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Heavy metal contents of vegetable crops treated with refuse compost and sewage sludge*

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Abstract

Refuse compost and sewage sludge were mixed with a loamy sand at various rates in pots and sown with *Brassica chinensis*, *Daucus carota* and *Lycopersicon esculentum* in a glasshouse. A commercial fertilizer was also applied to the same soil for comparison. Dry matter production of the three crops and contents of Cd, Cu, Mn, Pb and Zn in the harvested tissues were determined at the end of the experiment.

In general, crop yield in refuse compost treatment was improved over that in sandy soil alone, but was less than that in the sludge and fertilizer treatments. Despite the relatively high heavy metal contents of refuse compost, crops grown on compost-treated soils accumulated lower levels of metal than those grown on sludge-treated soils. This is probably due to the high pH and organic matter content of the composted refuse. Higher levels of heavy metals were found in the roots than in the aerial parts of *B. chinensis* and *L. esculentum*, but the reverse was found in *D. carota*. In the edible tissue of the three crops, *L. esculentum* accumulated metals to a lesser extent than the other two.

Introduction

The disposal of ever-increasing amounts of domestic refuse and sewage sludge is becoming a serious problem in many countries. Land application of such wastes is desirable on both environmental and economic grounds because they provide organic material, improve soil structure and offer the potential for recycling plant nutrients. Nevertheless, the agronomic efficiency and potential hazards of waste re-utilization have to be assessed, preferably by direct experimentation.

Some research has shown that the manurial value of garbage compost is similar to inorganic fertilizer, and that compost applied at high rates can produce better crop yields than sludge, manure and NPK fertilizer (Hortenstine and Rothwell, 1968 and 1973). Other work, however, suggests that the nutrient content of compost from refuse can be quite low and that its addition to soil should be complemented by chemical fertilizers (Terman *et al.*, 1973; Tietjen, 1964). The fertilizer and soil conditioning values of sewage sludge are well documented. However, the use of both sludge and compost for crop production may be limited by the potential hazards of associated heavy metals. Application of municipal wastes can lead to heavy metal contamination in both soil and crops. In a previous study with leafy vegetables, the contents of Zn and Cu have been found to be greatly elevated in the tissues of sludge- and refuse compost-treated crops of *Brassica juncea* and *B. parachinensis* (Wong *et al.*, 1983).

The present experiment therefore aimed to deter-

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mine how far the use of refuse compost and sewage sludge for the production of different kinds of edible crops including Chinese white cabbage, carrot and tomato may be limited by heavy metal problems. It was hoped to determine whether the edible parts contained metal concentrations that would impose health risks.

Materials and methods

Refuse compost (8-month old) and activated sludge (6-month old), were passed through a 1.2-cm sieve to remove coarse particles and were mixed with a sandy soil (red-yellow podzol of 86% sand, 5% silt and 9% clay) at the rates of 0, 25, 50, 75, 100, 125 and 150 tonnes.ha^{-1} and 0, 15, 30, 50, 100 and 150 tonnes.ha^{-1} for refuse compost and activated sludge respectively. They were sown with three different types of food crop: *Brassica chinensis* L. (Chinese white cabbage), *Daucus carota* L. var. *sativa* DC. (carrot) and *Lycopersicon esculentum* Mill. (tomato). A commercial fertilizer (Nitrophoska Permanent, N:P:K = 15:9:15) was also applied at the rate of 2 tonnes ha^{-1} for comparison. There were five replicates in each treatment.

The sandy soil, refuse compost and activated sludge were analysed for pH and conductivity (1:5 sample/distilled water suspension), organic C (Walkley and Black, 1934), total N (ammonia electrode after sulphuric acid digestion), total and extractable P (Molybdenum Blue Method (Watanabe and Olsen, 1962) after sulphuric acid digestion and 2.5% acetic acid extraction respectively), and total and extractable K, Ca, Mg, Na, Cd, Cu, Mn, Pb and Zn (atomic absorption spectrophotometry after mixed acid digestion and 1 *M* neutral ammonium acetate extraction respectively). The amended soils, prior to crop production, were also analysed for total and extractable heavy metals.

The experiment was carried out in a glasshouse in a completely randomized design using 14-cm plastic pots. Two seedlings were planted in each pot of *B. chinensis* or *D. carota*, or one of *L. esculentum*. For *L. esculentum*, a second application of fertilizer at 1 tonne ha^{-1} was applied to the fertilizer-treated pots at the 120th day to maintain fertility. *B. chinensis* was grown for 40 days, *D. carota* for 150 days and *L. esculentum* for 190 days. The harvested tissues were washed with de-ionized water and oven-dried (105°C for 24 h) for dry weight determination. The metal contents of the various parts of the three crops were determined by atomic spectrophotometry after mixed acid digestion.

Results

Characteristics of the growth media

The refuse compost was moderately alkaline with high contents of organic matter, Ca and Na,

Table 1. Properties of the sandy soil, refuse compost, activated sludge and fertilizer used in the experiment (mean of five samples)

	Sandy soil	Refuse compost	Activated sludge	Fertilizer
pH	6.5	8.0	6.0	6.1[a]
Conductivity (μS × 10^2)	0.61	53.2	49.9	69.5[a]
Organic C	0.20	28.4	18.1	nt[c]
Total N	0.30	1.67	3.14	15[b]
C:N Ratio	0.67	17.0	5.77	
P Total (%)	0.00	0.55	0.83	9[b]
Extractable (μg/g)	3.86	466	147	
K Total (%)	0.14	0.40	0.28	15[b]
Extractable (μg/g)	43.2	3050	363	
Ca Total (%)	0.08	2.25	0.16	nt[c]
Extractable (μg/g)	282	3520	3290	
Mg Total (%)	0.02	0.63	0.46	2[b]
Extractable (μg/g)	159	2160	2550	
Na Total (%)	0.01	0.82	0.34	nt[c]
Extractable (μg/g)	58.9	2930	2050	

[a] data from Wong *et al.*, 1983
[b] according to fertilizer formulation
[c] nt = not tested

but rather low N (Table 1). The activated sludge was slightly acidic and contained quite high levels of major nutrients. The refuse compost was higher in organic C, C/N ratio, total and extractable K, and total Ca, Mg and Na than the sludge but had lower total N and P. The fertilizer contained the highest amount of N, P, K and Mg. Sludge had the highest contents of total and extractable Zn and Cd while compost had the highest contents of total and extractable Mn and Pb, and extractable Cu (Tables 2 and 3). The fertilizer contained the highest amount of total Mn and appreciable Zn and Cd.

With the exception of Mn and Pb in sludge-added soils, all treatments showed elevated levels of total heavy metals. The contents of Cu, Mn and Pb were higher in compost-amended than sludge-amended soils, while the levels of Cd and Zn were similar. The extractable concentrations of Cd, Cu, Mn and Zn were all increased by waste applications. Higher Pb content was found only in refuse compost treatments. Fertilizer application also increased the metal content, but only to a slight extent.

Table 2. Total heavy-metal content ($\mu g.g^{-1}$) in refuse compost, activated sludge, fertilizer and the amended soils prior to crop cultivation (mean of five samples)

	Cd	Cu	Mn	Pb	Zn
Refuse compost	14.3	511	702	287	1460
Activated sludge	18.3	473	101	114	2530
Fertilizer	11.0	7.55[a]	936[a]	80.4[a]	174[a]
Sand (S)[b]	3.28	12.3	226	98.0	75.9
F[c]	4.14	14.7	243	120	112
RC25[d]	4.59	37.0	228	113	136
RC50	4.95	57.3	263	146	213
RC75	5.12	73.7	335	172	249
RC100	5.70	121	363	178	368
RC125	6.24	148	375	181	430
RC150	7.16	215	386	211	569
AS15[e]	4.51	20.4	242	119	136
AS30	4.57	29.7	247	115	183
AS50	5.20	34.3	225	109	209
AS100	6.12	60.6	219	122	329
AS150	7.85	85.7	176	114	501

[a] data from Wong *et al.*, 1983
[b] S = Pure sandy soil
[c] F = Sandy soil with 2 $t.ha^{-1}$ fertilizer
[d] RC25, 50, 75, 100, 125 and 150 = Sandy soil with 25, 50, 75, 100, 125 and 150 $t.ha^{-1}$ refuse compost
[e] AS15, 30, 50, 100 and 150 = Sandy soil with 15, 30, 50, 100 and 150 $t.ha^{-1}$ activated sludge

Plant growth

Crop yields followed a descending order of chemical fertilizer, activated sludge, refuse compost and sandy soil alone (Fig. 1). The highest yield for activated sludge was with 50 tonnes ha^{-1} (AS50) and for refuse compost was with 125 tonnes ha^{-1} (RC125) with the exceptions of carrot in refuse compost (RC50) and tomato in activated sludge (AS150).

In *B. chinensis*, applications of fertilizer and sludge gave a significantly higher yield compared with pure sandy soil ($p < 0.01$) and refuse compost ($p < 0.05$). All treatments significantly increased ($p < 0.001$) the yield of *D. carota*. The higher yield of RC50 for carrots compared with the higher rates of refuse compost was probably related to the sandy soil requirement of this species. The better yield obtained from the waste-treated soils compared with those treated with fertilizer may be due to the slow release properties of the organic wastes. Plants grown on the amended soils showed a markedly higher root to top ratio as compared with the sandy soil control. For *L. esculentum*, all treatments again resulted in significant increases ($p < 0.001$) in yield over the control. The total

Table 3. Extractable heavy-metal content ($\mu g.g^{-1}$) in refuse compost, activated sludge, fertilizer and the amended soils prior to crop cultivation (mean of five samples)

	Cd	Cu	Mn	Pb	Zn
Refuse compost	1.43	53.7	195	13.2	222
Activated sludge	2.31	9.06	20.1	1.60	372
Fertilizer	nt	1.04[a]	85.0[a]	20.5[a]	3.43[a]
Sand (S)[b]	0.51	0.48	6.06	4.15	6.82
F[c]	0.57	0.75	9.88	6.19	7.38
RC25[d]	0.78	3.88	18.8	7.25	17.1
RC50	0.84	8.13	30.2	8.13	31.4
RC75	0.88	12.4	39.3	9.00	37.9
RC100	0.99	16.8	56.4	9.13	62.2
RC125	1.04	21.0	84.1	9.31	88.3
RC150	1.06	36.4	104	10.4	111
AS15[e]	0.48	0.54	7.75	4.50	14.6
AS30	0.76	0.58	7.81	4.31	18.1
AS50	0.79	0.75	10.6	4.75	25.8
AS100	1.08	1.25	14.0	4.38	51.0
AS150	1.10	2.25	16.7	4.31	77.0

[a] data from Wong *et al.*, 1983
[b] S = Pure sandy soil
[c] F = Sandy soil with 2 $t.ha^{-1}$ fertilizer
[d] RC25, 50, 75, 100, 125 and 150 = Sandy soil with 25, 50, 75, 100, 125 and 150 $t.ha^{-1}$ refuse compost
[e] AS15, 30, 50, 100 and 150 = Sandy soil with 15, 30, 50, 100 and 150 $t.ha^{-1}$ activated sludge

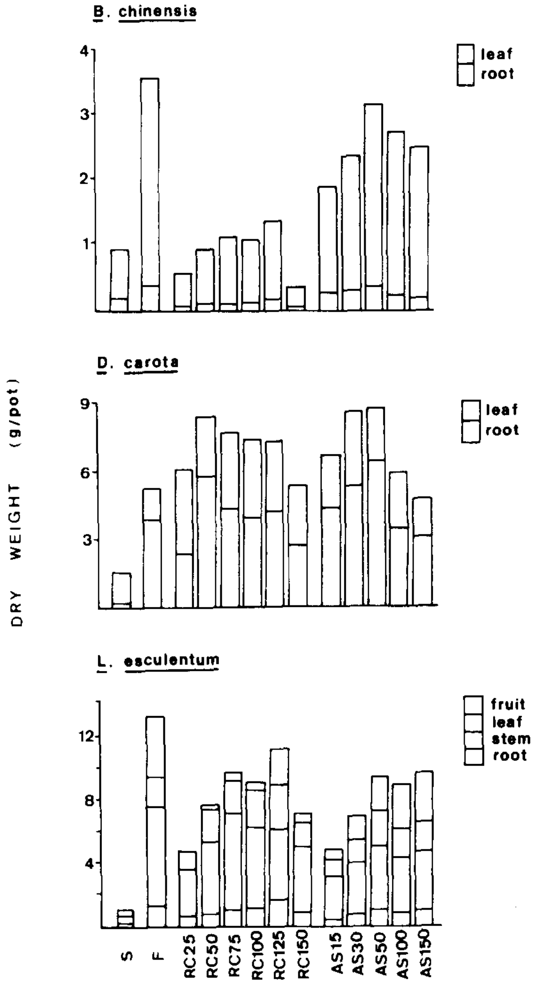

Fig. 1. Dry matter production of *Brassica chinensis*, *Daucus carota* and *Lycopersicon esculentum* from different treatments.
S = Pure sandy soil
F = Fertilizer-amended soil
RC = Refuse compost-amended soil (addition rate in tonnes/ha)
AS = Activated sludge-amended soil (addition rate in tonnes/ha)

yield was the highest with the fertilizer treatment, followed by RC125 and AS150. Fertilizer gave the highest productivity for the edible part of the plant. Higher fruit number, however, was obtained with the higher rates of sludge application; no fruits were produced in S and RC25.

Plant heavy-metal content

The distribution of various heavy metals in the leaves and roots of plants from different treatments is shown in Fig. 2. Plants grown on pure sandy soil were not analysed because of their stunted growth. In *B. chinensis*, the concentrations of Cd and Cu in roots from compost and sludge treatments and that of Mn and Zn from sludge-treated plants increased markedly at higher application rates. The Pb contents of roots for both treatments also increased, but to a lesser extent. Leaf concentrations of Cd and Pb for sludge, leaf and root concentrations of Zn for compost, and the concentration of Cu in leaves for both compost and sludge also showed slight increases with the amount of wastes applied. The concentrations of leaf Cd, root Pb, and leaf and root Mn of the fertilizer-treated crops were either similar to or higher than those from waste-amended soils. For *D. carota*, refuse compost addition increased Cu and Pb contents significantly ($p < 0.05$) at higher rates as compared with the fertilizer treatment. Sludge application at higher rates also resulted in significantly higher ($p < 0.05$) amounts of Cu in leaf, and Zn in both leaves and roots. Elevated concentrations of Cd and Mn were found in both leaves and roots and for Pb in roots in the fertilized pots. *L. esculentum* leaves contained significantly higher ($p < 0.05$) amounts of Cd when grown on sludge-amended soils and Zn on compost-amended soils. Significantly higher Cd and Zn concentrations ($p < 0.05$) were found in roots for sludge treatments and in levels of Cu for both compost and sludge treatments. Concentrations of Mn in leaves and roots and Pb in roots were significantly higher ($p < 0.05$) for the fertilized pots.

Discussion

The present study indicates that rather infertile sandy soils treated with refuse compost or sewage sludge can give better yields than the same soil without treatment. This is probably the result of increased pH and the greater supply of organic matter, macro-nutrients and trace elements. However, the increased levels of heavy metals brought about by application of the wastes clearly causes an elevation of metal concentrations in crop tissues. Toxic effects were evident at higher addition rates, indicated by the depression of yields but it cannot be concluded that this is a direct effect of elevated metal concentrations.

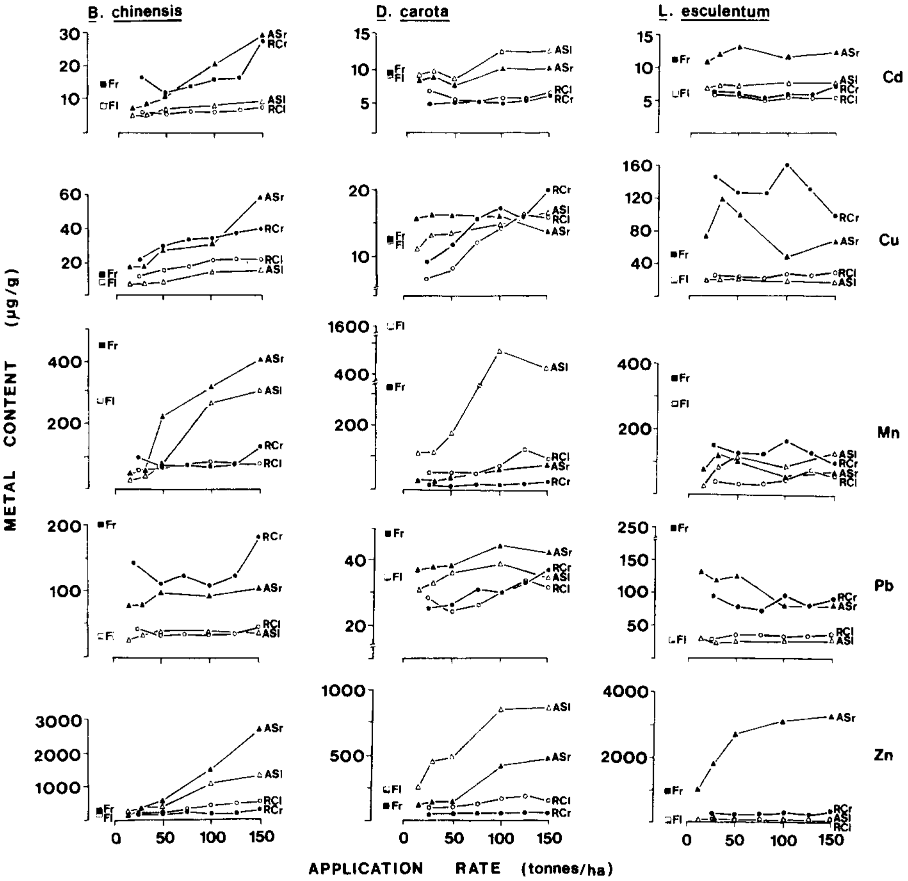

Fig. 2. Heavy-metal contents in leaf and root of *Brassica chinensis*, *Daucus carota* and *Lycopersicon esculentum* grown on sandy soil treated with fertilizer or different rates of refuse compost or activated sludge.
○ **RCl** = leaf from refuse compost treatment
● **RCr** = root from refuse compost treatment
△ **ASl** = leaf from activated sludge treatment
▲ **ASr** = root from activated sludge treatment
□ **Fl** = leaf from fertilizer treatment
■ **Fr** = root from fertilizer treatment

Copper contents in compost-treated crops were relatively higher than those treated with sludge, which might be attributed to the high Cu concentration in the composted refuse applied. Although it has been reported that Cu is less readily translocated to the tops of plants (Mitchell *et al.*, 1978), high Cu contents were found in the aerial parts of *B. chinensis* and *D. carota*, especially the latter. Nonetheless, the concentration was below the 40 $\mu g.g^{-1}$ associated with severe toxicity (Walsh *et al.*, 1972). Higher concentrations of Mn were found in fertilizer-treated plants than for the waste treatments. This is probably related to the high Mn content (0.1%) of the fertilizer used. The higher uptake of Mn in sludge-amended soils than compost-treated pots could be the result of low pH caused by sludge incorporation (King and Morris, 1972). No significant correlations were found between soil Pb levels and Pb contents in crops harvested from sludge-applied soil. This may be due to background contamination of the sandy soil used. The low Pb content of the sludge probably explains why Pb concentrations in plant tissues were low. Lower Pb content for compost-treated crops, as compared with the fertilizer-treated ones, may be the result of low Pb availability related to the high pH and organic matter content of the compost-treated soils (Cox and Rains, 1972; John and van

Table 4. Heavy metal content ($\mu g.g^{-1}$) in the edible parts of *Brassica chinensis, Daucus carota* and *Lycopersicon esculentum* under different treatments (mean of five pots)

	Cd	Cu	Mn	Pb	Zn
B. chinensis (leaf)					
F	8.68c	7.51a	277e	33.6b	256b
RC25	6.98b	12.0b	59.5b	41.8c	149a
RC50	6.28ab	15.1c	70.0c	34.8b	210b
RC75	6.86b	18.9d	81.6d	35.8b	313c
RC100	6.31ab	22.0e	77.4cd	31.5b	389d
RC125	6.72b	20.6e	78.3cd	35.0b	425d
RC150	8.21c	20.6e	79.3cd	43.4c	495e
AS15	5.53a	6.83a	35.2a	26.8a	210b
AS30	5.61a	7.72a	45.4ab	34.7b	296c
AS50	6.68b	6.90a	76.5cd	39.3bc	397d
AS100	8.10c	12.9b	270e	40.0c	1110f
AS150	8.67c	13.9bc	309f	39.8c	1380f
D. carota (root)					
F	9.16c	12.6b	311g	48.1d	123c
RC25	4.75a	9.28a	15.5ab	25.3a	36.9a
RC50	4.66a	11.6b	12.4a	26.6a	41.4a
RC75	4.94a	15.6bc	15.0ab	30.1b	51.0a
RC100	4.53a	16.8c	16.3b	29.8b	59.7ab
RC125	4.63a	15.4bc	17.6bc	32.2b	58.9ab
RC150	5.14a	19.7c	25.6cd	37.0c	74.0b
AS15	7.84bc	15.7bc	32.3de	36.6c	121c
AS30	8.12bc	15.9c	26.3cde	37.6cd	130c
AS50	7.21b	15.8bc	37.4e	38.2cd	161c
AS100	9.49c	15.4bc	68.0f	44.5d	421d
AS150	9.66c	13.5b	78.2f	41.8d	472d
L. esculentum (fruit)					
F	4.24a	12.1a	71.8d	22.7a	31.8a
RC25	–	–	–	–	–
RC50	4.21a	15.9b	13.8a	24.7a	46.8bc
RC75	4.33a	15.1b	19.7b	27.3a	34.5a
RC100	3.84a	15.0ab	19.2ab	24.8a	32.5a
RC125	3.62a	16.5b	19.5b	26.5a	37.5b
RC150	4.11a	20.6c	21.4b	30.1b	40.9b
AS15	6.11b	19.4c	24.2b	34.6b	50.4c
AS30	4.73a	15.0ab	21.1b	25.2a	38.6b
AS50	4.80a	16.0b	43.2c	28.4ab	42.3
AS100	4.34a	16.9bc	28.1bc	25.9a	54.4c
AS150	4.05a	16.0b	29.9bc	23.7a	56.5c

Values followed by the same letter within each column are not significantly different by Duncan's Multiple Range Test at the 5% level

Laerhoven, 1972). As in the case of Mn, high tissue Cd content for the sludge treatments may be associated with the low pH and organic content of the sludge-enriched soils, since Cd availability is strongly influenced by soil acidity and organic matter (Street *et al.*, 1977).

In general, the fertilizer treatment caused rather high concentrations of heavy metals in plant tissues. Fertilizers which contain trace metals as impurities or inclusions can result in significant effects upon soils. It has been reported that phosphatic fertilizers may be a potential source of Cd in soil and plants (Schroeder and Balassa, 1963; Williams and David, 1976), and the application of fertilizers containing trace elements can result in increased concentrations of these elements in topsoil (Purves, 1977; Williams and David, 1976).

The degree of metal accumulation varies with the type of plant tissue. With the exception of Zn in tissues harvested from compost-treated soils, root tissues of *B. chinensis* for both compost and sludge treatments appeared to accumulate more heavy metals than the aerial portion. Roots of *B. chinensis*, from RC150 and AS150 respectively, accumulated Cd 3.5 and 3.4 times, Cu 2 and 4.2 times, Mn 1.6 and 1.3 times, Pb 4.2 and 2.6 times and Zn 0.5 and 2 times higher than the aerial tissues. Similarly, Cheung and Wong (1983) found that metal uptake was in the order of root > stem > leaf in *B. parachinensis* grown on soils amended with sludges and manures. The accumulation of Mn and Zn in *D. carota* was found to be the reverse of the case in *B chinensis*, being higher in the aerial part than in the root portion. A particularly high ratio of leaf to root metal content was observed for Mn, being 4 and 6 times greater in compost and sludge treatments respectively. The fruit of *L. esculentum* accumulated less metal than leaf, stem and root. The pattern of accumulation followed the order of fruit < stem < leaf < root.

The various edible portions of food crops accumulate metals to differing extents. The results of this study show that the levels of metal accumulation in edible tissue are in a descending order of *B. chinensis*, *D. carota* and *L. esculentum* (Table 4). This finding suggests that tomato is the crop species which is best suited to waste-amended soils. Of the elements that are potentially hazardous to food chain transfer, only Cd was found in concentrations above the critical levels for animal consumption for all three crops (National Research Council, 1980). Concentrations of lead in *B. chinensis* and *D. carota* and Zn in sludge-grown *B. chinensis* also exceeded the maximum tolerable level. The amount of metals taken up by plants can be reduced by limiting the quantities of waste added to soil. Plants like *B. chinensis* should be avoided to ensure the safe cropping of waste-amended soils.

Another point of interest is that crops grown on sludge-amended soils can accumulate higher levels of metals than those grown on compost-amended soils, in spite of the higher amounts of heavy metals (Cu, Mn and Pb) in refuse compost than in sludge. It is well known that high soil pH can reduce metal uptake and phytotoxicity to plants growing on it. Municipal compost has a definite liming effect which lowers the uptake of metal by plants. In addition, refuse compost contains 1.5 times more organic matter than activated sludge, which also limits metal availability and results in lower metal accumulation in crops. The results of the present study suggest that sludge is superior to compost in terms of crop yield. However, refuse compost may be a valuable soil amendment due to the lower metal uptake by plants. The major nutrients in refuse compost, particularly N, can be enriched by co-composting with sewage sludge or by inoculating nitrogen-fixing organisms into the composted material. The manurial value of refuse compost can also be increased by its co-application with fertilizer or sludge. The combination of high pH and organic matter content of refuse compost, together with the high nutrient content of sewage sludge, provides a promising means of increasing crop yields whilst maintaining low metal accumulation in waste recycling.

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