SW-882

Sewage Sludge:

Factors Affecting the Uptake of Cadmium by Food-Chain Crops Grown on Sludge-Amended Soils

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The following is in response to a request by Albert Peter, Jr., U.S. EPA, for the W-124 SEA-CR Technical Research Committee to respond to the September 13, 1979, Interim Final Criteria as they pertain to the items contained in his letter, dated December 7, 1979. This document was drafted January 17, 1980, following the Annual W-124 SEA-CR Technical Committee meeting and is the result of discussions which occurred during the P.M. on the 16th and A.M. on the 17th. Therefore, the time constraint limited the details in the response.

I. Background on the Use of Cation Exchange Capacity (CEC) in Conjunction with Cumulative Cd Addition to Soils

The following is a summary of the development of metal limitations by NC-118/W-124 for application of sewage sludge on agricultural land. The approach has always included Pb, Zn, Cu, Ni, and Cd rather than just Cd as adopted in the Criteria.

1. 1971. Chumbley (ADAS No. 10, 1971) in England suggested use of a Zn equivalent approach (Zn eq) to limit Zn, Cu, and Ni additions to soils in sludge. The equation used was Zn eq = Zn + 2 Cu + 8 Ni, with the coefficients reflecting the potential phytotoxity of Zn, Cu, and Ni. Sludge Zn eq added was limited to 500 lbs/acre and soil pH $\geq$ 6.5. Personal communications with research personnel from England involved revealed that the Zn eq was based upon solution and pot cultures and limited field data. It was designed for protection of sensitive crops grown on acid soils. It was intended for use as an internal document to provide guidance for local extension personnel.

2. 1972. Leeper (Report to Army Corps of Engineers) proposed that soil CEC could be combined with the Zn eq approach because numerous field and greenhouse studies have suggested that phytotoxicity from Zn, Cu, and Ni was related to soil CEC. Leeper suggested adding sludges at a Zn eq rate equal to 5% of the CEC.

3. 1974. The U.S. EPA published a draft technical bulletin which proposed a modified version of the Zn eq concept to limit sludge Zn, Cu, and Ni additions to soils. Since total sludge applications would be quite low, and research indicated that phytotoxicity problems were not occurring, the Zn eq added to soils was increased from 5 to 10% of the CEC. In addition, the sludge Cd/Zn, presumably to minimize Cd uptake by crops, was suggested not to exceed 1/100. Also soil pH was specified as pH $\geq$ 6.5 and, based upon research data, the relative phytotoxicity coefficient for Ni was decreased from 8 to 4.

4. 1974. A NC-118 subcommittee met in Chicago (August 1974) to respond to the draft U.S. EPA sludge application guidelines. The consensus of the group based upon research data suggested:

a) The Zn eq approach implied more knowledge than existed concerning the relative phytotoxicity of Zn, Cu, and Ni.

b) Pb and Cd additions to soil should also be limited due to phytotoxicity and human health considerations respectively.

c) Soil pH should be 6.5 at the time of sludge application and maintained at $\geq$ 6.2 after application.

d) The annual rate of sludge application should be controlled by either (1) the nitrogen required by the plant (minimize NO_3^- leaching, or (2) 2 lbs Cd/acre/yr, whichever is lower.

e) The annual Cd application of 2 lbs/acre was based, in part, on field data from Wisconsin where corn was grown and no increase in grain Cd occurred at this rate (Soil pH 6.0-6.2). Slight but not statistically significant grain Cd increases were observed at 4 lbs Cd/acre.

f) The cumulative amount of Cd should be limited to 10 lbs/acre based on:

1) 5 years of sludge application at 2 lbs/acre/yr would result in an average soil concentration of 10 lbs Cd/acre in the plow layer (typically 0-6 inches) a level within the range encountered for natural mineral soils (based upon information published by Alloway, 1968), and 2) additional data would be available within this 5 year period.

g) The amounts of Pb, Ni, Zn, and Cu added to soils should be limited because of evidence for relative phytotoxicity. Data were used from greenhouse and limited field studies.

h) The limits were chosen for medium textured soils in the North Central states region. The NC regional committee proposed the following limits for metal additions to soils in the form of sludge.

Pb	1000 lbs/acre
Zn	500 lbs/acre
Cu	250 lbs/acre
Ni	100 lbs/acre
Cd	10 lbs/acre

Sludge applications should cease when any one of the above exceeded the limit specified above.

5. 1976. The NC-118 Committee at the request of USDA (Cincinnati, Jan. 1976) adopted a combination of the single metal limits and the Zn eq at 10% of the CEC. Sludge applications should be lower for coarse textured soils because of the potential for a lower pH buffering capacity, lower metal adsorption capacity, and to minimize possible metal leaching. Coarse, medium, and fine textured soils were selected based upon CEC. The metal limits suggested as guidelines were

	CEC (meq/100 g)		
	<5	5 - 15	>15
Pb	500	1000	2000
Zn	250	500	1000
Cu	125	250	500
Ni	50	100	200
Cd	5	10	20

The 15 meq/100 g category was selected because of known trace element deficiencies that can occur in high organic matter/high CEC soils. Also, metal adsorption was correlated with CEC. These metal addition limits also assumed soil pH control at pH $\geq$ 6.5 during and after sludge application. The committee did not have research data to show a relationship between Cd uptake by plants and CEC. Rather CEC was chosen as an easily measured soil property that is directly related to the ability of a soil to minimize Cd solubility and thus reduce plant uptake of Cd. That is, as CEC increases, the concentration of soil components responsible for metal retention and metal buffering capacity also increase, i.e., organic carbon, Fe and Al oxides and clay content. Numerous exceptions exist to this general statement. It should be emphasized that the above metal additions approach was

1. Conservative in nature for Pb, Zn, Cu, and Ni because of insufficient data at high application rates.

2. Capable of providing adequate protection for the continued productivity of agricultural soils.

3. Based on CEC because soil properties, in addition to pH, were believed to be important in controlling uptake, including Pb, Zn, Cu, Ni, and Cd by plants and because CEC was a routinely determined soil parameter in soil testing labs.

4. Designed for use as a guideline for state and local extension personnel in the NC and NE regions where soil organic carbon makes an important contribution to CEC. The limits were not intended to be used as a regulatory tool.

5. By following these guidelines farmers utilizing sewage sludge would only have to utilize their current soil testing programs which include soil pH and lime requirements. No soil or groundwater monitoring for N and metals was thought to be needed.

6. The consensus of the committee is that CEC serves as a useful guideline to limit applications of Pb, Zn, Cu, and Ni. Its application for limiting Cd application to soils cannot be supported on a broad scale.

II. Is CEC a viable soil factor controlling the uptake of Cd by crops from soils amended with sewage sludge?

A consensus of the committee regarding this item follows.

1. The NC-118, W-124, USDA Committee did not propose that increasing the CEC would decrease Cd uptake by crops in all cases.

2. Most studies involving soils with varying CEC have also had varying pH and other soil properties which confound the interpretation of the data and result in the inability to relate Cd uptake by plants to any single soil factor.

3. Studies relating CEC to Cd uptake show conflicting results.

4. Not all soils should receive the same cumulative Cd loading rates. CEC does not adequately reflect all soil factors which influence the uptake of Cd by plants. Therefore it is not applicable as a regulatory tool over a broad range of soils from the various regions throughout the USA. Some examples where CEC is not applicable include:

a) Calcareous soils which are generally insensitive to CEC effects on Cd uptake by plants (see glossary of Soil Science terms (SSAJ) for definition of calcareous soils).

b) Some soils in the Southeastern USA have low CEC but high Cd sorption capacities due to Fe and Al oxides. Data available suggests that when these soils are at pH $\geq$ 6.5, Cd uptake by plants is less than one would predict based upon soil CEC.

c) Organic matter, Fe and Al oxides, texture, and pH buffering capacity were identified as factors which probably regulate Cd uptake by plants, but these are interrelated and our knowledge is not presently adequate to quantify their independent effects.

III. Priorities for alternative soil factors to use as a regulatory tool to limit Cd uptake by plants.

1. From the standpoint of Cd uptake by plants, soil pH is the soil factor which has the greatest and most consistent effect on Cd uptake in various studies, and is most readily supported by available research data.

2. Other soil factors identified were: organic matter content, content of Fe and Al oxides, texture, and buffering capacity. Because of the interrelationships of these factors, lack of research data to describe their effects on Cd uptake, and the lack of routine procedures for their measurement (except texture), the committee did not feel that any single factor could be used, at this time, to set Cd loading limits for all soils in all regions of the USA.

3. Research indicates that calcareous soils greatly limit Cd uptake over a range of soil CEC. Field research data show that a cumulative Cd application of 20 kg/ha results in a Cd concentration in crops which falls in the range for crops grown on natural (not amended with Cd) non-calcareous soils.

4. Cd loading rates should not be the same on all non-calcarous soils. Low organic matter sandy soils should have lower cumulative Cd loading limits than high organic matter medium textured soils. There is insufficient information at this time to differentiate between these two broad groups of soils for regulatory purposes.

IV. Based on research data of W-124 committee representatives and the published data of other researchers, the W-124 Technical Research Committee would summarize the current knowledge of annual and cumulative Cd additions to soils, and the resulting Cd uptake by plants, as follows:

At any given level of Cd in soil, whether that soil Cd is naturally-occurring or has been applied by annual or cumulative additions, Cd uptake by plants will be dependent on several soil, plant, and environmental factors. Because several factors can affect the amount of Cd taken up by plants, it is difficult to make generalizations about Cd uptake that will hold for all soil-plant systems. However, with a given soil and plant variety, some generalizations can be made as to how annual and cumulative additions of Cd will affect Cd uptake. (One must recognize that with similar Cd additions the actual amount of Cd taken up will be different with a different soil type, a different plant species, or a different climate.)

1) The pH of a soil will influence the Cd uptake by a given plant variety from annual or cumulative Cd additions.

A) Cd uptake is more pronounced at acid pH's than at slightly-acid, neutral or alkaline soil pH's.

B) Cd uptake into vegetative tissues is greater than in the fruit, grain, or tubers of plants.

2) Annual Cd loadings are important because Cd uptake by plants is related to the annual application rate.

3) Total Cd (or cumulative Cd) level in soils is important because Cd uptake by plants is dependent on the soil Cd level, but the availability of Cd to plants may be different than with annual Cd loadings.

4) For an operating site, plant uptake of Cd will depend on annual and cumulative Cd additions to soils, as summarized above.

5) For a closed site, plant uptake of Cd will be dependent on the cumulative Cd present in the soil rather than on the rate of annual Cd additions made to reach that soil Cd level. However, the rate of annual Cd loadings will have an effect on how fast the Cd uptake by plants will decline to a level that is dependent on the total Cd level in soil, following site closure. The plant uptake level of Cd eventually reached may or may not return to the normal background level in plant tissue, depending on the soil, plant, and climatic factors indicated above.

6) The background document accompanying the criteria is not considered adequate for completely addressing annual vs. cumulative Cd additions to soils because: (1) limited field data were used without adequate discussion of their limitation; (2) differences in uptake rate as a function of annual or cumulative rate of application was not sufficiently documented; and (3) there was not adequate support for a phase reduction of the annual loading rate. However,

we support the use of field data for establishing these guidelines. New research data and forthcoming data from continuing research projects will provide further insights on annual vs. cumulative Cd additions to soils. The forthcoming CAST report on this topic should contain the current state-of-the-art on this subject.

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