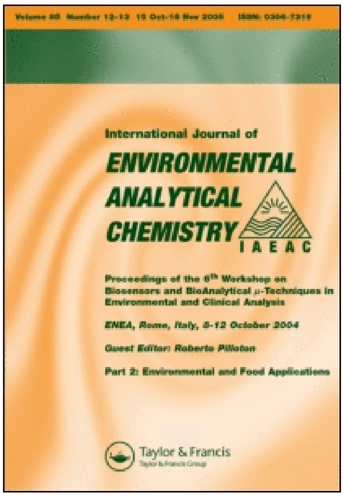

International Journal of Environmental Analytical Chemistry
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713640455

Prediction of Plant Contamination by Cadmium and Zinc Based on Soil Extraction Method and Contents in Seedlings

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To cite this Article Sanka, M. and Dolezal, M.(1992) 'Prediction of Plant Contamination by Cadmium and Zinc Based on Soil Extraction Method and Contents in Seedlings', International Journal of Environmental Analytical Chemistry, 46: 1, 87 — 96
To link to this Article: DOI: 10.1080/03067319208027000
URL: http://dx.doi.org/10.1080/03067319208027000

Intern. J. Environ. Anal. Chem., Vol. 46, pp. 87–96
Reprints available directly from the publisher

Printed in the United Kingdom

PREDICTION OF PLANT CONTAMINATION BY CADMIUM AND ZINC BASED ON SOIL EXTRACTION METHOD AND CONTENTS IN SEEDLINGS

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(*Received, 13 March 1991; in final form, 18 July 1991*)

Prediction of plant contamination on the basis of environmental conditions seems to be an important task. In order to assess the suitability of three soil extractants and seedlings as a prediction media for the content of Cd and Zn in mature plants, three independent pot trials were conducted. In these trials six soil types of different properties were used. The total number of pots was 160 (40 variants in 4 replicates). Soils were artificially contaminated by Cd and the selected variants also by Zn. The contents of Cd and Zn in soil extractants and seedlings were compared with the contents of these elements in corn mature plants (roots and stems) by means of regression analysis. For cadmium, the best results as to the prediction of its content in mature plants were obtained with $NaNO_3$, whereas for zinc the best results were given by the seedlings.

KEY WORDS: Cadmium, zinc, soil pollution, plant pollution, soil extractant, bioavailability.

INTRODUCTION

As a result of human activity, more and more agricultural products are being contaminated by toxic substances, especially by heavy metals. There are two main ways for the heavy metals to enter plants—atmospheric deposition and uptake from soils. Both ways are influenced by many factors during the plant growth and that is why it is difficult to assess the real danger of final contamination of foodstuffs. In order to prevent farmers both from growing of unutilizable products and/or from restricting farming in polluted areas, it is useful to investigate the methods of prediction of contamination.

As far as the uptake from soil is concerned, it is obvious that soil properties influence the content of an element both in soil extracts and in plants growing on that soil. The extent of plant and extract influence is, however, different and that is why the prediction of an element content in plants based on its content in soil extract is ambiguous. On the other hand, there are specific extractants which can relatively precisely reflect the uptake of an element by plants, for which reason they are more suitable for assessing the plant contamination danger. Another possibility is the estimation of this contamination based on the content of an element in seedlings.

Table 1 Variants of three experiments included in the prediction media testing.

Experiment—objective		*Properties of soil*		*Amendment*				*Soil temperature °C*
		pH	*CEC meq 100 g^{-1}*	*Cd mg kg^{-1} ($CdSO_4$)*	*Zn mg kg^{-1} ($ZnSO_4$)*	*Peat g kg^{-1}*	*CaO t ha^{-1}*	
Influence of Zn	1	7.20	37.00					
or peat adding	2	7.20	37.00	10.00				
on the uptake of	3	7.20	37.00	10.00	100.00			
Cd and Zn by	4	7.20	37.00	10.00	100.00	38.00		
plants	5	7.10	22.00					
	6	7.10	22.00	10.00				
	7	7.10	22.00	10.00	100.00			
	8	7.10	22.00	10.00	100.00	38.00		
	9	6.60	13.00					
	10	6.60	13.00	10.00				
	11	6.60	13.00	10.00	100.00			
	12	6.60	13.00	10.00	100.00	38.00		
Influence of soil	13	5.80	27.00					
pH and CEC on the	14	5.80	27.00	3.00				
uptake of Cd and	15	5.80	27.00	10.00				
Zn by plants	16	5.80	27.00	20.00				

	17	5.80	27.00		0.30	
	18	5.80	27.00	3.00	0.30	
	19	5.80	27.00	10.00	0.30	
	20	5.80	27.00	20.00	0.30	
	21	6.06	17.00			
	22	6.06	17.00	3.00		
	23	6.06	17.00	10.00		
	24	6.06	17.00	20.00		
	25	6.06	17.00		0.35	
	26	6.06	17.00	3.00	0.35	
	27	6.06	17.00	10.00	0.35	
	28	6.06	17.00	20.00	0.35	
	29	7.24	7.00			
	30	7.24	7.00	3.00		
	31	7.24	7.00	10.00		
	32	7.24	7.00	20.00		
	33	7.24	7.00		0.30	
	34	7.24	7.00	3.00	0.30	
	35	7.24	7.00	10.00	0.30	
	36	7.24	7.00	20.00	0.30	
Influence of soil temperature on the uptake of Cd by plants	37	7.10	22.00	3.00		22
	38	7.10	22.00	3.00		19
	39	7.10	22.00	10.00		22
	40	7.10	22.00	10.00		19

Table 2 Contents of Cd and Zn (mg kg^{-1}) in soil extractants, seedlings and mature plants (dry matter) in the variants of three experiments (arithmetic means of four replicates).

	Soil						*Seedlings*		*Mature plants*			
	HNO_3		*$NaNO_3$*		*CH_3COONH_4*				*Roots*		*Upper parts*	
	Cd	*Zn*	*Cd*	*Zn*	*Cd*	*Zn*	*Cd*	*Zn*	*Cd*	*Zn*	*Cd*	*Zn*
1	0.060	16.930	0.037	0.033	0.009	0.013	0.540	62.040	1.730	83.530	0.030	44.100
2	10.430	17.130	0.037	0.020	3.028	0.018	13.960	39.640	23.380	100.850	2.350	41.530
3	10.000	32.230	0.012	0.045	3.150	8.435	13.660	127.230	20.300	141.730	2.270	69.800
4	9.720	18.850	0.010	0.050	2.930	0.013	10.190	26.680	16.900	100.200	2.240	48.480
5	0.060	20.500	0.020	0.093	0.037	0.010	0.510	29.410	4.550	114.480	0.210	43.580
6	13.490	15.350	0.052	0.050	4.330	0.223	17.830	33.290	30.300	138.900	2.590	44.400
7	14.820	33.530	0.066	0.066	7.303	13.105	20.060	100.590	30.900	137.020	2.380	60.080
8	9.130	21.000	0.038	0.059	4.425	0.150	11.750	31.800	22.080	105.280	3.120	47.450
9	0.030	9.050	0.009	0.228	0.125	1.200	1.370	50.690	2.350	137.400	0.060	28.680
10	14.010	7.580	0.429	0.117	6.930	0.840	103.620	61.830	90.080	125.400	8.560	29.450
11	14.360	39.000	0.521	3.198	7.590	14.513	107.290	272.050	109.350	286.100	6.300	126.050
12	14.130	8.050	0.526	0.213	7.600	0.920	86.120	94.300	102.050	130.780	6.400	33.780
13	0.430	25.780	0.001	0.245	0.074	5.705	0.980	38.390	0.770	97.780	0.030	47.300
14	2.520	25.350	0.017	0.204	0.740	1.665	7.550	52.890	14.580	96.730	1.140	45.350
15	13.750	25.400	0.157	0.230	3.866	1.735	13.880	35.180	34.930	76.230	2.710	42.450

16	21.810	24.930	0.289	0.245	7.343	1.973	23.500	39.850	60.130	153.980	5.560	45.380
17	0.370	25.630	0.001	0.158	0.110	1.980	1.090	28.890	3.980	79.380	0.090	42.700
18	2.390	25.750	0.123	0.208	0.653	1.888	4.480	35.000	9.800	86.980	0.810	39.480
19	11.560	25.670	0.122	0.160	4.328	2.028	11.780	29.070	28.450	107.350	3.540	40.550
20	24.480	25.880	0.316	0.155	10.067	1.830	23.520	31.540	28.880	93.650	4.440	44.380
21	0.060	22.700	0.006	0.066	0.031	0.048	1.440	22.260	300.630	100.000	0.060	31.580
22	1.920	22.500	0.017	0.095	0.968	0.075	4.820	26.590	7.630	75.580	0.790	33.530
23	12.040	21.580	0.200	0.094	5.439	0.023	8.960	23.800	50.600	138.230	2.410	31.480
24	15.200	21.430	0.420	0.110	11.492	0.100	13.100	27.460	41.350	106.930	5.340	34.200
25	0.110	22.350	0.005	0.090	0.038	0.125	0.870	24.490	4.450	119.300	0.080	28.380
26	2.240	21.550	0.010	0.139	1.061	0.073	5.630	27.700	8.680	98.380	0.790	31.230
27	8.250	20.330	0.145	0.138	4.863	0.225	11.550	25.080	32.200	153.650	2.190	35.600
28	21.510	22.950	0.368	0.119	10.739	0.088	14.270	23.220	65.100	85.280	3.820	31.000
29	0.190	15.800	0.002	0.191	0.035	0.150	0.100	21.190	1.180	67.280	0.070	20.600
30	1.900	13.180	0.018	0.173	0.623	0.018	1.610	21.060	6.630	93.600	0.370	22.630
31	13.280	13.450	0.006	0.164	3.123	0.130	4.580	20.200	14.600	89.150	1.990	27.720
32	21.080	13.830	0.028	0.166	7.833	0.050	6.480	19.600	32.700	75.880	2.340	22.280
33	0.220	13.580	0.004	0.216	0.008	0.200	1.060	22.470	1.380	67.050	0.200	20.870
34	1.620	13.130	0.004	0.203	0.614	0.015	2.120	20.670	14.880	157.230	0.550	26.800
35	12.770	12.700	0.013	0.163	4.865	0.225	3.750	19.680	19.280	100.410	1.420	22.780
36	20.310	12.450	0.034	0.169	9.638	0.028	6.400	21.530	37.930	113.400	2.170	27.630
37	2.410		0.010		1.160		1.730		5.800		0.510	
38	1.750		0.010		0.900		2.400		6.680		0.430	
39	9.370		0.040		6.190		5.280		22.050		1.780	
40	9.190		0.050		5.660		5.530		14.230		1.690	

Three independent pot experiments with six soil types of different properties were carried out, with two main aims:

a) to elucidate the influence of physical and chemical soil properties on Cd and Zn uptake by plants,

b) to test the suitability of three soil extractants and seedlings as prediction media of an element content in mature plants.

The latter aim is pursued on the basis of the joined results of all three experiments. The experimental variables are indicated in Tables 1 and 2.

EXPERIMENTAL

Zea mays was used as a test plant and it was grown in Mitscherlich pots. All variants (Table 1) had four replicates, the total number of pots thus being 160. Cadmium was added into the soil in the form of $CdSO_4$ solution at levels of 0, 3, 10, 20 mg kg^{-1}. Zinc was applied in the first experiment in six variants only in the form of $ZnSO_4$ at the level of 100 mg kg^{-1}. Pots were situated on desks in the open air and plants were regularly watered. 23 days after the sowing, the plants were thinned to four per pot and samples of seedlings were taken. After the trial was over, the contents of Cd and Zn in air dried and sieved (through 2 mm) soils were analyzed by the following extraction procedures:

2MHNO_3 extraction: 10 g of soil are weighed in a 250 ml polyethylene bottle; 100 ml of 2M HNO_3 are added, shaken for 6 hours and filtered. In soils with a content of $CaCO_3 > 3\%$, 4M HNO_3 is added in order to reach the final 2M dilution.

1M CH_3COONH_4 extraction: 15 ml of 1M CH_3COONH_4 (pH 4.2) are added in a 250 ml polyethylene bottle with 10 g of soil and shaken for 20 min. After sedimentation the supernatant solution is filtered and 15 ml of ammonium acetate is added to the sediment, shaken manually and filtered again. This step is repeated once more and finally the dilution is completed up to 50 ml.

0.1M $NaNO_3$ extraction: 50 ml of 0.1M $NaNO_3$ are added into a 250 ml polyethylene bottle with 20 g of soil, shaken for two hours and filtered through filter paper (celulose acetate)[4].

The total content of these elements was measured in seedlings and mature plants (separately roots and stems). Both soils and plants were analyzed by means of AAS-graphite furnace.

RESULTS AND DISCUSSION

The contents of cadmium and zinc in soil extracts, seedlings and both roots and stems of mature plants are shown in Table 2 (arithmetic means of four replicates for each variant). The selected extractants, particularly HNO_3 and CH_3COONH_4, are

Table 3 Correlation coefficients between contents of Cd and Zn in prediction media and plants. Significant at 1%.

Prediction medium	*Correlation coefficent*					
	Seedlings		*Mature plants*			
			Roots		*Upper parts*	
	Cd	*Zn*	*Cd*	*Zn*	*Cd*	*Zn*
HNO_3	0.40	0.50	0.67	0.34	0.75	0.74
Extractant NH_4OAc	0.46	0.84	0.72	0.62	0.78	0.83
$NaNO_3$	0.81	0.83	0.90	0.75	0.88	0.77
Seedlings	1.00	1.00	0.88	0.77	0.83	0.89

common and they are widely used in soil analysis. $NaNO_3$ was also tested in a number of experiments as a bioavailability reflecting extractant[2–10,12,13]. Also seedlings were used for that purpose[11]. Comparison of these methods on the basis of correlation coefficients is shown in Table 3 and Figures 1–3. In this case the seedlings were used not only as a prediction medium but, along with mature plants, also for the assessment of the tested extractants.

$NaNO_3$ has proved to be the best extractant for prediction of mature plants. The correlation coefficients of Cd contents in mature plants (roots and upper parts) with Cd contents in $NaNO_3$ extractant (0.90 for roots; 0.88 for upper parts) were even better than those with Cd content in seedlings (0.88 for roots; 0.83 for upper parts).

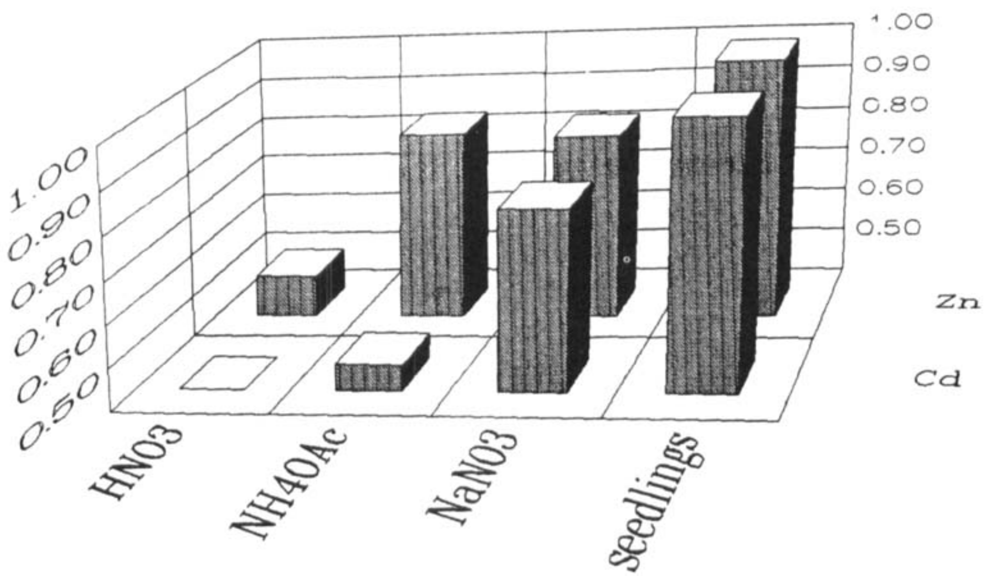

Figure 1 Correlation coefficients for prediction media v. seedlings.

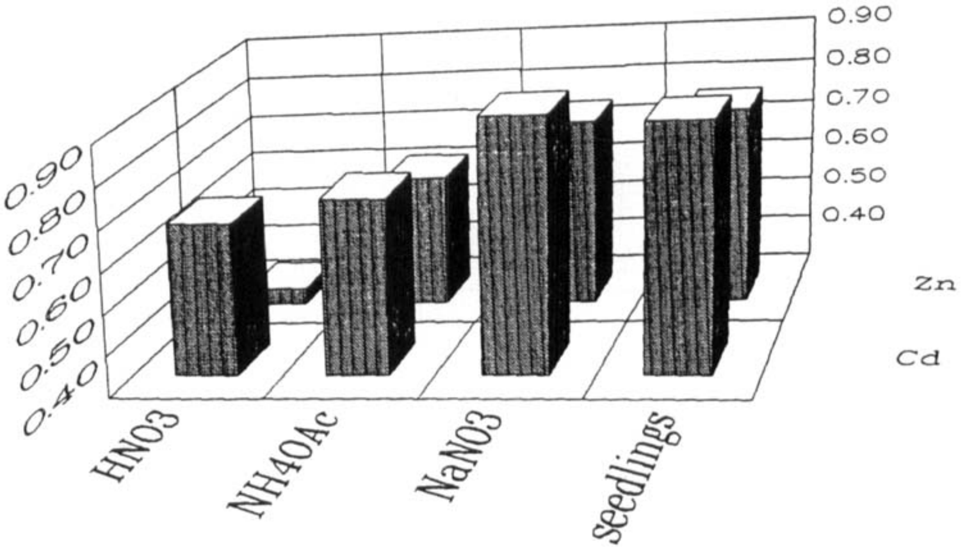

Figure 2 Correlation coefficients for prediction media v. mature plants-roots.

In spite of this, it may not be the rule, especially for naturally contaminated soils or other kinds of plants and elements.

The same interactions in the case of Zn indicated that the seedlings are the best prediction media of an element content in mature plants. As far as the extractants is concerned, NH_4OAc gave better results for the upper parts of mature plants of corn than $NaNO_3$, although for the roots, the best correlation was obtained again

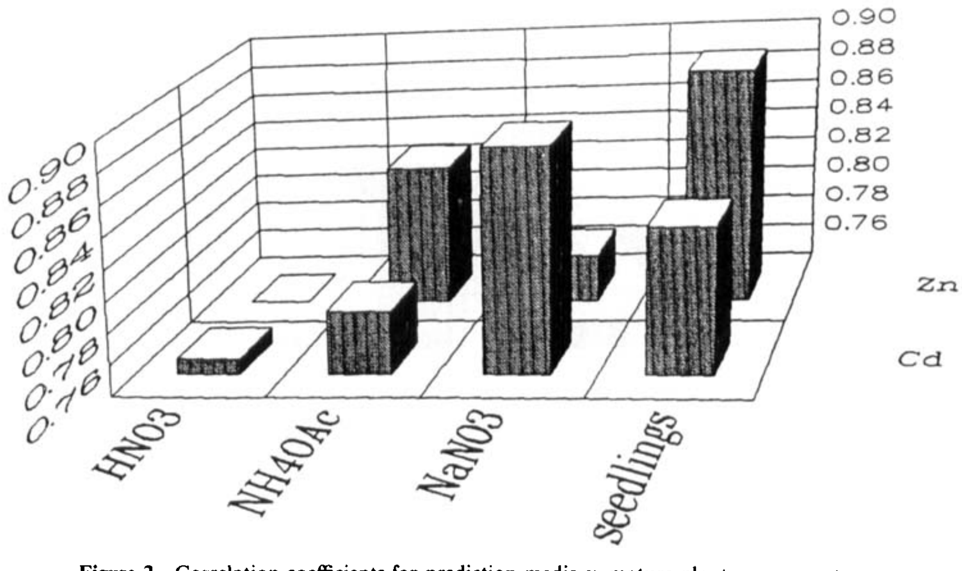

Figure 3 Correlation coefficients for prediction media v. mature plants-upper parts.

by $NaNO_3$. HNO_3, as a strong extractant, has proved to be the worst prediction medium both for Cd and Zn in all parts of plants and the metal content in this extractant evidently does not follow the data for plants. On the other hand, the data for $NaNO_3$ and NH_4OAc correspond with that of plants and reflect relatively well the soil properties like low pH and low CEC (Table 1).

Chemical analyses of seedlings were proposed as the suitable means for prediction of contamination in mature plants[11]. However, there are certain disadvantages of this method, especially the fact that results are available only after the germination. Moreover, the rapid decreasing of an element concentration in plants during their growth may depend not on plant properties only but also on original soil properties. These properties should be reflected by a specific extractant. It is obvious that each element will have its own "ideal" extractant as far as the bioavailability is concerned. But their finding and subsequently their use in agriculture is difficult and rather problematic. For that purpose it seems optimal to choose an universal extractant for bioavailable content of all elements and analyze soils for both total and bioavailable content of an element and, at the same time, to have limits for these two contents as was already proposed[14]. Such demands could be fulfilled by a mild extractant like $NaNO_3$ which was verified in many experiments[2,3,5,7,10] and in this work as well. Good results were obtained also with $CaCl_2$ extractant[13] which dissolves higher amounts of metals in the soil and that is why it can be used in less contaminated soils.

CONCLUSIONS

In areas, where agricultural soils are exposed to the negative human activity and to inputs of various substances, the possible danger of agricultural plant pollution should be assessed. In the case of heavy metals, besides of the total content in the soil we should measure also their bioavailable part, in order to indicate their uptake by plants. In accordance with several previous studies the 0.1M $NaNO_3$ extractant has proved to be the best prediction medium of the cadmium content in mature plants (roots and upper parts) and seedlings. The situation is not so clear in the case of zinc, where its content in mature plants was in the best way predicted by the Zn content in seedlings. As far as the extractants is concerned, NH_4OAc gave the best results for the upper parts and $NaNO_3$ for roots. As to the prediction of Zn content in seedlings NH_4OAc and $NaNO_3$ gave almost the same results. 2M HNO_3 gave the worst results in all cases.

References

1. A. J. Aller and L. Deban, *Sci. Tot. Environ.* **79**, 253–270 (1989).
2. S. K. Gupta, Recherche Agronom. Suisse, **23**, 209–225 (1984).
3. S. K. Gupta, International Conference "Heavy metals in the Environment", New Orleans (S. E. Lindberg and T. C. Hutchinson eds.), September 1987, Vol. 1, pp. 417–420.
4. S. K. Gupta and H. Hani, Concerted action treatment and use of sewage sludge. Final report of the Community-Cost Concentration Committee from the meeting in Portici, Italy, 1981, p. 253.

5. S. K. Gupta and H. Hani, Proceedings of Intern. Conference on "Environmental Contamination" (London, U.K.), CEP Consultants Ltd. 26 Albany Street, Edinburgh, July 1984, pp. 300–306.
6. S. K. Gupta and H. Hani, Proceedings of XIII. Congress ISSS, on "Chemical Methods for Predicting Biological Effects of Accumulated Metals in Soils", Hamburg, 13.-20.8 1986, pp. 1–8.
7. S. K. Gupta, Proceedings of the Conference "Heavy Metals in the Environment", Geneva (Switzerland), 12–15 Sept. 1989, pp. 1–4.
8. H. Hani, *Intern. J. Environ. Anal. Chem.* **39**, 197–208 (1990).
9. H. Hani and S. K. Gupta, Proceedings of Workshop on "Environmental Effects of Organic and Inorganic Contaminants in Sewage Sludge, Stevenage, May 25–26, 1982 Commission of the European Communities, Brussels Riedel NL Pub. 121, 1983, pp. 121–129.
10. H. Hani and S. K. Gupta, Proceedings of the Fourth International Symposium on "Processing and Use of Organic Sludge and Liquid Agricultural Wastes, Rome, 8–11 Oct. 1985, pp. 157–166.
11. H. Lehn and M. Bopp, *Angev. Botanik* 467–481 (1987).
12. M. Sanka and M. Dolezal, In: Proceedings from the conference "Heavy metals in the Environment", 15–17 May 1990, Ceske Budejovice, pp. 79–82.
13. D. R. Sauerbeck and P. Styperek, In: Chemical methods for assessing bio-available metals in sludges and soils (R. Leschber, R. D. Davis and P. L' Hermite, eds. Elsevier, New York and London, 1985), pp. 49–66.
14. Swiss Ordinance on Heavy Metal Contents in Soil. Bundesrates vom 9 Juni 1986.