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ASSESSMENT OF HEAVY METAL POLLUTION WITH APPLICATIONS OF SEWAGE SLUDGE AND CITY COMPOST FOR MAXIMIZING CROP YIELDS

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Abstract

ASSESSMENT OF HEAVY-METAL POLLUTION WITH APPLICATIONS OF SEWAGE SLUDGE AND CITY COMPOST FOR MAXIMIZING CROP YIELDS.

Land application of municipal sewage sludge and city compost as organic manures make it imperative to assess heavy-metal pollution in soils and crops. Greenhouse experiments, conducted on maize in a vertisol and an ultisol amended with various doses of dry sewage sludge and city compost from Mumbai, indicated significant increases in dry matter-yields only in the vertisol. Significantly higher concentrations of Zn, Cu, Co, Pb, Ni and Cd were obtained in plants grown in the amended ultisol, but not in the amended vertisol. As Cd is the most toxic, experiments were conducted with four contrasting soils amended with varying doses of Cd-enriched sewage sludge and city compost. Results showed significant reductions in dry-matter yields of maize shoots at the higher rates of sludge or compost in the ultisol and an alfisol, but with no significant effects in the vertisol or an entisol. The levels of Cd and Zn were significantly elevated in plants in all four soil types. There were negative residual effects from the sludge and compost amendments: dry-matter yields of a succeeding maize crop were decreased in the ultisol and alfisol. Experiments with soils amended with sludge enriched with either Cd or Zn at 80 mg kg^{-1} indicated significant reductions in dry matter in all soils with Cd, but not with Zn. The results demonstrate that sewage sludges and city composts may be effectively used for maximizing crop yields, especially in vertisols and entisols. However, caution has to be exercised when using sludges containing even relatively low levels of Cd, or high levels of Zn, depending upon soil type.

1. INTRODUCTION

Integrated nutrient management offers the opportunity to not only maximize but also sustain crop productivity. The approach encompasses the complementary use of all available organic and biological sources of plant nutrients, along with chemical fertilizers. Among these are farmyard manure, composts, crop residues, green manures, blue-green algae, and recyclable wastes such as sewage sludge, biogas slurry, industrial wastewater, press-mud and fly ash. Sewage sludge is a nutrient-rich, largely organic by-product of municipal wastewater treatment, which has to be removed and disposed of by ocean-dumping, incineration, land-filling or utilization in agriculture and horticulture. Land application of municipal sewage sludge is practised throughout the world. High levels of N, P, and of organic matter make it excellent as fertilizer and soil conditioner [1, 2]. Whether applications are made at increasing rates per hectare or repeatedly in consecutive years [3-6], beneficial effects are well documented in terms of crop-yield improvement, increased soil organic matter content and cation-exchange capacity, improved water-holding capacity, and general fertility [7-10].

However, sewage sludge and city compost, besides providing macro-and micro-nutrients, also contain heavy metals, such as Cd, Cr, Ni, Pb, Co and Hg, in amounts beyond those normally encountered in soils. A limiting factor, therefore, is the excessive accumulation of heavy metals in soil and resultant phytotoxicity [11-13]. Hence, fertility benefits must be balanced against the potential hazards of metal contamination through repeated heavy dressings over time.

Guidelines for applying sewage sludge, developed in Western countries, are based on N application rates, pH, cation-exchange capacity, or on crop responses determined within a short time following sludge application, with major concern over Cd uptake [14, 15]. Limits for maximum loading rates of specific toxic elements like Cd have also been prescribed [14]. The Zn-equivalent concept, which is the sum of Zn + 2Cu + 8Ni (μg g^{-1} soil) was developed to monitor maximum allowable metal concentrations (not to exceed 250 μg g^{-1}) in soils [16]. Several reviewers have summarized metal uptake by a range of crops, and heavy-metal phytotoxicity has been demonstrated with plants grown in solution culture [17-19], in greenhouse pot experiments [13, 20-24] and in the field [13, 25, 26].

Plant availability of Pb and Cr is low, but their entry into the food chain can occur by direct ingestion of sludge by grazing animals [27]. Cadmium may pose a health problem since plants can accumulate it to levels toxic to animals or humans, although not to the plants [27]. High levels of Cd are encountered in many sludge-amended soils [28] and in soils near Zn smelters [29] that can affect plant growth and dry matter yield adversely [19, 30, 31]. Plant uptake is controlled, in part, by sludge Cd chemistry, specifically sludge Cd content [32], soil pH and soil cation-exchange capacity [7-10]. Cadmium accumulates in the kidneys, liver, pancreas and thyroid of humans and animals, and it has been associated with hypertension, emphysema, chronic bronchitis and even death in extreme circumstances [11, 33].

Although there is insufficient sewage sludge and city compost available to make a significant impact on total fertilizer needs in our country, low cost and availability make it an attractive alternative in areas near sewage-treatment plants. The composition of sludges from Ahmedabad, Delhi, Jaipur, Kolhapur, Madras, Nagpur and Vijayawada were summarized recently, and the ranges of values for the major nutrients were as follows: N, 0.82-2.3%; P_2O_5, 0.84-2.1%; K_2O, 0.53-1.7%; and for organic matter, 27-55% [34]. Their heavy-metal contents, total and available (in brackets) in mg kg^{-1} were as follows: Cu, 194-535 (17.2-50.3); Zn, 833-2146 (70-216); Mn, 176-465 (1.3-26.5); Cd, 0.6-8.3 (0.1-1.4); Cr, 17-185; Ni, 11-815 (0.3-52.2) and Pb 14-77 (1.8-8.3). Little work has been done in our country to evaluate the fertilizer value and heavy-metal contributions of sewage sludges and city composts for different soil/crop combinations.

This paper reports pot-culture studies on the effects of a sewage sludge and a city compost from Mumbai on plant growth, and an assessment of the heavy-metal pollution of soil and plant. As Cd is one of the most toxic elements and Zn is chemically and geochemically related to it, their accumulation in soils and plants were separately examined.

2. MATERIALS AND METHODS

Four contrasting soils, an ultisol from Phondaghat, a vertisol from Hatkanangale, an entisol from Mahad, all in Maharashtra, and an alfisol from Chittoor, Andhra Pradesh, were selected. Their physicochemical properties are shown in Table I, and the concentrations of micronutrients and heavy metals in Table II. Total heavy-metal determinations were made by extracting the soils with 2 *M*

TABLE I. SOIL CHARACTERISTICS

	Ultisol laterite	Alfisol red	Entisol alluvial	Vertisol black
pH (1:2.5)	5.1	6.4	6.6	8.2
Moisture equivalent (%)	30.0	18.0	34.0	35.0
CEC (meq 100 g^{-1})	10.5	13.0	31.6	60.7
Organic C (%)	1.4	0.12	1.36	1.32
Free $CaCO_3$ (%)	1.00	0.50	3.00	6.75
Texture	Sandy loam	Sandy loam	Silt loam	Clay loam

HNO_3 (soil:acid 1:10) in a boiling-water bath for 2 h [35]; this represents 75 to 80% of the metals that would be extractable with hydrofluoric acid. Plant-available metals were determined by extracting 10 g of soil with 20 mL of a solution of 0.005 *M* diethylenetriaminepentaacetic acid (DTPA), 0.01 *M* $CaCl_2$, and 0.01 *M* triethanolamine (TEA), pH 7.3, in a rotary evaporator for 2 h [36].

The soils were separately amended with sewage sludge from the Dadar Municipal Sewage Plant, Mumbai, and with city compost from the Bombay Organic Manures Co. Ltd., Devnar, Mumbai. The concentrations of micronutrients and heavy metals are in Table III. In the first experiment, these materials were separately applied to one kg of two soil types, namely the ultisol and the vertisol, at 0, 56, 112, 224 and 448 t ha^{-1}. The pots were kept at field capacity for a week, after which time basal nutrients of N, P_2O_5, K_2O were applied at 60:40:60 kg ha^{-1}; two maize (*Zea mays* L.) plants were grown in each pot for eight weeks.

In order to assess Cd accumulation by maize, these soils were amended with Cd-enriched sewage sludge or city compost. The enrichment procedure consisted of preparing a slurry of the sewage sludge or compost with a solution of $3CdSO_4.2H_2O$ (300 μg Cd g^{-1} sludge or compost) and subsequent air drying. The sieved soils were treated with doses of 25, 50 and 100 g Cd-enriched sludge or compost per kg soil, representing 56, 112 and 224 t ha^{-1}, respectively. The Cd concentration in these treatments amounted to 7.5, 15.0 and 30.0 mg kg^{-1} soil. Two maize plants were grown for six weeks as described above. Residual effects were evaluated by allowing the soils to dry for a month followed by thorough mixing, maintenance of field capacity for 15 days, and then growing two maize plants for 30 days.

Sewage sludges of various Cd or Zn concentrations were applied at the agronomic rate of 44.8 t ha^{-1} to the four soil types, to obtain levels of 5, 10, 20, 40 and 80 mg Cd or Zn kg^{-1} (ppm) amended soil. The enrichment procedure and plant-growth conditions were as described above. Two maize plants were grown for six weeks.

TABLE II. CONCENTRATIONS OF MICRONUTRIENTS AND HEAVY METALS IN FOUR SOILS EXTRACTED WITH 2*M* HNO_3 AND DIETHYLENETRIAMINEPENTA-ACETIC ACID (DTPA)

	Ultisol		Vertisol		Alfisol		Entisol	
	HNO_3	DTPA	HNO_3	DTPA	HNO_3	DTPA	HNO_3	DTPA
	($\mu g\ g^{-1}$ dry wt.)							
Fe	28,400	38.9	27,900	1.7	11,845	7.0	49,500	41
Mn	318	71.6	1,085	4.9	272	32	1,212	292
Cu	74	6.8	107	4.9	8.5	1.3	117	13
Zn	44	1.34	54	0.9	8.0	0.6	92	3.0
Co	17.2	0.43	29.5	0.17	11.0	0.5	48	2.5
Pb	12.7	0.44	13.5	0.42	10.0	0.63	16	0.32
Ni	27.2	0.14	35.9	0.06	10.0	0.25	46	1.4
Cd	0.3	0.01	0.05	0.02	0.25	0.02	0.9	0.06
Cr	24.3	trace	22.0	trace	19.0	0.02	57	0.02

All treatments were replicated four times. After harvest, plant shoots were dried at 70°C, weighed and wet-ashed using a 5:1 HNO_3:$HClO_4$ acid mixture. The concentration of the heavy metals in the clear-acid extracts were determined using a Perkin-Elmer Model 380 Atomic absorption spectrophotometer equipped with a D_2-arc background corrector. The data were statistically analysed adopting Duncan's multiple range test.

3. RESULTS AND DISCUSSION

The ultisol was less fertile than the vertisol (Fig 1). In the vertisol, significantly higher yields were obtained with sludge and compost amendments. In the ultisol, responses were not signficant, and there was a decreasing yield trend with increasing compost rate. Even at the very high application rates of 224 and 448 t ha^{-1} (levels in excess of those allowed by Western regulations and representing worst-case situations), no visual toxicity symptoms were exhibited by the maize. It is possible that the

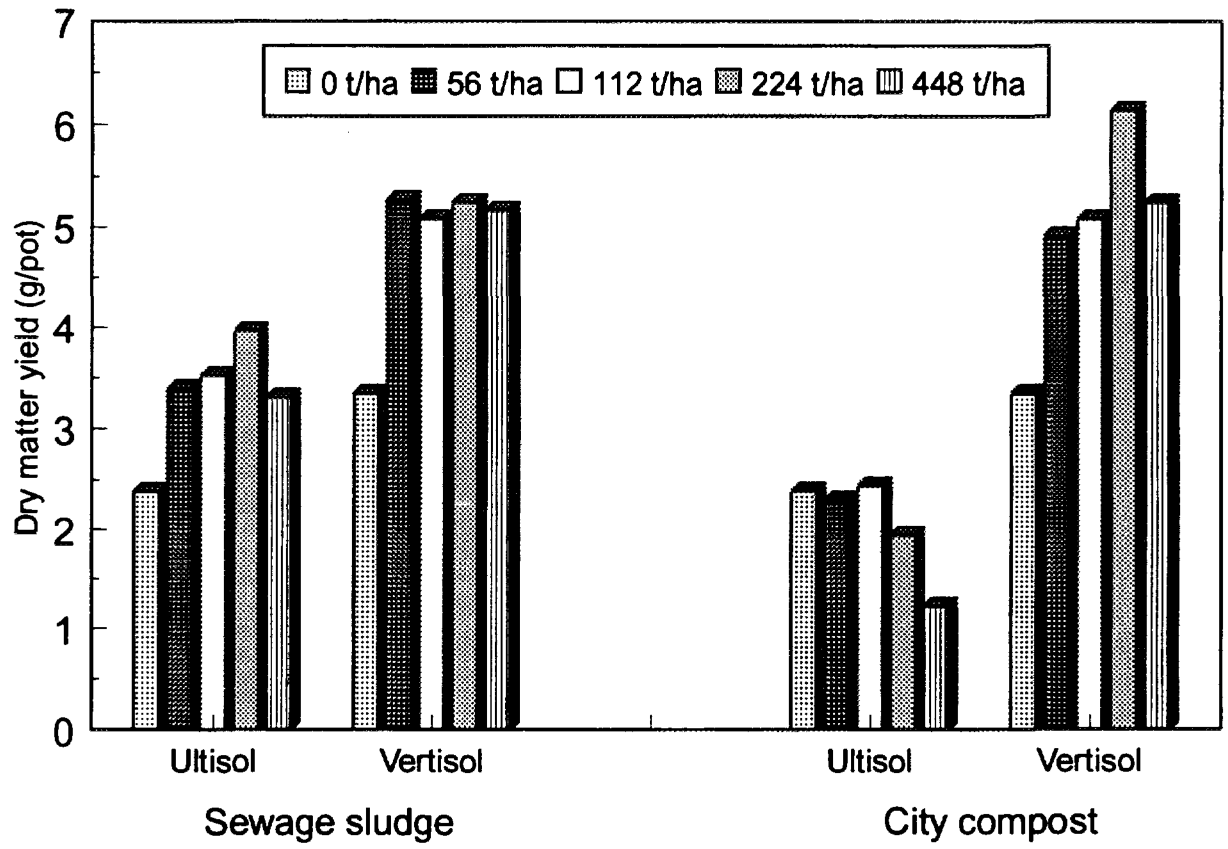

FIG. 1. Dry matter yields of maize grown on two soils amended with sewage sludge and city compost. (Bars denote LSD values, $P<0.05$*)*

short duration of this experiment (8 weeks) was a contributory factor; a longer period of organic-matter mineralization might reveal a positive effect in the ultisol, at least with the low application, 56 t ha^{-1}. These data show that although beneficial effects are not obtained in all soils, these organic fertilizers can significantly improve yields, as indicated in earlier studies [3, 4, 6, 8].

The micronutrient (Fe, Mn, Cu, Zn) and heavy-metal (Co, Pb, Ni, Cd, Cr) concentrations in plant shoots grown on sludge-amended soils are shown in Table IV. In the ultisol, there were decreases in the Fe and Mn concentrations with sludge amendment; whereas, significantly higher concentrations of Cu and Zn were obtained with the higher rates of sludge. In the vertisol, there were no significant changes in the Fe, Mn and Cu concentrations, whereas Zn concentration in the plants increased with increasing rates of sludge. It is noteworthy that higher plant levels of Co, Pb, Ni and Cd were obtained at higher doses of sludge application in the ultisol, whereas, there were no similar trends in the vertisol. The Cr concentration in plants was not affected by sludge amendments in either soil type.

The compost-amendment data, (Table V) show trends similar to those with sludge amendment, mainly reduction in Fe and Mn and enhancement in Cu and Zn concentrations in plants grown on the ultisol. There was no significant variation in the Fe, Mn and Cu contents, but increased Zn, in plants grown in the vertisol. Addition of city compost also increased Ni, Pb, and Cd plant contents in the ultisol, whereas in the vertisol increased plant levels of Co and reduced levels of Ni were observed. The levels of these metals attained in plants are comparable to those reported by Maclean et al. [37]. Thus, a clear soil-specificity existed for plant uptake of the metals supplied in sludge and compost.

TABLE III. CONCENTRATIONS OF MICRONUTRIENTS AND HEAVY METALS IN SEWAGE SLUDGE AND CITY COMPOST EXTRACTED WITH 2 *M* HNO_3 AND DIETHYLENETRIAMINE-PENTAACETIC ACID (DTPA)

	Sewage sludge		City compost	
	HNO_3	DTPA	HNO_3	DTPA
	($\mu g\ g^{-1}$ dry weight)			
Fe	14,650	42	1,575	106
Mn	378	6.0	622	45
Cu	600	108	435	83
Zn	1,190	132	922	253
Co	11	0.54	15	0.47
Pb	129	0.94	246	47
Ni	65	47	48	3.0
Cd	3.0	0.72	1.0	0.78
Cr	137	0.14	51	0.09
	(%)			
N	2.0		1.2	
P_2O_5	1.39		0.34	
K_2O	0.37		0.60	
Organic C	15.0		10.4	
C:N	7.00		8.67	
pH (1:2.5)	6.2		7.7	

Earlier studies [7-10] have shown that metals in sewage sludge differ in their availability to crops depending upon soil pH and organic-matter content, and cation-exchange capacity. The lower pH and cation-exchange capacity of the ultisol in this study must have contributed to greater accumulation of Cu, Zn, Pb, Ni and Cd. The restricted uptake of Fe and Mn with sludge and compost must have resulted from conversion of the Fe and Mn to insoluble forms by the high levels of organic matter.

Data on Cd toxicity are presented in Tables VI and VII. Significant reductions in the dry matter yields of both crops of maize occurred at the higher rates of Cd-enriched sludge in the ultisol and alfisol (Table VI); however, in the vertisol, only the second crop was adversely affected, and no significant effects were observed in the entisol. In the compost-amended soils (Table VII), significant losses in yield were observed also in the ultisol and alfisol, but only with the second crop.

Significantly larger accumulations of Cd were observed in the shoots of both crops in all four soils amended with the Cd-enriched sludge (Table VI) or city compost (Table VII). Moreover, the highest levels of accumulation, at any particular Cd level, occurred in the ultisol and the alfisol, which

TABLE IV. CONCENTRATION OF MICRONUTRIENTS AND HEAVY METALS IN MAIZE SHOOTS GROWN ON TWO SOILS AMENDED WITH SEWAGE SLUDGE

Soil and sludge rate	Fe	Mn	Cu	Zn	Co	Pb	Ni	Cd	Cr
	(μg g^{-1} dry shoot)								
Ultisol									
0	331b[a]	245c	5.8a	41a	3.7a	11.8a	1.2a	2.3a	0.9a
56 (t ha^{-1})	129a	46a	5.6a	57a	12.0d	4.3a	8.7b	2.9ab	1.3a
112	150a	55a	7.7ab	122b	9.0bc	35.8c	11.4c	3.3b	1.1a
224	103a	49a	6.8a	123b	9.9cd	36.8c	10.1bc	4.6c	0.8a
448	111a	85a	11.4b	168c	7.1b	22.1b	11.8c	4.5c	1.0a
Vertisol									
0	67a	60b	8.3a	21a	3.8a	27.3ab	23.4c	2.0a	0.9a
56 (t ha^{-1})	64a	63b	13.9a	59b	5.5ab	41.8c	17.9abc	2.3ab	0.5a
112	65a	62b	8.4a	92c	6.3b	38.8bc	22.4bc	2.6b	0.9a
224	76a	64b	10.0a	110c	5.5ab	34.6abc	15.7ab	2.1a	0.6a
448	68a	39a	8.9a	146d	5.1ab	24.0a	14.0a	2.4ab	0.8a

[a] Numbers within columns followed by the same letter are not significantly different by Duncan's Multiple Range Test ($P < 0.05$).

may explain the depression of yields in these two soils types. Although the Cd accumulated by the unaffected plants in the entisol and vertisol did not reach toxic levels, contamination of fodder and food is possible. The residual effects of the sludge and compost in terms of depressed plant yields and high Cd levels in the succeeding maize crop demonstrate continued availability to plants. These data are consistent with earlier reports of decreased availability of Cd to plant shoots in soils of higher pH and high cation exchange capacity [38-42].

Simulated sewage sludges containing varying levels of either Cd or Zn were evaluated by applying sludge at a uniform agronomic rate to the four soils with maize as the test crop. Sludge addition without Cd enrichment significantly enhanced the dry-matter yields of shoots only in the vertisol (Table VIII). Addition of sludge with increasing levels of Cd resulted in progressive yield reduction in the vertisol, entisol and alfisol, but not in the ultisol in which yield potential was already low. Significant negative correlations were obtained between soil Cd concentration and dry matter yield (Table IX). Further, plant Cd contents increased with Cd supply in all four soils, indicating that yield depression was due to Cd accumulation in plant tissue (Table VIII). There were positive

TABLE V. CONCENTRATIONS OF MICRONUTRIENTS AND HEAVY METALS IN MAIZE SHOOTS GROWN ON TWO SOILS AMENDED WITH CITY COMPOST

Soil and compost rate	Fe	Mn	Cu	Zn	Co	Pb	Ni	Cd	Cr
	(μg g^{-1} dry shoot)								
Ultisol									
0	331b[a]	245d	5.8a	41a	3.7a	11.8a	1.2a	2.3a	0.9a
56 (t ha^{-1})	81a	48a	6.8a	50a	5.0a	11.5a	9.7c	1.9b	1.3a
112	124a	73b	8.3a	61a	4.4a	27.7b	5.5b	1.6b	0.9a
224	136a	110c	7.9a	91b	8.6a	21.8b		2.4a	0.9a
448		131c	12.0b	125c				2.7a	0.4a
Vertisol									
0	67a	60b	8.3b	21a	3.8ab	27.3a	23.4b	2.0a	0.9a
56 (t ha^{-1})	62a	40a	3.6a	47b	3.4a	20.6a	12.0a	2.8b	0.8a
112	93b	45a	6.0ab	63b	6.4b	27.5a	11.8a	2.6b	0.5a
224	60a	50ab	5.2ab	60b	9.4c	22.1a	12.1a	2.4ab	1.0a
448	96b	51ab	13.3c	105c	9.5c	29.2a	10.8a	2.6b	1.1a

[a] Numbers within columns followed by the same letter are not significantly different by Duncan's Multiple Range Test ($P < 0.05$).

correlations between soil Cd level and plant Cd content for all four soil types (Table IX). In general, the Cd contents of maize grown on the alfisol and ultisol were greater than for the vertisol and entisol, possibly due to higher pH and cation-exchange capacity as discussed above.

As mentioned above, the addition of unamended sludge resulted in the enhancement of dry matter yield only in the vertisol (Table VIII, Fig. 2). Zn-enriched sludge amendments did not further affect yield in the vertisol, whereas in the alfisol and ultisol 5 ppm Zn produced significant yield enhancement. A significant yield reduction was observed at 80 ppm in the entisol. The Zn content of the maize shoots was significantly enhanced with sludge application (without enrichment) in all soils except the ultisol (Fig. 2). Progressive enhancement in Zn uptake occurred as the added Zn level increased from 5 to 80 ppm, with positive correlations for all soils (Table X). Negative correlations were obtained between added Zn and dry-matter yield in the vertisol and entisol, whereas a positive correlation was observed in the alfisol (Table X), showing that high levels of Zn in sludge will depress plant yields in some soils.

TABLE VI. YIELDS AND CADMIUM CONTENT OF MAIZE GROWN ON FOUR SOILS AMENDED WITH CADMIUM-ENRICHED SEWAGE SLUDGE

Crop and cadmium level	Dry matter yield (g pot^{-1})				Cadmium content (μg g^{-1} dry shoot)			
	Ultisol	Alfisol	Entisol	Vertisol	Ultisol	Alfisol	Entisol	Vertisol
First crop								
0	0.81a[a]	1.14a	1.18a	1.09ab				
7.5 (ppm)	0.88a	1.04a	1.27a	0.95a	43.8a	56.4a	15.8a	19.8a
15.0	0.90a	0.58b	1.10a	1.25ab	66.7b	63.4ab	34.5b	29.0b
30.0	0.40b	0.29c	1.17a	1.40b	92.7c	74.3b	64.7c	32.9b
Second crop								
0	1.08a	1.32a	0.93a	1.14a				
7.5 (ppm)	0.75b	0.65b	0.95a	1.02ab	63.1a	55.5a	12.5a	16.2a
15.0	0.62c	0.74b	0.93a	1.04ab	56.2a	92.7b	26.6b	37.3b
30.0	0.61c	0.66b	0.96a	0.71b	78.7b	101.9b	48.3c	55.8c

[a] Numbers within columns followed by the same letter are not significantly different by Duncan's Multiple Range Test ($P < 0.05$).

4. CONCLUSIONS

In general, the results demonstrate that sewage sludges and city composts may be effective as organic fertilizers for maximizing crop yields. However, depending upon soil type, caution has to be exercised with sludges containing even relatively low levels of Cd, or high levels of Zn. Little work has been done under field conditions, and research is needed to establish guidelines for safe application of these materials to Indian soils. The guidelines should take into account crop requirements for N and P, the heavy-metal levels in the organic amendment and in the native soil, pH and cation-exchange capacity of the soil, and overall sludge chemistry in soils. The effects of repeated application over long periods (5 years and more) should be evaluated and ameliorative measures, such as application of lime or fly ash, should be considered so as to maintain sludge-amended soils at a pH of around 6.5. Further, chemical speciation of heavy metals in sludge-amended soils has to be studied in order to evaluate availability to plants in order to develop methods of restricting entry into the human food chain. Therefore, future research should be aimed not only at evaluation of sewage sludges and city composts as effective and economical fertilizer sources, but also to establish guidelines to limit their application to soils based on phytotoxic effects, maximum allowable metal concentrations, and metal build-up in soils.

TABLE VII. YIELDS AND CADMIUM CONTENT OF MAIZE GROWN ON FOUR SOILS AMENDED WITH CADMIUM-ENRICHED CITY COMPOST

Crop and cadmium level	Dry matter yield				Cadmium content			
	Ultisol	Alfisol	Entisol	Vertisol	Ultisol	Alfisol	Entisol	Vertisol
	(g pot^{-1})				(μg g^{-1} dry shoot)			
First crop								
0	0.79a[a]	0.83a	0.84a	0.87a				
7.5 (ppm)	0.59b	0.92b	1.09a	1.26b	55.7a	56.8ab	15.9a	22.0a
15.0	0.67ab	0.88a	1.10a	0.71a	72.1a	72.9ab	37.2b	27.8a
30.0	0.72ab	0.55a	0.95a	0.83a	82.1a	90.5b	64.5c	50.3b
Second Crop								
0	0.51a	0.75a	0.91a	0.64a				
7.5 (ppm)	0.40ab	0.66ab	0.85a	0.54ab	36.4a	42.4a	16.1a	27.1a
15.0	0.38ab	0.55ab	0.77a	0.44b	69.8b	75.8b	24.4b	39.3ab
30.0	0.26b	0.37b	0.82a	0.47ab	108c	108c	52.4c	55.1b

[a] Numbers within columns followed by different letters are significantly different by Duncan's Multiple Range Test ($P < 0.05$).

TABLE VIII. YIELDS AND CADMIUM CONTENT OF MAIZE GROWN ON FOUR SOILS AMENDED WITH CADMIUM-ENRICHED SEWAGE SLUDGE

Treatment	Dry matter yield				Cadmium content			
	Vertisol	Alfisol	Entisol	Ultisol	Vertisol	Alfisol	Entisol	Ultisol
	(g pot^{-1})				(μg g^{-1} dry shoot)			
No amendment	5.65a[a]	7.68c	14.5cd	3.64a				
Sludge alone	10.45c	8.20c	11.7c	3.73ab				
Sludge								
+ 5 ppm Cd	10.9c	5.05b	16.0d	5.50b	12.0a	3.6a	20.5a	27.9a
+10	10.4c	4.50b	12.8cd	5.10ab	14.8a	8.9a	57.5b	37.1a
+20	9.24bc	4.96b	11.1bc	4.96ab	22.1b	16.3b	71.9b	53.3b
+40	7.75b	3.65ab	7.92b	4.61ab	36.1c	22.1b	118c	75.4c
+80	4.87a	2.35a	4.42a	4.93ab	42.3c	35.5c	128c	100d

[a] Numbers within colums followed by different letters are significantly different by Duncan's Multiple Range Test ($P < 0.05$).

TABLE IX. RELATIONSHIPS BETWEEN ADDED CADMIUM, MAIZE YIELD, AND MAIZE CADMIUM-CONTENT

	x vs y_1[a]		x vs y_2	
Soil	Correlation coefficient	Regression equation	Correlation coefficient	Regression equation
Vertisol	-0.988^{**}	$y_1 = 10.86-0.075x$	0.923^{**}	$y_2 = 8.71+0.484x$
Entisol	-0.816^{*}	$y_1 = 6.15-0.053x$	0.975^{**}	$y_2 = 3.40+0.426x$
Alfisol	-0.913^{*}	$y_1 = 13.80-0.122x$	0.889^{*}	$y_2 = 26.7+1.51x$
Ultisol	NS[b]	-	0.936^{**}	$y_2 = 20.33+1.11x$

[a] x = μg Cd g^{-1} soil y_1 = dry matter in g y_2 = μg Cd g^{-1} dry matter.

*Significant at $P < 0.05$.

**at $P < 0.01$.

[b] Not significant.

TABLE X. RELATIONSHIPS BETWEEN ADDED ZINC, MAIZE YIELD, AND MAIZE ZINC-CONTENT

	x vs y_1[a]		x vs y_2	
Soil	Correlation coefficient	Regression equation	Correlation coefficient	Regression equation
Vertisol	-0.821^{**}	$y_1 = 0.79 - 0.036x$	0.982^{***}	$y_2 = 38.73 + 0.63x$
Entisol	-0.782^{*}	$y_1 = 6.99 - 0.033x$	0.938^{***}	$y_2 = 49.00 + 0.31x$
Alfisol	0.834^{**}	$y_1 = 13.69 + 0.059x$	0.984^{***}	$y_2 = 90.53 + 1.42x$
Ultisol	NS[b]	-	0.950^{***}	$y_2 = 71.60 + 0.71x$

[a] x = μg Zn g^{-1} soil y_1 = dry matter in g y_2 = μg Zn g^{-1} dry matter.

*Significant at $P < 0.10$.

**at $P < 0.05$.

***at $P < 0.01$.

[b] Not significant.

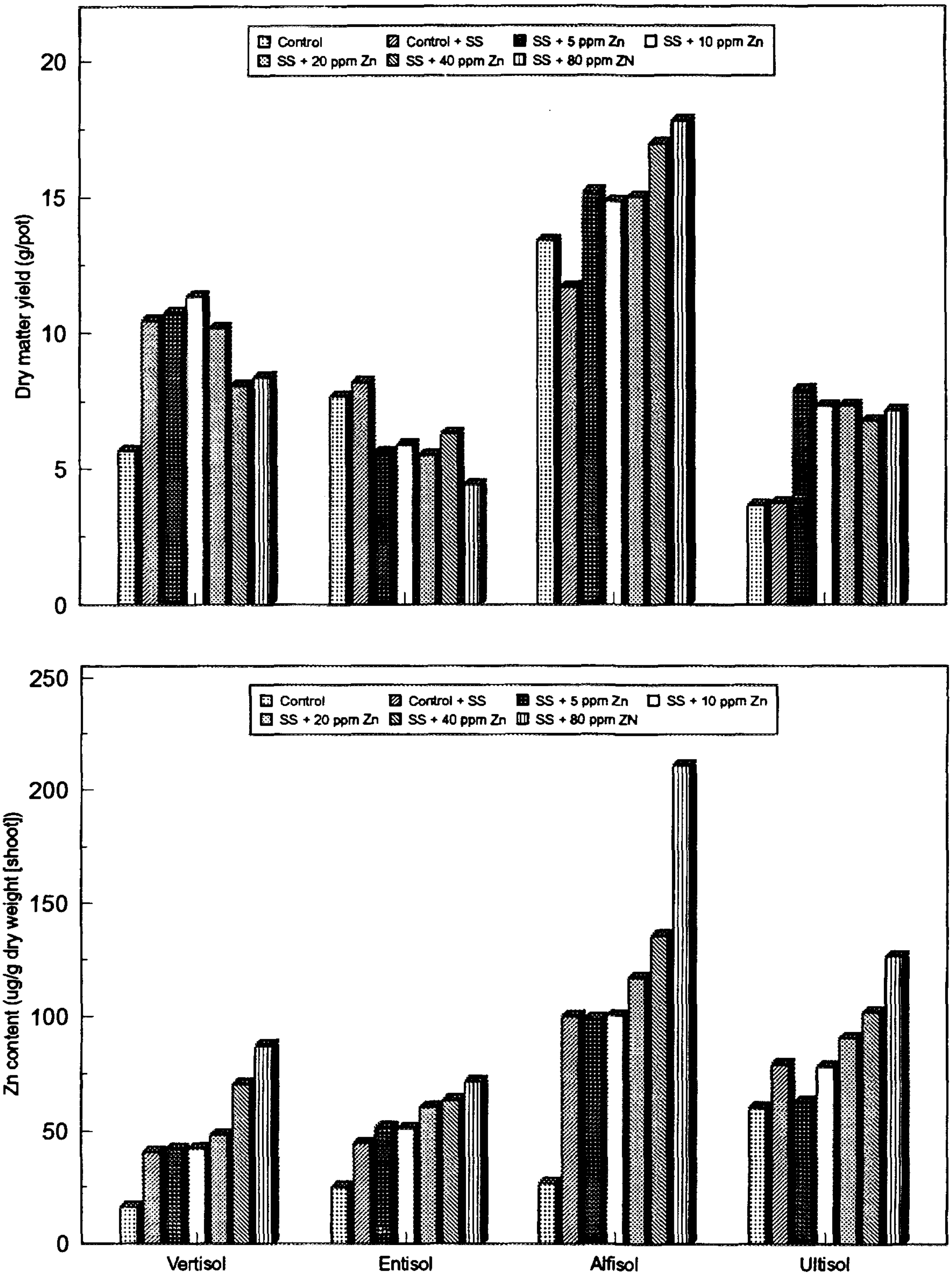

FIG. 2. Dry matter yields and zinc content of maize grown on four soils amended with zinc-enriched sewage sludge. (Bars denote LSD values, P*<0.05)*

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