 ppm cadmium in the ash of its leaves and branches. Cadmium concentrations in samples of surface soils at this site were all less than 1 ppm.

Studies of environmental pollution resulting from industrial smelting of ores in the Helena Valley area of Montana were conducted by the U.S. Environmental Protection Agency. Samples of soil from the plow zone and deeper zones were collected and analyzed for cadmium, lead, zinc, and arsenic by Miesch and Huffman (1972). Concentrations of cadmium were found to be greatest in samples of the upper soil layers from sites on the downwind side of the smelter stack; cadmium in these samples ranged from 26 ppm at a distance of 1 mile from the stack to 2 ppm at a distance of 8 miles. Hindawi and Neely (1972) reported the cadmium concentration in vegetation (alfalfa, lettuce, pinto bean, beet, and carrot) to range from 0.1 ppm when grown in vermiculite to 8.6 ppm when grown in garden soil near the smelters (whether dry weight, ash weight, or wet weight was used in calculating concentrations was not stated). Samples of a variety of garden plants and field plants obtained from gardens and ranches in the area ranged in average cadmium concentration from less than 0.05 to 9.8 ppm, on a wet-weight basis. Dry-weight or ash-weight conversions were not given for these data; therefore, they cannot be compared with other data (except those of Schroeder and Balassa, 1963) in this report. Cadmium content in soils used for the greenhouse and garden experiments conducted by Hindawi and Neely ranged from 2.0 to 56 ppm. Results of their greenhouse experiments led them to conclude that plants can absorb cadmium through their roots.

Gordon (1972) reported that cadmium concentrations in samples from the Helena Valley area, Montana, ranged from 1 to 6 ppm in grasses and from 6 to 33 ppm in soils (both ranges determined on a dry-weight basis). He also reported that cadmium concentrations in garden soils ranged from less than 1 to 31 ppm, and in lettuce that grew on these soils, from less than 1 to 28 ppm (dry-weight basis). Cadmium concentrations in samples of lettuce from Missoula, Mont. (where there was no smelter pollution), were reported to be less than 1–1.2 ppm, and in samples of garden soils less than 1 ppm.

Warren, Delavault, and Fletcher (1971) suggested that the background concentration of cadmium in soils is 0.5 ppm (the same value as that given as average by Vinogradov, 1959). These investigators (1971, p. 5) listed cadmium concentrations that they considered "normal or average" in ash of some vegetables as follows: Lettuce, potato, cabbage, and beet, 1 ppm; bean (except broad bean), 2 ppm. They reported maximum cadmium concentrations in ash of the same kinds of vegetables collected from industrial and urban communities in Canada and the United Kingdom as follows: Lettuce, 87 ppm; potato, 12.7 ppm; cabbage, 3.9 ppm; bean, 2.4 ppm, and beet, 3.0 ppm.

Certain areas in Japan have been heavily polluted with cadmium and other metals released by mines and smelters, and chronic poisoning of the population has occurred. This pollution, which was extensively investigated by Kobayashi (1972, p. 123–124), was of two types: (1) that originating from waste water from mines and smelters, and (2) that emanating from smelter chimneys. At some locations both airborne and water-borne cadmium were present. The water-borne cadmium entered irrigation systems and was carried to the soil in rice fields, where it was absorbed by rice plants. The polished rice grains in 27 samples from fields polluted by both water-borne and airborne cadmium had an average cadmium content of 0.49 ppm; the cadmium content of wheat and barley was several times greater than that of rice.

Studies of the annual growth rings of sugi trees (*Cryptomeria japonica* Don) that grew in the Jinzu River basin of Japan where cadmium pollution derived from mining and smelting is widespread were reported by Ishizaki, Fukushima, Kurachi, Sakamoto, and Hayashi (1970). They found that the narrow growth rings indicated suppression of the trees from 1910 to 1943 and attributed this suppression to the absorption of cadmium that was released from smelter clinkers through the action of sulfur dioxide. High cadmium values were found in the tree rings formed during this period.

In studies of contamination from a zinc refinery, Kobayashi (1972) found that the concentration of cadmium in mulberry leaves (used for silkworm feed) was inversely proportional to the distance of the mulberry trees from the refinery. At 400 m, the dried leaves contained about 17 ppm cadmium; at 1,000 m, 7 ppm; and at 2,500 m, 4 ppm. Control samples of the leaves contained less than 1 ppm. Approximate cadmium concentrations, in parts per million, in dried vegetables from gardens at various distances from the refinery were reported as follows: Asparagus, 8; azuki beans, 1; burdock root, 5; cabbage outer leaves, 6; cabbage inner leaves, 3; carrots, 8; Chinese cabbage, 41; corn, 2; eggplant fruit, 8; greens, damaged, 56; greens used for salting, 32; potatoes, 2; pumpkin, <1; radish roots, 3; radish leaves, 15; taro potatoes, 2; turnip roots, 5; turnip leaves, 15; tomatoes, 2; and Welsh onions [leeks?], 14. An unidentified species of moss that grew in the gardens contained 61 ppm cadmium, the highest cadmium content found in any plant sample. In both the areas studied, Kobayashi (1972, p. 125) reported that "the principal cause of the high content of trace metals in plant tissues was the absorption and accumulation of metals through the roots from the polluted soil, rather than direct deposition of metals on the plant surfaces from the metal-containing air."

This observation by Kobayashi—without further explanation—regarding the manner in which cadmium entered the plants does not seem to be supported by the levels of cadmium that he gave for vegetables, although it may be true for the cadmium contents that he reported for rice, wheat, and barley. The vegetable analyses show relatively low amounts of cadmium in plant parts that have a low surface-to-volume ratio (asparagus stems, pumpkin, tomato, and eggplant fruit), in parts that are surrounded by protective outer structures (bean and corn seeds), and in plant parts that grow underground (potatoes, radish roots, taro potatoes, and turnip roots). Leaves, in contrast, have a high surface-to-volume ratio and were shown to usually contain much larger amounts of cadmium. The highest concentration of cadmium was found in a moss sample. Because of the finely divided nature of moss plants, they have an extremely high surface-to-volume ratio, and their cadmium contents are expected, therefore, to be strongly affected by airborne cadmium pollution.

A species of fruticose lichen (*Cladonia alpestris* (L.) Rabenh.) was sampled as an indicator of cadmium pollution from a recently constructed zinc refinery in Finland (Jaakkola and others, 1971). Background cadmium concentrations in this species, determined by analyzing specimens from Lappland, were found to be 0.1–

0.2 ppm in dry plants. Samples from locations near the zinc refinery contained about 1 ppm cadmium, and those collected elsewhere in Finland contained 0.3–0.4 ppm. Jaakkola, Takahashi, and Miettinen stated (p. 7) that in this lichen "Only 6 months of operation have increased the cadmium level five-fold at about 1 kilometer's distance from the zinc works, but no increase is yet noticeable at a distance of about 4 kilometers."

A fruticose lichen (*Cladonia ?rangiferina*) that grew on shallow soil over dolomite was sampled by the author near Bellevue, Iron County, Mo., in an area apparently free from airborne pollution. Ash of this sample, No. D414121, contained 1.8 ppm cadmium (C. S. E. Papp, analyst), which is equivalent to about 0.19 ppm in dry material, a value that agrees well with the cadmium background value for the Lappland lichens.

Cowgill (1970) reported a study of the hydrogeochemistry of a small lake in Connecticut that was subjected to pollution resulting from the development of the lake basin as a residential area. The pollution arose from raw sewage emptied into the lake and from vehicular emissions. She found (p. 58) an average content of 17 ppm cadmium in the dry matter of duckweed (*Lemna minor* L.), a very small floating aquatic plant. The source of cadmium was believed to be snow and ice in the drainage basin of the lake, because the increase in cadmium of the lake water occurred during periods of snowmelt. Catkins of willow (*Salix nigra* L.) and blossoms of apple (*Pyrus malus* L.) that grew on the lake shore contained 25 ppm and 24 ppm cadmium, respectively, in dry material. Cowgill implied that vehicular emissions had contaminated these plants with heavy metals. These cadmium values for plants seem to be abnormally high, as judged from the degree of pollution that was thought to be present. In regard to preparation of the plant samples for analysis, she stated (p. 16): "Two and a half grams [of pulverized dry material] were placed in a cadmium ring and pressed at 1.6 metric tons cm^{-2}." In using this procedure, significant contamination of the sample by the cadmium ring seems highly probable.

Results of a study of airborne nonferrous metal pollution in the area around Swansea, Wales, as measured by analyses of soil, a moss (*Hypnum cupressiforme*), and a grass (*Festus rubra*), were reported by Goodman and Roberts (1971). These authors found these sampling media to be useful indicators and integrators of aerial metallic burdens. In areas of little suspected aerial pollution the moss contained 1.0–1.8 ppm cadmium in dry matter, the grass contained 0.7–0.8 ppm, and the soil contained 0.4–0.5 ppm. In heavily contaminated areas, the following cadmium concentrations were found: Moss, 1.0–9.5 ppm (the moss could not grow at the sites of greatest contamination); grass, 1.3–40.0 ppm; and soil, 0.5–26.0 ppm. They reported that grass which caused the death of a horse by plumbism contained 9.9 ppm cadmium, whereas samples of the control grass contained 1 ppm. In transplant experiments, specimens of the moss in nylon mesh bags were suspended from trees at sites having various levels of airborne metal pollution. At the site of greatest pollution, the cadmium level in the moss specimens rose from 2.0 ppm (background value for this moss) to 337 ppm in the dry matter after 2 weeks' exposure. In evaluating their technique as useful indicators of airborne metal pollution they stated: "Our methods are much more rapid, inexpensive, and probably more meaningful than spot-sampling of air by filtration for which prohibitive resources are needed for a few months' operation."

Tyler (1972) discussed the effects on plants and soils of heavy-metal concentrations that originated from local industrial pollution in an area of central Sweden. He reported the following cadmium values (mg kg in dry material) in different plants and plant parts:

Spruce (*Picea abies*) samples: First-year twigs, 5.4; second-year twigs, 4.6; third-year twigs, 4.2; fourth-year twigs, 3.3; 5- to 7-year twigs, 2.7; bark, 2.5; roots, 1.5; fine roots, 2.7.

Mosses: 30.

Bilberry (*Vaccinium myrtillus*) shoots: 4.4.

Hairgrass leaves: 7.6.

This heavy-metal pollution was postulated by Tyler (1972) to reduce productivity of the ecosystem through a chain of events that begins with a reduced rate of decomposition of the forest litter owing to the adverse effects of these metals on soil microorganisms. This reduced decomposition leads at first to an increase in the amount of surficial litter, but because the essential plant nutrients held in the undecomposed litter are not available for recycling through the ecosystem, primary productivity by photosynthetic plants is gradually reduced. The reduced production of litter results in the distribution of the continuing heavy-metal fallout through a smaller amount of organic matter in the substrate; therefore, the amount of heavy metals per unit of substrate material is increased. These increased accumulative concentrations were thought to cause a rapid decrease in productivity of the ecosystem.

AIRBORNE CADMIUM MEASURED BY ANALYSIS OF SPANISH MOSS

In a U.S. Geological Survey study of elements in Spanish moss (*Tillandsia usneoides* L.), samples were obtained from 123 sites throughout the range of the plant and were analyzed for 37 chemical elements. This flowering plant is in the Bromeliaceae (pineapple) family and is not a true moss (bryophyte), although superficially it resembles some mosses. It grows commonly on the branches of trees, but also at places on other supports such as posts, fences, and utility wires, in the Atlantic and Gulf coastal plains. Its range in the United States extends from Great Dismal Swamp in North Carolina to southern coastal Texas; inland it ranges as much as 250 miles from the coast, in southwestern Arkansas (fig. 1). The complex factors thought to control the distribution of this plant were discussed by Garth (1964).

Although short-lived structures resembling roots support young seedlings, mature Spanish moss plants have no root system and are supported on trees and other objects by means of their intricately branched stems and interwoven leaves that collect all the essential nutrients, and other materials, from the atmosphere. These nutrients are gasses, materials carried in particulate matter (dust), and solutes in airborne water; consequently, the plant has no direct dependence on local soil for its nutrients. In addition to the finely divided plant body, abundant peltate scales throughout the plant present a very large surface area in relation to the volume of the plant, thus providing an effective filter for airborne materials and a ready absorbent for water. In some habitats Spanish moss may receive drip water that contains nutritive materials in the leachate from tree leaves, but the plant grows well without this added source of nutrients.

The samples were analyzed in a sequence that was randomized with respect to geographic location and date of collection. The cadmium analyses were made by T. F. Harms, using an atomic-absorption method. The analytical determinations were transformed to logarithmic values through a computer program which also determined the minimum and maximum values, as well as the basic statistics, and printed a histogram of the analytical values and a table of frequencies and cumulative frequencies for each class designation on the histogram. Through examination of the table of frequencies, the range of reported values was divided into five classes of cadmium concentration that centered around the geometric mean, as shown on the histogram in figure 1. Symbols were selected to represent each class, and the appropriate symbol was placed on the base map at the collection locality of each sample (fig. 1). The same procedure was followed for presenting the ash contents of the samples (fig. 2).

The data presented in figure 1 suggest that, in general, the concentrations of cadmium in Spanish moss are related to the degree and kind of aerial pollution at a location. In order to present

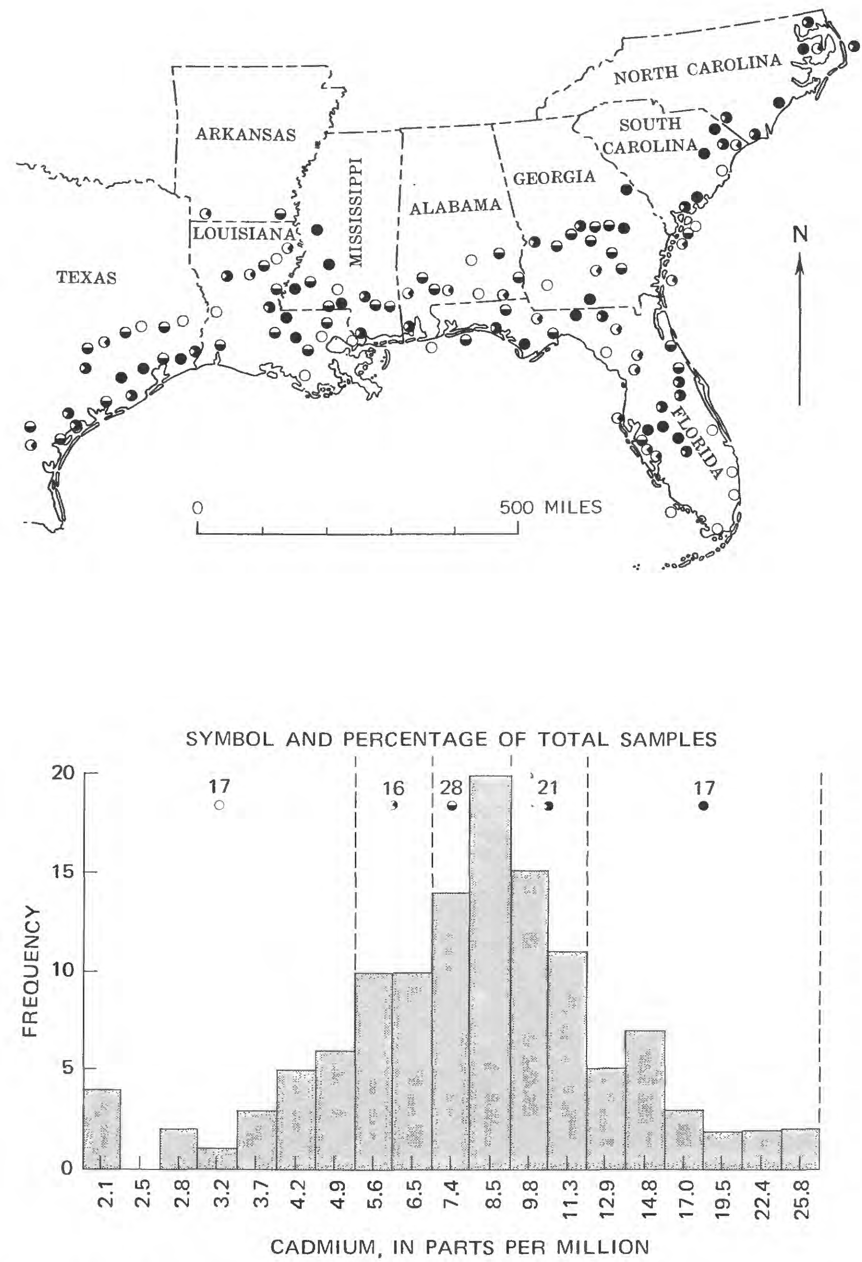

FIGURE 1. — Localities of Spanish moss samples, and cadmium concentrations found in these samples. Seashore localities are plotted offshore. Geometric mean, 7.9; geometric deviation, 1.65; number of samples and analyses, 122.

the contrast in localities where the high-cadmium and the low-cadmium samples were collected, samples in the highest category (12.2 ppm and more) and the lowest category (5.3 ppm and less), as shown by the histogram in figure 1, are ranked within each category by cadmium content and are discussed below.

The samples having extremely high cadmium contents (at least 20 ppm), arranged in decreasing values, are from Natchez, Adams County, Miss. (27 ppm) ; Limona, near Tampa, Hillsboro County, Fla. (25 ppm) ; Panama City, Bay County, Fla. (23 ppm) ; and East Baton Rouge Parish, La. (21 ppm). These locations are all in areas where considerable industrial and vehicular contamination of the air is expected to occur.

Samples having very high cadmium contents (15–19 ppm) were collected at the following locations: Near Batchelor, Point Coupee Parish, La. (19 ppm) ; 8 miles east of Roper, Washington County, N.C. (19 ppm) ; near Verona, Onslow County, N.C. (17 ppm) ; 6 miles west of Yazoo, Yazoo County, Miss. (16 ppm) ; Sugar Land, Fort Bend County, Tex. (15 ppm) ; and near Monticello, Jefferson County, Fla. (15 ppm).

Samples having high cadmium concentrations (12.2–14 ppm) were collected at the following locations: Near Latta, Dillon County, S.C. (14 ppm) ; near Lake City, Florence County, S.C. (14 ppm) ; 5 miles east of the junction of Interstate Highway 10 with I–160, Harris County, Tex. (14 ppm) ; 2 miles south of Jackson, Hinds County, Miss. (13 ppm) ; Beaumont, Jefferson County, Tex. (13 ppm) ; 2 miles north of Valdosta, Lowndes County, Ga. (13 ppm) ; Charleston, Charleston County, S.C. (13 ppm) ; and about 3 miles west of Stillmore, Emanuel County, Ga. (13 ppm).

At some of the locations listed for the above two categories of cadmium values, potential sources of aerial pollution were evident, whereas at others, none was noted but still might have been present.

Locations of samples plotted in figure 1 that fall in the lowest category of cadmium values (2.0–5.3 ppm), as illustrated by the histogram, for the most part were expected to have minimal airborne cadmium pollution. Within this category, samples with a cadmium content of 2 ppm were considered to be extremely low in cadmium concentration. One of these samples was from an area where significant airborne cadmium pollution is extremely unlikely—Paradise Key, Everglades National Park, Dade County, Fla. Another sample that contained 2 ppm cadmium was taken 6 miles south of Monticello, Lawrence County, Miss., in a rural environment where airborne industrial pollution is expected to be low, and the third sample in this category was from West Palm Beach, Palm Beach County, Fla.

Samples found to be very low in cadmium (2.2–3.8 ppm) were from the following locations: Vero Beach, Indian River County, Fla. (2.2 ppm) ; Fort Lauderdale, Broward County, Fla. (3 ppm) ; 7 miles west of Opp, Covington County, Ala. (3.4 ppm) ; Robert, Tangipahoa Parish, La. (3.6 ppm) ; 1 mile northeast of Winnsboro, Franklin Parish, La. (3.6 ppm) ; and 1 mile east of San Jacinto, Polk County, Tex. (3.8 ppm).

Samples considered to be low in cadmium (4.2–5.2 ppm) were from the following locations: Route 8 at the Sabine River bridge, Vernon Parish, La. (4.2 ppm) ; Georgetown, Georgetown County, S.C. (4.2 ppm) ; Coximba area, Marco Island, Collier County, Fla. (4.3 ppm) ; 3 miles south of the Letohatchee exit from Interstate Highway 65, Lowndes County, Ala. (4.4 ppm) ; 1 mile east of the Neches River on Route 190, Jasper County, Tex. (4.6 ppm) ; Cross City, Dixie County, Fla. (4.8 ppm) ; Route 27 at the State line, Walthall County, Miss. (4.8 ppm) ; Gibson, Terrebonne Parish, La. (5 ppm) ; on the beach at Josephine, Baldwin County, Ala. (5.2 ppm) ; and Hunting Island State Park, Beauford County, S.C. (5.2 ppm).

The percentages of ash obtained by burning the dry samples are presented in figure 2. A comparison of ash contents of the samples (fig. 2) and their cadmium concentrations (fig. 1) shows no consistent relationship between the two factors. Some samples that are placed in the highest category of cadmium concentrations have high ash contents, whereas others have low ash contents. The samples classed as extremely low in cadmium all have high ash contents; other samples with low cadmium concentrations have low ash contents. These inconsistencies in the relation of cadmium and ash contents indicate that the surficial deposits on Spanish moss are not necessarily similar in composition from place to place and that both composition and amount of the deposits influence the cadmium concentrations in ash of the plants.

Only a small proportion of the dry Spanish moss tissue is believed to consist of noncombustible material (ash)—probably no more than 2 percent. Ash percentages greater than this most likely represent surficial accumulations (principally dust) that are not held within the tissues. If these deposits are largely composed of dust from soil, increasing the amount of dust most likely will depress the proportion of cadmium, because soil typically contains very little cadmium. The effect of this type of deposit on the concentration of cadmium in ash is illustrated by a sample from the

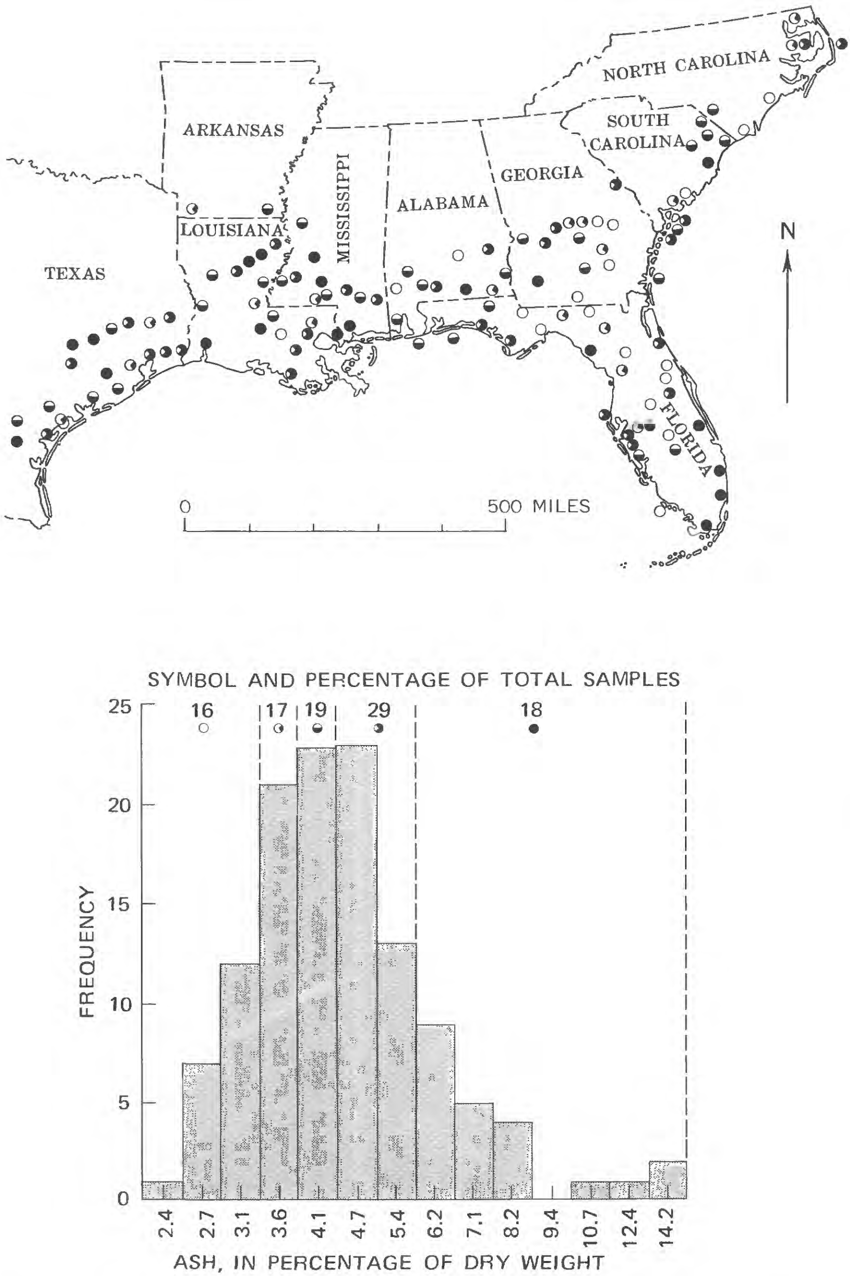

FIGURE 2. — Localities of Spanish moss samples, and ash content of the samples. Seashore localities are plotted offshore. Geometric mean, 4.5; geometric deviation, 1.40; number of samples and analyses, 122.

bank of the San Antonio River, Kearns County, Tex., that was very heavily contaminated with soil dust (34 percent ash) and contained the lowest concentration of cadmium (0.8 ppm) that was found in this study. This highly anomalous sample was excluded from the data presented in figures 1 and 2.

On the other hand, if the surficial accumulations consist largely of particulate matter resulting from the combustion of coal and petroleum products, or from certain types of industrial processes, an increase in amount of these surficial deposits most likely will increase the cadmium content of the plant ash, yet the ash yield may be low. The four highest concentrations of cadmium found (27, 25, 23, and 21 ppm) were in samples that contained 4, 3.4, 5, and 2.8 percent ash, respectively. The cadmium in these samples is presumed to have come from industrial or vehicular airborne pollution. A study of the relative concentrations of many elements in the samples would give a better estimation of the type of airborne contamination that was present at each sampling location.

If the different kinds of particulate matter, as well as specific chemical elements, are considered to constitute atmospheric pollution, then the ash yield and element content of Spanish moss can be considered to be indicators of the relative degrees of total airborne pollution that has prevailed at locations over a period of several years.

DISCUSSION AND SUMMARY

Reliable estimates of typical cadmium concentrations in plant tissues are difficult to make because of the great variability in cadmium content among the different plant species and plant organs. Moreover, reports in the literature use different bases for computing cadmium concentrations in plants. For example, Malyuga (1964, p. 15) gave the cadmium concentration in plant ash but did not give the percentage of ash obtained from the dry tissue; Schroeder and Balassa (1963) gave cadmium values based on the wet weight of vegetables but gave neither the percentage of water nor the percentage of ash in the samples, and Hanna and Grant (1962), among many others, gave cadmium concentrations on a dry-weight basis but did not give the ash yield of the samples. Data on cadmium in plants that are presented for the first time in this report include cadmium concentrations in both ash and dry tissue, or give the concentrations in ash and the ash yield of the dry material with an equation that can be used to determine approximate cadmium concentrations in the dry tissue.

Another source of inconsistency in the reported data on cadmium in plants is the difference in methods of analysis that were used to obtain the data. Methods that were used included acid digestion and atomic absorption, acid digestion and polarography, X-ray emission, neutron activation, and ashing by heat followed by emission spectrographic analysis of the ash. Some reports do not specify the analytical method that was used. This report does not attempt to judge the relative accuracy and precision of analyses determined by these different analytical methods.

To summarize data from the numerous reports of cadmium in plants, a table has been prepared that gives estimates of cadmium concentrations in plants or plant parts from environments presumed to have the normal low levels of cadmium, and in those from environments reported to have greater than normal levels of cadmium (table 3). Because most reports give cadmium on a dry-weight basis but do not give ash weights, the data from other reports were converted to parts per million in dry plant material. Some data based on ash weight, but without the ash yield being given, were converted to approximate concentrations in dry weight by assuming a reasonable ash yield for the particular kind of plant tissue that was analyzed. In instances of conflicting data, personal judgment was used in selecting the data to include in the table.

The values given in table 3 must be used with caution in evaluating specific problems of cadmium content in plants. The categories of plants and plant parts used in this table were, of necessity, often very broad and doubtless included certain species or varieties and plant parts whose normal cadmium contents differ greatly from the value given for the category. It should be noted that some of the cadmium values in the table were based on very few samples. Furthermore, for some kinds of plant materials, the cadmium concentrations in the environments where the plants grew were only loosely characterized, or were unknown.

Concentrations of cadmium in Spanish moss can be used to give estimates of the relative amounts of airborne cadmium at different localities within the regions where this plant occurs. Samples that contained the highest concentrations of cadmium were from locations where greater than normal levels of cadmium in the air were expected to occur as a result of industrial, domestic, and vehicular emissions. In contrast, samples that contained the lowest concentrations were from locations apparently remote from sources of significant cadmium pollution. Samples having cadmium concentrations in the central range of values could not be adequately evaluated without more detailed studies of the environments from which the samples came.

The yield of ash obtained by burning Spanish moss plants provides an estimate of the relative total particulate contamination of the air at the different localities where the samples originated.

TABLE 3.—*Estimates of cadmium concentrations (parts per million in dry material) in some plants and plant parts*

[........, no data available; <, less than the value stated]

Kind of plant or plant part	Reported or estimated cadmium concentrations, or ranges in concentrations	
	In environments presumably having normal cadmium levels	In environments having greater than normal cadmium levels
Marine algae	0.1–1	....
Mosses (bryophytes)	0.7–1.2	8–340
Lichens (fruticose type)	0.1–0.4	1
Grasses	0.03–0.3	0.6–40
Alfalfa	0.02–0.2	[1]0.2–2.4
Grains:		
Corn (*Zea mays*)	0.1	2
Rice (polished)	....	0.5
Barley, wheat, and oats	0.1–0.5	[2]0.1–1.5
Vegetables:		
Asparagus	....	8
Beet root	.05	0.24
Cabbage leaves	.05	6–12
Carrots	<.35	8
Chinese cabbage	....	41
Eggplant fruit	....	8
Kale	1	....
Leafy vegetables used as pot herbs or salads	0.3–0.5	3–50
Leeks	....	14
Lettuce	0.3–0.5	4–16
Potatoes	0.05–0.3	0.6–2
Spinach	0.6–1.2	....
Turnip roots	....	5
leaves	....	15
Tomatoes	....	2
Trees, deciduous:		
Leaves	0.1–2.4	4–17
Stems (branches)	0.1–1.3	0.14–1.5
Trees, coniferous:		
Leaves	0.1–0.9	0.05–1
Stems	....	0.03–1.5
Epiphytes (Spanish moss)	0.1	1
Floating aquatic plants (duckweed)	....	17
Marine flowering plants (*Zostera marina*)	0.23	....

[1]Original data given in wet weight; converted to concentration in dry material by assuming 25 percent water in original sample.

[2]Original data given in wet weight; because the water content of grains is very low, these values were not converted to a dry weight basis.

Excessive contamination of the plants by particulate soil materials reduces the reported cadmium values in the plant ash, whereas if the particulate material originated from combustion of hydrocarbons or from certain industrial processes, increased surficial contamination is thought to increase the reported cadmium values in the plant ash.

CONCLUSIONS

Cadmium in low concentrations most likely is a normal constituent of all plant tissues. The concentration in the tissue is determined by the inherent ability of a plant species to absorb cadmium and by the cadmium concentration in the environment. At low levels of cadmium in soils, differences in cadmium content among plant species commonly are greater than differences in amounts of cadmium in the soils where the plants grew. Beyond certain background amounts of cadmium in soils, the cadmium content of plant tissue tends to increase with increased concentrations of cadmium in the soil.

Airborne cadmium, originating in emissions from the combustion of hydrocarbons or from certain industrial processes, may enter the soils and be absorbed by plants, or may be deposited on the surface of plants in particulate matter, until very high levels of cadmium are accumulated by the plant. There appears to be no natural means by which cadmium is eliminated from plant tissue, and no cultural practice has been found effective in reducing or preventing the absorption of cadmium by plants.

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