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Cadmium Additions to Agricultural Lands Via Commercial Phosphate Fertilizers

A Preliminary Assessment

CADMIUM ADDITIONS

TO AGRICULTURAL LANDS VIA COMMERCIAL PHOSPHATE FERTILIZERS

A Preliminary Assessment

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U.S. ENVIRONMENTAL PROTECTION AGENCY

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ABSTRACT

Current literature was reviewed to determine cadmium (Cd) concentrations in phosphate rock and commercial phosphate fertilizers. The data were utilized to estimate annual Cd loading rates and 100-yr Cd accumulations in soil attributable to the use of phosphate fertilizers. The annual quantity of cadmium contributed to the environment in the form of phosphate fertilizers was estimated and compared to other Cd emission sources. In addition, the probable impacts of Cd loading and accumulation via phosphate fertilizers and municipal sewage sludge were compared.

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INTRODUCTION

Cadmium has been found to be a potentially toxic heavy metal. Chronic human exposure and animal studies on cadmium indicate a positive correlation between the quantities of cadmium (Cd) intake or accumulation and kidney damage (10, 19, 28, 36, 48).

One source of cadmium entering our environment is phosphate ore used in the production of phosphate fertilizer. Cadmium is also present in sludge from treatment plants. When these fertilizers or sludges are applied to agricultural lands, the potential exists for cadmium to enter the food chain through plant uptake or grazing animals.

In the latest market basket studies for Cd, the U.S. Food and Drug Administration (FDA) determined that teenage male Cd intake is approaching the recommended maximum (72 ug/gm/day). In deriving this finding, FDA used maximum weekly Cd intakes suggested by the World Health Organization. Accordingly, several states have taken steps to regulate the amount of cadmium applied to agricultural lands from municipal wastewater treatment plant sludge.

The requirements and the proposed Cd levels are being challenged. Accordingly, the U.S. Environmental Protection Agency (EPA) sponsored this research effort to identify the following:

- The range of Cd concentrations present in commercial phosphate fertilizers,
- Annual Cd loading rates to agricultural land via phosphate fertilizer application,
- Short and long-term Cd additions to agricultural lands through phosphate fertilizer applications,
- Potential effects of cadmium in phosphate fertilizers on groundwater and plants, and
- Comparative assessment of potential Cd additions to agricultural lands from phosphate fertilizers and sewage sludge.

To perform the research, a review of the literature was conducted, and data supplied by knowledgeable individuals were assessed. Where data necessary to the project were lacking, assumptions were made and are noted.

SOURCES, PRODUCTION, AND TRENDS IN THE PHOSPHATE FERTILIZER INDUSTRY

SOURCES OF ORE

All of the principal types of phosphate ore deposits are found in the United States. McKelvey (23) noted that one or more types of phosphate deposits are found in 30 of the continental states (Figure 1). The reserves in the U.S.A. are located in two major geographic locations: the western region, comprised of mines in Idaho, Montana, Wyoming, and Utah; and the southeastern region, comprised of mines in Florida, North Carolina, and Tennessee. The Western states contain the largest reserves, but most of the mining activity is presently centered in Florida (30).

PRODUCTION AND TRENDS

Phosphate ore production in the United States for the 1960-1975 period is tabulated in Table 1 and illustrated graphically in Figure 2. Major products derived from the ore are phosphate fertilizers, elemental phosphorus, and phosphoric acid; the latter is used as a feed stock in the manufacture of phosphate fertilizer.

Consumption figures for phosphate fertilizers for the years 1960-1975 are presented in Table 2. While total phosphate fertilizer consumption (expressed as P_2O_5)* has increased, led by concentrated superphosphates and diammonium phosphates, the production of normal superphosphates has decreased.

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*In phosphate fertilizers, P_2O_5 is more often used than P. To convert P to P_2O_5, multiply by 2.29.

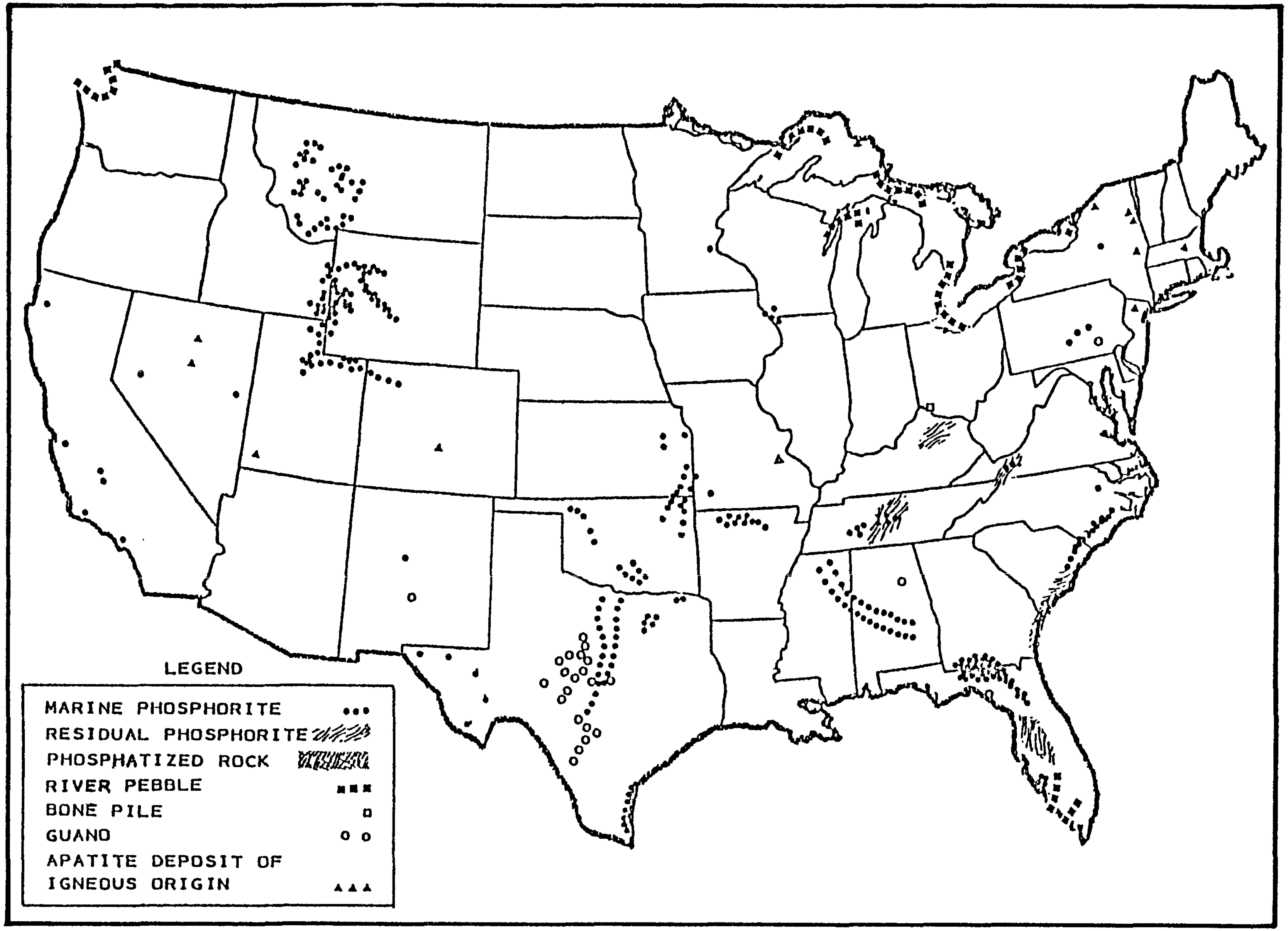

Figure 1. Types and locations of phosphate deposits (23).

TABLE 1. PHOSPHATE ORE PRODUCTION--UNITED STATES*

Year	Western Sources Amount Produced		Southeastern Sources Amount Produced	
	(10^3 t)†	(% of Total)	(10^3 t)	(% of Total)
1960	5,276	29.7	12,517	70.3
1961	4,845	25.7	14,008	74.3
1962	5,519	28.0	14,170	72.0
1963	5,347	26.5	14,823	73.5
1964	5,945	25.5	17,379	74.5
1965	7,182	26.5	19,558	73.1
1966	8,360	23.6	27,053	76.4
1967	7,066	19.6	28,942	80.4
1968	7,462	19.5	29,952	80.1
1969	7,070	20.6	27,147	79.4
1970	6,767	19.3	28,369	80.7
1971	6,109	17.3	29,161	82.7
1972	6,086	16.4	30,948	83.6
1973	6,993	18.3	31,225	81.7
1974	7,896	19.1	33,541	80.9
1975	7,362	16.6	36,914	83.4

* Fertilizer Trends (11).

† t denotes metric ton; to convert metric ton to ton, multiply by 1.12.

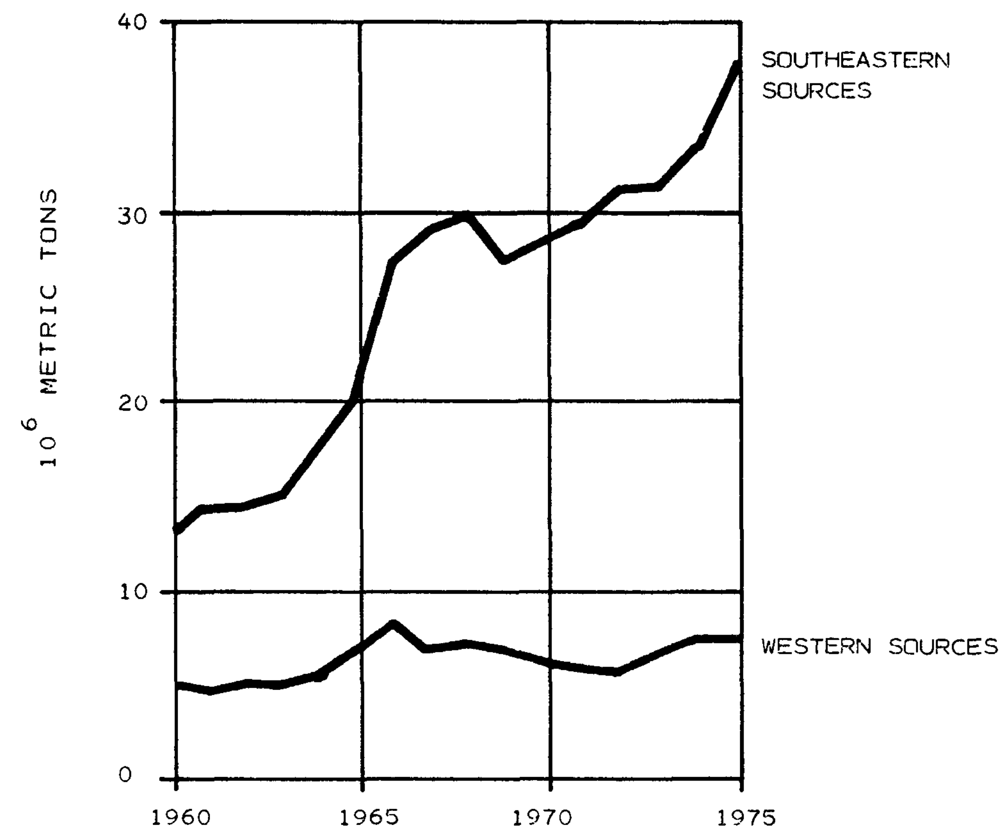

Figure 2. Phosphate ore production (data from Table 1).

TABLE 2. U.S. PHOSPHATE FERTILIZER CONSUMPTION*

Year	Total P_2O_5 Consumption	Diammonium Phosphate Consumption		Normal Superphosphate Consumption		Concentrated Superphosphate Consumption	
	(10^3 t)†	(10^3 t)	(% of Total)	(10^3 t)	(% of Total)	(10^3 t)	(% of Total)
1960	2,341	32.1	1.4	93.3	4.0	168	7.2
1961	2,407	57.8	2.4	90.9	3.8	185	7.7
1962	2,554	100.2	3.9	88.3	3.5	197	7.7
1963	2,796	161.5	5.8	89.4	3.2	200	7.2
1964	3,704	222.3	6.0	84.7	2.3	263	7.1
1965	3,196	274.9	8.6	86.3	2.7	281	8.8
1966	3,546	380.2	10.7	85.2	2.4	376	10.6
1967	3,917	410.8	10.5	77.9	2.0	393	10.0
1968	4,053	553.5	13.6	71.6	1.8	444	11.0
1969	4,246	658.6	15.5	65.7	1.5	532	12.5
1970	4,162	661.1	15.9	56.5	1.4	497	11.9
1971	4,371	741.6	17.0	50.1	1.2	506	11.6
1972	4,426	804.3	18.2	39.6	0.9	525	11.9
1973	4,627	976.6	21.1	32.1	0.7	518	11.2
1974	4,640	956.8	20.6	35.1	0.8	490	10.6
1975	4,105	944.7	23.0	33.1	0.8	483	11.8
1976	4,746	---#	--	26.1	0.5	397	8.3

* Fertilizer Trends (11).

† t denotes metric ton; to convert metric ton to ton, multiply by 1.12.

Data not available.

CADMIUM IN PHOSPHATE FERTILIZERS

CADMIUM CONCENTRATIONS IN PHOSPHATE ORES

Several available reports indicate that Cd concentrations in phosphate ores are highly variable. Table 3 presents data and appropriate references relating Cd content in phosphate ore to geographical location. In general, Cd concentrations in phosphate deposits in the southeastern United States are low (approximately 10 ppm*); concentrations in western U.S. phosphate deposits are considerably higher (approximately 150 ppm).

CADMIUM CONCENTRATIONS IN PHOSPHATE FERTILIZERS

Virtually all phosphate-derived fertilizers contain cadmium. Schroeder and Balassa (36) recognized that phosphate fertilizers were a contributing source of cadmium to agricultural lands. Lee and Keeney (21) estimated that the amount of cadmium contained in fertilizers added annually to farmland in Wisconsin was equivalent to that contained in all sewage sludge from Wisconsin wastewater treatment plants.

The literature, however, contained little substantive data on Cd concentrations in domestic fertilizers. Fifty-nine commercially available phosphate fertilizer samples from western sources were collected and analyzed by EPA Region X (46). These data (Table 4) compare with the phosphate ore Cd values noted above and affirm the difference in Cd concentrations reported for the western and southeastern region ores. Results of work by Mortvedt and Giordano (24), presented in Table 5, also substantiate the previous findings.

Considerably more data would be required to determine how the Cd content in phosphate ores differs with the phosphate ore source, method of processing, or fertilizer formulation.

DISTRIBUTION OF PHOSPHATE FERTILIZERS

The proceedings of the 1977 Tennessee Valley Authority (TVA) Fertilizer Conference (38) provided national and regional phosphate fertilizer consumption data for 1974. Reported were:

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*For the purposes of this report, the terms ppm, μg/g, and mg/kg are identified by one term - ppm.

TABLE 3. CADMIUM CONCENTRATIONS IN PHOSPHATE ORES

Origin	Concentration (ppm)*	References
Southeastern	10	44
Florida	8-15	†
	2-10	†
North Carolina	10-25	13
Southeastern Idaho		
Meade Peak	60-340	†
Mudstone	50	45
Carbonate	40	45
Phosphoria formations	90	45
Vanadiferous zone#	470-980	45
Other Western Ores	60-100	†
	150	45

*Given as a range where possible, single values are averages.

†Unpublished data from industrial sources.

#These *high* Cd deposits are *not* currently mined.

TABLE 4. CONCENTRATIONS OF CADMIUM IN PHOSPHATE FERTILIZERS (WESTERN AND SOUTHEASTERN SOURCES)

	Range of Cd Concentration (ppm Fertilizer)	
Fertilizer Type	Western Region Fertilizers*	Southeastern Region Fertilizers
Triple superphosphate (0-45-0)	40-175	12-14
Diammonium phosphate (11-46-0)	50-160	6-14
Monoammonium phosphate (11-48-0)	40-90	6-7
Superphosphate (various percent mixture)	25-40	5-7

* Unpublished data - EPA, Region X (46).

TABLE 5. CONCENTRATIONS OF CADMIUM IN PHOSPHATE FERTILIZERS*

Fertilizer Type	Cd Concentration (ppm Fertilizer)
Diammonium phosphate (Reagent)	0.9
Diammonium phosphate (Idaho phosphate rock)	50.0
Diammonium phosphate (North Carolina phosphate rock)	30.0
10-15-0 (Idaho phosphate rock)	44.0
10-15-0 (North Carolina phosphate rock)	17.0

* Mortvedt and Giordano (24).

- Tons of phosphate fertilizers (as P_2O_5) consumed, and
- Harvested acreage for major crops (feed grains, wheat, soybeans, cotton, and tobacco), for which fertilizers were used.

For this assessment, the various regions denoted in the TVA Conference proceedings have been classified as belonging to either the western or eastern regions (Figure 3). The following assumptions were made to simplify the distribution analysis:

- Phosphate fertilizers consumed in the western region were manufactured using western phosphate rock.
- Similarly, phosphate fertilizer consumed in the eastern region were manufactured with southeastern phosphate rock.
- All acreage planted to agricultural crops utilized phosphate fertilizers.

In 1974, a total of 3,098,550 t* of phosphate fertilizer (expressed as P_2O_5) was distributed nationally to a total of 94,015,000 ha under cultivation to the above-noted crops. On a regional basis, the western region (Figure 3) distributed an average of 19.6 kg of P_2O_5/ha; in the remainder of the United States, P_2O_5 was distributed at an average rate of 37.9 kg/ha for 1974.

DISTRIBUTION OF CADMIUM TO AGRICULTURAL LAND

Tables 6 and 7 present estimated low, intermediate, and high Cd loading rates for acreage utilized for the cultivation of the five crops. The following assumptions were made in performing the calculations:

- All land identified with a specified crop received equal application rates of fertilizer.
- No losses of cadmium occurred as a result of erosion, floods, or natural causes.
- The low-intermediate-high Cd values of western fertilizers were assumed at 25, 100, and 175 ppm, respectively; corresponding values for southeastern fertilizers were 5, 15, and 30 ppm.
- Phosphate fertilizers were assumed to have an average P_2O_5 content of 50 percent.

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*Denotes metric tons.

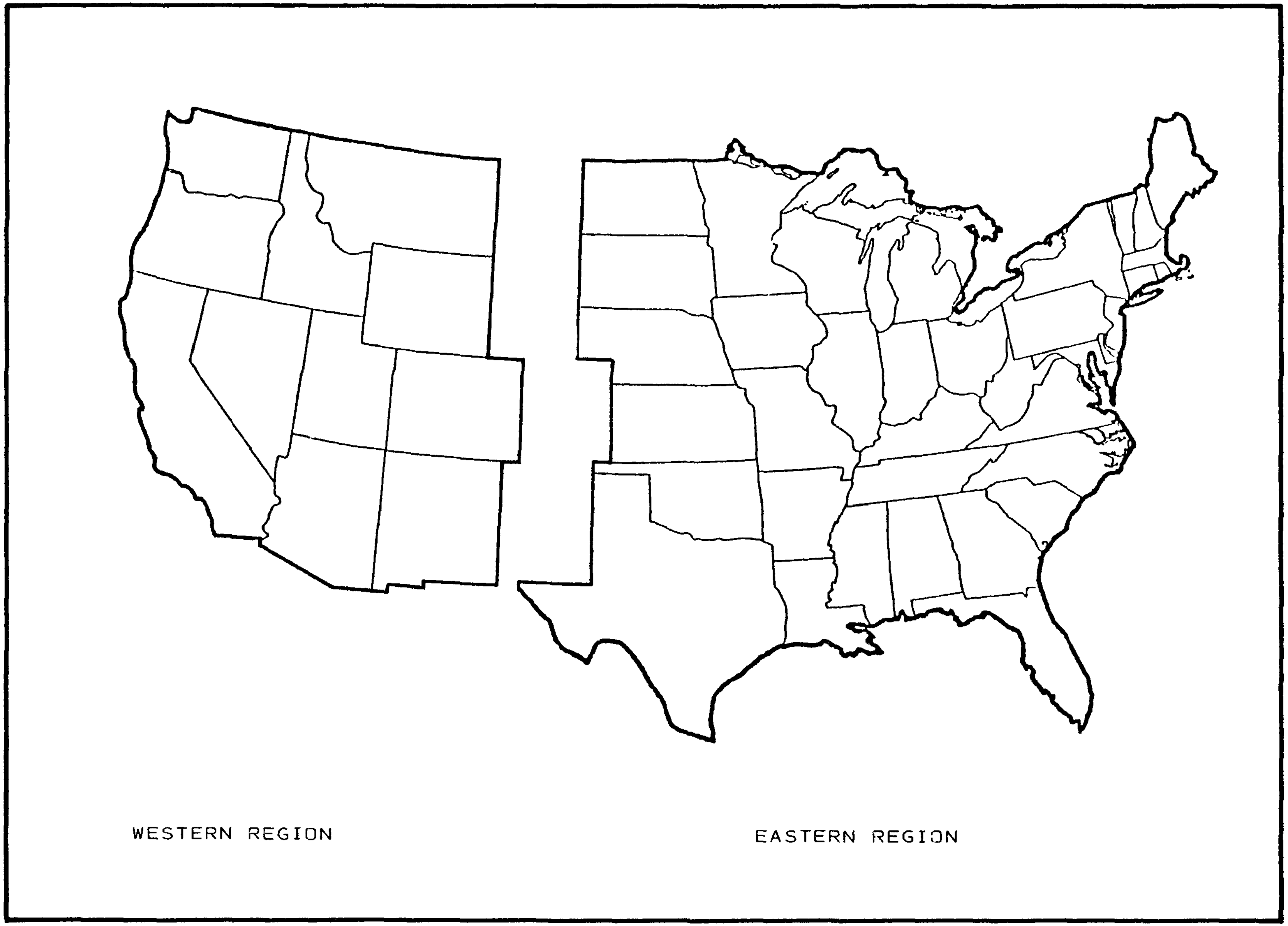

Figure 3. Partitioning of states as to source of phosphate fertilizers.

TABLE 6. ANNUAL Cd LOADING RATES ATTRIBUTABLE TO PHOSPHATE FERTILIZERS IN THE WESTERN REGION - 1974

Crop	Total Area Under Cultivation (10^3 ha)	Total Fertilizer Applied* (10^3 t)	Average Fertilizer Applied* (kg/ha)	Annual Cd Loading Rate (kg/ha) for Fertilizer containing		
				25 ppm Cd	100 ppm Cd	175 ppm Cd
Feed Grain	2,548	236	93	0.0023	0.0092	0.0161
Wheat	6,084	92	15	0.0004	0.0016	0.0028
Soybeans	0	0	0			
Cotton	738	40	54	0.0014	0.0056	0.0098
Tobacco	0	0	0			

* Based on proceedings of TVA Fertilizer Conference (38).

TABLE 7. ANNUAL Cd LOADING RATES ATTRIBUTABLE TO PHOSPHATE FERTILIZERS IN THE EASTERN REGION - 1974

Crop	Total Area Under Cultivation* (10^3 ha)	Total Fertilizer Applied† (10^3 t)	Average Fertilizer Applied* (kg/ha)	Annual Cd Loading Rate (kg/ha) for Fertilizer containing:		
				5 ppm Cd	15 ppm Cd	30 ppm Cd
Feed Grain	38,198	4,484	117	0.0006	0.0018	0.0036
Wheat	20,493	934	46	0.0002	0.0006	0.0012
Soybeans	21,209	580	27	0.0001	0.0003	0.0006
Cotton	4,352	310	71	0.00036	0.0010	0.0022
Tobacco	390	280	716	0.0036	0.0108	0.0216

* Based on proceedings of TVA Fertilizer Conference (38).

† This is total phosphate fertilizer applied, not as P_2O_5.

From the tabulations, the maximum annual average Cd contribution in the western region would be 0.0162 kg/ha on feed grain fields. In the eastern region, tobacco fields would receive the maximum average contribution of 0.0214 kg/ha of cadmium.

ASSESSMENT

A preliminary assessment of the above estimated Cd contributions from phosphate fertilizers follows. Four topic areas are addressed:

- Total Cd contributions from phosphate fertilizers,
- Cd effects on soils,
- Cd effects on groundwater, and
- Cd effects on plants.

For comparison, potential Cd loadings from sewage sludge applications are also discussed.

Total Cd Contributions from Phosphate Fertilizers

The utilization of phosphate fertilizers results in quantifiable additions of cadmium to the environment, as shown above. Table 8 presents a breakdown of estimated quantities on a regional and national basis. Quantities were calculated based on the following assumptions:

- Intermediate Cd concentrations were 100 ppm (western sources) and 15 ppm (southeastern sources) in the phosphate fertilizers consumed.

- 83 percent of the fertilizer consumed was obtained from southeastern manufacturing sources (derived from 1975 TVA statistics).

In 1976, Cd addition from the use of phosphate fertilizers on a national basis was approximately 280 t.

To place these quantities in perspective invites further comparisons between (43) cadmium contributed to the environment from the utilization of sewage sludges, and (1) total Cd emissions to the environment from all sources.

Estimated Cd Loadings from Sewage Sludge--

An estimated 73 t of elemental cadmium was distributed to cropland from municipal sewage sludge sources during 1976, based on the following assumptions:

- 1976 national generation of municipal sewage sludge was 4.5 million dry t (1).

TABLE 8. ESTIMATED TOTAL Cd CONTRIBUTION TO THE ENVIRONMENT FROM THE USE OF DOMESTIC PHOSPHATE FERTILIZERS - 1976

Phosphate Fertilizer Production (1976)*	
Western Sources	1,614,000 t
Southeastern Sources	7,878,000 t
Intermediate Cd Concentrations	
Western Sources	100 ppm
Southeastern Sources	15 ppm
Annual (1976) Contribution of Cd	
Western Sources	162 t
Southeastern Sources	118 t
Total	280 t

* Unpublished data - EPA, Region X (46).

- Average Cd concentration in dry sludge was 81 ppm (12).

- 20 percent of all municipal sludge generated was utilized on agricultural lands (44).

Cadmium distribution from fertilizer sources was slightly more than four times greater than distribution from municipal sewage sludge.

The phosphate application rate normally depends on the soil type, crop to be grown, and method and frequency of application. Typically, fertilizers are applied prior to planting and, for some crops, during various stages of crop growth. Based on which particular fertilizer formulations are used, application rates may range from 50 to 250 kg P/ha.

Sewage sludge, on the other hand, offers a source of phosphorus but in a greatly diluted form. Usually, the sludge is utilized on an available N basis (5) with application rates ranging from 2 to 50 t/ha (40). If all available sludge were used as a soil amendment, distribution would approach 2 percent of available agricultural land (5).

Phosphate fertilizers, on the other hand, are utilized at much lower application rates - 25 to 250 kg/ha - and are liberally distributed to a high percentage of the nation's croplands.

Estimated Cd Loadings from All Sources--

Under contract to the EPA Office of Toxic Substances, Versar (33) had revised Cd emission estimates based upon data originally calculated by Fulkerson and Goeller (11) for all contributing sources (Table 9). Cadmium from phosphate fertilizers constitutes approximately 5.5 percent of the total. If the total estimated 1976 quantity (280 t) shown in Table 8 were substituted, this percentage would increase to approximately 14 percent. The difference in Cd contributions from sewage sludge shown in Table 9 and the sewage sludge contributions presented earlier (73 t) is attributed to the following:

- The Versar study (Table 9) cites all land disposal of sludge, e.g., landfill, lagooning, and agricultural utilization.

- The 73 t estimate reflects the loading of cadmium from only those sludges employed for agricultural utilization - approximately 40 percent of the total sludge destined to land (44).

TABLE 9. ESTIMATED Cd CONTRIBUTIONS TO THE ENVIRONMENT FROM ALL SOURCES, 1974-75*

Source	Airborne Emissions	Waterborne Effluents	Land-Destined Wastes	Total Emissions
Zinc Ore Mining & Beneficiation	0.2 †	~0	250	
Primary Zinc Industry	102	2.0(1977)	~0	
Total: Extraction, Refining & Production	102	~7(1974-75)	250	359(1974-75)
Electroplating Shops	~1	4.0(1977)	80(1977)	
Pigment Manufacture	9.5 †	0.75	16.5	
Stabilizer Manufacture	2.7 †	~0	~0	
Alloy Manufacture	2.3 †	~0	~0	
Battery Manufacture	0.7 †	0.3	11.4(1977)	
Total: Industrial Conversion	15	~8(1974-75)	~102(1974-75) ~ 75(1980)	125(1974-75) 93(1980)
Secondary Non-Ferrous Metals	2.2	~0	20	
Iron and Steel Industry	10.5	~0	330	
Galvanized Products	~0	~0	40	
Rubber Tire Wear	5.2 †	~0	~0	
Incineration	16	~0	70	
Total: Consumption & Disposal of Cd-containing products	34	~0	460	494
Phosphate Fertilizers	~0	~0	100(1975) 130(1980)	
Phosphate Detergents	~0	10.2	~0	
Coal Combustion	80(1974)	~0 ~0	370(1974) 680(1980)	
Diesel & Fuel Oil Combustion	50 †	~0	~0	
Lubricating Oils	0.8 †	~0	~0	
Sewage Sludge	20	~0	250	
Total: Inadvertent Sources	151	10	720(1974-75)	831(1974-75)
Grand Totals	300	25(1974-75)	1,500(1974-75)	1.800(1974-75)

*Metric tons per year as elemental cadmium.

†Estimates unchanged from Fulkerson-Goeller estimates (11).

- Calculations within the Versar study are based on an annual sludge generation of 10.9 million dry t. In our study a more conservative figure of 4.5 million dry t (1) was used.

Cadmium Effects on Soils

To assess the soil effects of cadmium from the use of phosphate fertilizers, naturally occurring Cd levels in soils must be considered.

Page and Bingham (28) suggested that soils derived from igneous rock contain 0.1 to 0.3 ppm Cd and that soils of sedimentary origin contain 0.1 to 1.0 ppm Cd. Page (27) reported that typical soil Cd concentrations range from 0.03 to approximately 1.4 ppm, and that a median level for U.S. soils is approximately 0.3 ppm. Stearns, Lofy, and LaConde (40) reported naturally occurring Cd levels ranging from 0.24 ppm for a Morley clay loam to 3.77 ppm for a Salinas silty clay loam (Table 10).

A preceding section presented estimated annual mass Cd emissions to the environment. To examine the potential effects of Cd loading, however, fertilizer application rates must be examined over longer time frames to determine both net addition and cumulative effects. Table 11 presents such an approach showing the hypothetical cumulative Cd loadings for 100 continuous years of phosphate fertilizer addition. The data in this table were based on the following assumptions:

- Fertilizer was applied annually for 100 yr at the two rates indicated.
- The intermediate values of Cd concentration (western-100 ppm, southeastern-15 ppm) represented the phosphate fertilizer used.
- The natural Cd concentration of the soil was 0.3 ppm.
- Application rates of 100 and 250 kg P/ha represented the range of typical phosphate fertilizer application rates.
- Phosphate fertilizers contained 50 percent P_2O_5.

The Cd loading data in Table 11 are presented in two forms. The first shows the 100-yr cumulative Cd addition in kg/ha for two different application rates; the second presents a factored Cd addition in terms of 1,000 kg/ha fertilizers added.

TABLE 10. CADMIUM CONCENTRATIONS IN SELECTED U.S. SOILS*

Soil Type	Average Cd Concentration† (ppm)
Congaree sandy loam	0.76
Salinas silty clay loam	3.77
Xenia silty clay loam	0.87
Britwater silt loam	0.73
Burkhardt sandy loam	0.46
Pembroke silt loam	0.83
Morley clay loam	0.24
Ross silty clay	0.78

* From Stearns, Lofy, and LaConde (40).
† HNO_3-$HClO_4$, oven-dry (110°C) basis.

TABLE 11. 100-YR ACCUMULATION OF CADMIUM IN SOIL FROM THE ANNUAL APPLICATION OF PHOSPHATE FERTILIZERS FROM WESTERN AND SOUTHEASTERN SOURCES

	Fertilizer Source*			
	Western		Southeastern	
Fertilizer Applied (kg P/ha/yr)†	100 Year Total Cd Added (kg/ha)	Cd Increase per 1,000 kg P/ha Fertilizer Added (kg/ha)	100 Year Total Cd Added (kg/ha)	Cd Increase per 1,000 kg P/ha Fertilizer Added (kg/ha)
100	4.6	0.46	0.7	0.07
250	11.5	0.46	1.7	0.07

*Cadmium concentrations assumed as follows: western sources, 100 ppm; southeastern sources, 15 ppm.

†Fertilizer assumed to be equally mixed within the top 15 cm of soil with bulk density of 1.33 and a total natural (background) Cd content of 0.3 ppm (equivalent to 0.67 kg/ha).

It is recognized that farming practices may preclude the continuous addition of phosphate fertilizers. When such addition is assumed, the above calculations indicate that the annual amount of cadmium added to soils via phosphate fertilizers is quite small. However, the long-term (100 years) accumulation of cadmium from the western fertilizer source could be significant. Total Cd additions of 4.6 and 11.5 kg/ha, respectively.

Williams and David (49) performed a similar analysis on Australian phosphate fertilizers. Soils that had received regular top-dressing of superphosphate for 30 to 45 yr and total cumulative dressings of 2,500 to 4,500 kg fertilizer/ha were analyzed for cadmium. The results were expressed in terms of Cd increase per 1,000 kg fertilizer/ha and ranged from 0.023 to 0.053 kg Cd per 1,000 kg fertilizer/ha (0.12 to 0.26 kg Cd per 1,000 kg P/ha). The data presented in Table 11, 0.07 to 0.46 kg Cd per 1,000 kg P/ha, are in general agreement with the Australian findings.

Some state regulatory agencies have proposed restricting annual Cd additions to 0.5 kg/ha after 1985. Data from Table 11, when expressed on an annual basis, indicate that the greatest possible incremental net increases in cadmium from the use of phosphate fertilizers are quite small - 0.12 kg/ha for western and 0.02 kg/ha for southeastern sources, both at fertilizer application rates of 250 k P/ha. As a result, the use of typical amounts of phosphate fertilizers, regardless of source, will not result in annual Cd concentrations greater than those indicated.

In regard to heavy-metal loading from sewage sludge, it has been recommended that soils with a cation exchange capacity (CEC) value less than 5 meq/100 g soil be restricted to a total cumulative Cd addition of 5 kg/ha; those with CEC's between 5 and 10, to a maximum of 10 kg/ha; and those with CEC's greater than 15, 20 kg/ha (18). Table 12 extends that data in Table 11 and shows the number of consecutive years that phosphate fertilizer can be applied before the first two limits are exceeded.

The following assumptions were made in calculating these data:

- Cadmium concentration of western phosphate fertilizer was 100 ppm; of southeastern phosphate fertilizer, 15 ppm.
- Five percent of the cadmium applied in the form of phosphate fertilizer was removed with the harvested plant tissues. (Williams and David (49) showed that plant uptake ranged from 0.4 to 7 percent.

TABLE 12. PROJECTED YEARS OF ALLOWABLE PHOSPHATE FERTILIZER APPLICATIONS BASED ON Cd LOADING LIMITS RECOMMENDED BY THE NC-118 STUDY GROUP (18)*

	Fertilizer Source			
	Western		Southeastern	
Fertilizer Application Rate	Total Cd Loading of 5 kg/ha†	Total Cd Loading of 10 kg/ha#	Total Cd Loading of 5 kg/ha†	Total Cd Loading of 10 kg/ha#
kg P/ha	Years			
100	115	230	766	1,532
250	46	92	306	613

* Assumed 5 percent plant uptake and fertilizers applied contained 50 percent P_2O_5 (P x 2.29 = P_2O_5).

† Based on soils with CEC $\leq$5 meq/100g.

Based on soils with CEC $\geq$5 meq/100g.

- Phosphate fertilizers contained 50 percent P_2O_5.

- Annual applications of phosphate fertilizers were spread at the suggested rate.

The loading period encompassing the shortest time span for western phosphate fertilizers would occur at the heavier application rate of 250 kg P/ha. Even at this rate, an estimated 46 yr would be required to reach a cumulative total of 5.0 kg Cd/ha. Using southeastern fertilizer, more than 1,532 yr would be required to exceed 10.0 kg Cd/ha at the lower loading rate.

Cadmium Effects on Groundwater

Williams and David (49, 50) examined soils (10 percent or greater clay) that had received cumulative additions of superphosphate of up to 4,000 kg/ha over 20 or more years. They indicated that more than 80 percent of the fertilizer cadmium was retained in the surface 10 cm of soil. In one soil containing siliceous sand (2 percent clay), 50 percent of the cadmium had been retained over a time span encompassing a 900 kg/ha cumulative loading of phosphate fertilizer.

These data suggest that available cadmium applied to soils by the use of phosphate fertilizers is chemically precipitated or retained by the soil matrix (e.g., cation exchange). Thus, its mobility is greatly reduced.

Cadmium Effects on Plants

The use of phosphate fertilizers on vegetable crops presents one of the greatest potential hazards of Cd addition to the food chain. The CAST Report (5) indicated that crops may contain undesirable Cd concentrations in their tissues without showing visible symptoms of phytotoxicity. Further, Bingham et al. (3), CAST (5), Dowdy and Larsen (8), and others have shown that leafy vegetables take up more cadmium than other vegetable or grain crops. Table 13 presents relative Cd uptake by selected vegetables and grains. The ultimate Cd concentration in plant tissues is dependent upon many factors, such as application rates, form of applied cadmium, crop species and variety, CEC, soil pH, texture, organic matter content, and concentrations of other heavy metals present in the soil.

Williams and David (49) reported that cadmium in superphosphate was soluble in water. The cadmium was associated with both the phosphate and sulfate compounds of the fertilizer, and appeared to be as readily available to plants as $CdCl_2$. However, they found low Cd concentrations (0.012 to 0.036 ppm) in grain and breakfast-cereal foods made from Australian wheat grown

TABLE 13. CONCENTRATIONS OF CADMIUM IN THE EDIBLE TISSUE OF VARIOUS CROPS GROWN IN SOILS CONTAINING 20 ppm Cd*

Crop species	Cd Concentration	Crop species	Cd Concentration
	ppm †		ppm †
Rice grain	0.6	Red beet	7.4
Zucchini squash	1.0	Wheat grain	8.7
Field bean	1.0	Turnip	11
Corn grain	2.4	Soybean grain	17
Cabbage	3.4	Carrot	19
Tomato fruit	3.6	Lettuce	135
Radish	6.3	Curlycress	154
		Spinach	188

* Derived from Bingham et al. (3); to produce a concentration of 20 ppm Cd in soil, 1% sewage sludge which had been spiked with $CdSO_4$ was mixed with the soil.

† Oven dry weight ($70^{o}C$) basis.

in fields with a long history of superphosphate usage (containing 44 ppm of Cd). Plant uptake of cadmium from these fields ranged from 0.4 to 7 percent of total cadmium, and the uptake was greatly influenced by soil type.

Assuming that only a small percentage of the cadmium from fertilizer sources is available for plant uptake, the effects of incremental vs. cumulative Cd loadings will be examined.

The CAST Report (5), commenting on Cd concentrations in corn leaves, stated:

> "...data on repeated annual applications of sludge to soil cropped to corn show that the amounts applied in a given year influenced the cadmium content in the leaves to a greater extent than did the total cumulative amounts of cadmium applied. The implication of these results is that, at the rates used, most of the applied cadmium was being converted to forms of relatively low availability to plants."

Recent studies on ryegrass (2) and snap beans (9) also suggest that cadmium in plant tissues is more a function of periodic incremental Cd additions than the cumulative Cd total.

Reuss, Dooley and Griffis (31) recently reported a linear relationship between Cd additions to soils in the form of phosphate fertilizers and resultant plant (various species) uptake. These data, while suggesting a relationship between total soil and plant Cd concentrations, are seemingly in contradiction with the above referenced studies. Several limitations of the study, however, are noted:

- The study entailed greenhouse potting studies conducted over a one-year period.
- The test conditions may not have been typical of field conditions.
- Extrapolation of one year's data may not be valid, especially in light of the previously presented references.
- The fertilizers were "spiked" with cadmium.

The calculations in this study show a range of annual Cd loading from 0.007 to 0.12 kg/ha, depending on the fertilizer sources (Table 11). Williams and David (49) presented data showing that up to 7 percent of cadmium in Australian phosphate fertilizer was available for uptake by plants. Using this availability as a maximum, the above-cited range would diminish to 0.00049 to 0.0084 kg Cd/ha/yr.

If cumulative loadings play an important role in plant uptake, a specific but unknown amount of cadmium in phosphate fertilizers applied to soil will increase the latter range somewhat. It should be considered, however, that of the available 100-yr Cd total, some cadmium will be precipitated or fixed in the soil matrix. Therefore, it would seem unlikely that reasonable application rates of phosphate fertilizer containing an average of 100 ppm cadmium would increase the Cd levels of plant species to any significant degree.

There are not sufficient data which can be used to compare the plant availability of cadmium in phosphate fertilizers with that in sewage sludge. Cunningham et al. (7) presented data which showed that the treatments involving inorganic salts of heavy metals (Cr, Cu, Zn, and Ni) resulted in lower corn yields, and in general, higher metal concentrations than the equivalent sludge treatments. Chemical speciation affects rates of precipitation and dissolution of metals in soil, thereby influencing their availability to plants (22). These data seem to indicate that cadmium in phosphate fertilizers would be more available for plant uptake than that in sewage sludge, assuming Cd loadings were the same from both sources. However, more research is needed to substantiate this speculation.

COMPARISON OF Cd LOADINGS FROM SEWAGE SLUDGE AND PHOSPHATE FERTILIZERS

A recent study by Stearns, Lofy, and LaConde (40) provided Cd loading data at nine agricultural locations where sewage sludge had been utilized for 5 to 17 yrs (Table 14). With the exception of Site 7, the Cd loading rates ranged from 0.08 to 1.0 kg/ha/yr. It is worthy of note that the Cd concentration of sludges used at Sites 1, 2, 3, 5, 6, and 9 were of the same magnitude as Cd concentrations of southeastern phosphate fertilizers. Sites 4 and 8 approximated Cd values of western phosphate fertilizers.

Site 8 received an annual Cd application rate of 1.0 kg/ha when amended with Cd-containing sewage sludge. If this site were to be treated with an additional western source phosphate fertilizer (100 ppm Cd) at an annual fertilizer application rate of 250 kg P/ha (equivalent to 55 kg P/ha), the Cd loading rate attributable to the fertilizer would be 0.025 kg/ha. By comparison, therefore, the annual Cd addition from sewage sludge at Site 8 would be 40 times greater than that from phosphate fertilizer.

TABLE 14. ANNUAL Cd LOADING RATES AT NINE U.S. SEWAGE SLUDGE SPREADING SITES*

Site	Crop	Avg. Cd Concentration in Sludge† (ppm)	Annual Sludge Application Rates (m t/ha)†	Avg. Annual Cd Loading Rate (kg/ha)
1	Bromgrass	11.9	16.7	0.30
2	Ryegrass	11.9	18.9	0.60
3	Alfalfa	11.2	6.8	0.08
4	Fescue	56.1	31.4	0.80
5	Soybeans	7.03	12.4	0.11
6	Fescue	7.60	24.1	0.17
7	Wheat	1505	46.	45
8	Alfalfa	50.0	12.9	1.0
9	Corn	5.7	12.5	0.37

* From Stearns, Lofy, and LaConde (40).

† Oven dry weight (110°C) basis.

Similarly, Lee and Keeney (21) indicated that sludge additions, compared to phosphate fertilizer additions, had a greater potential of significantly increasing the soil concentration of cadmium because of the much higher application rates used. They estimated that 186 yr of continuous (once per year) phosphate fertilizer application at 50 kg/ha/yr would be required to equal one application of sewage sludge at a rate of 9 dry t/ha (assuming a sludge Cd concentration of 18 ppm).

The largest contributing difference in the above cited example stems from the application rates of the sewage sludge compared to those of the fertilizer. On a short-term basis, therefore, the net addition of cadmium to soil by the use of phosphate fertilizers is probably not significant. The long-term cumulative additions are, however, of potential significance.

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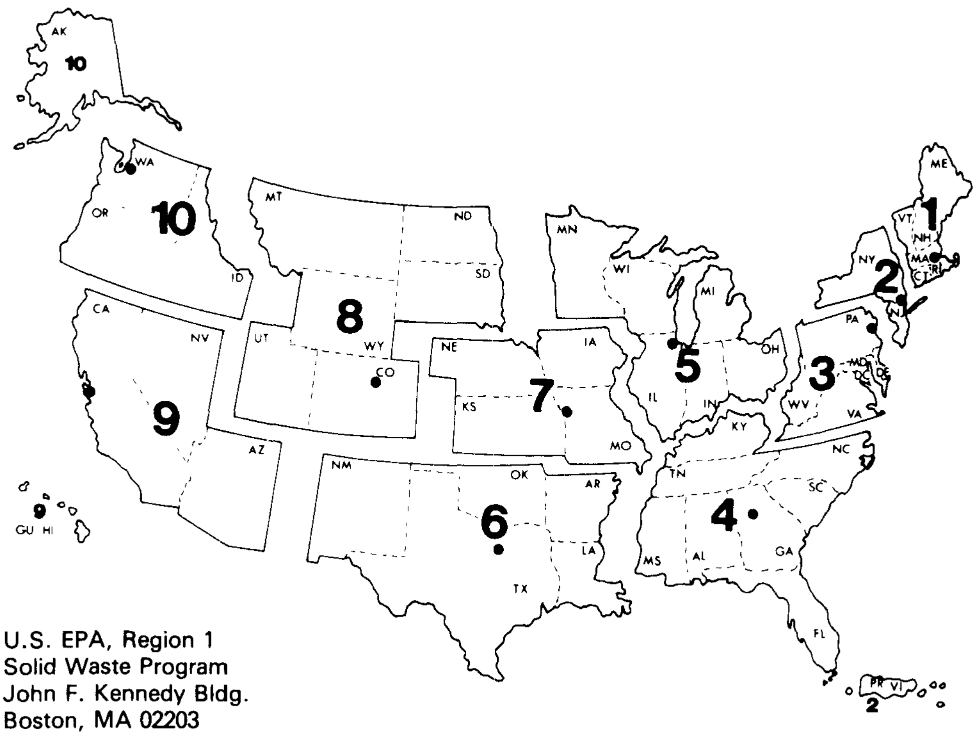

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