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Article

Effects of Composted Urban Solid Waste Addition on Yield and Metal Contents of Lettuce

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Foi desenvolvido um estudo para avaliar a acumulação de Cu, Mn, Ni, Pb e Zn, em alface cultivada em Latossolo, ao qual foram adicionados compostos de resíduos sólidos urbanos provindos de uma grande cidade (Rio de Janeiro, Estado do Rio de Janeiro) e de uma pequena cidade (Coimbra, Estado de Minas Gerais). As amostras de composto foram aplicadas ao solo em doses crescentes e em diferentes tempos de contato entre o composto e o solo. Foi avaliada ainda a influência dos metais na produção de matéria fresca e seca de folhas da alface. A produção de alface aumentou com a elevação das doses dos compostos, sendo a produção máxima obtida entre 15 e 20 dias. As concentrações de metais nas folhas aumentaram com o acréscimo da dose de composto e com o tempo de contacto entre o composto e o solo, porém não atingiram os limites máximos permitidos pela Legislação Brasileira para alimentos. A aplicação do composto de Coimbra promoveu maior produção e concentrações menores dos metais na planta, em relação ao composto do Rio de Janeiro.

A study was performed to evaluate Cu, Mn, Ni, Pb, Ni and Zn accumulations in lettuce grown in an oxisol amended with composted urban solid wastes collected in Brazil from a big city (Rio de Janeiro, Rio de Janeiro State) and from a small city (Coimbra, Minas Gerais State). The compost samples were applied to the soil at increasing doses and different times of contact between compost and soil. The influence of the metals on the fresh and dry matter yield of leaves was also examined. Lettuce yield enhanced when the doses of the composts were increased and maximum yield was achieved in the cropping time between 15 and 20 days. The metal concentrations in the leaves augmented with the increase of the applied compost and with the increase of the time of contact between compost and soil. However, metal concentrations in the plant were below the maximum limits allowable by the food Brazilian legislation. The application of the compost from the smaller city resulted in increased lettuce productivity and lowest metal concentrations in the plants as compared to the results of the application of the compost from the bigger city.

Keywords: lettuce, compost, fresh matter, dry matter, metal

Introduction

The addition of urban solid waste compost to soil allows the reduction of the applied levels of Nmineral fertilizer and may increase the efficacy of the mineral fertilizers.[1] One major problem is the lack of consistency in crop response, with the response ranging from no significant effect to over a twofold increase in yield. Specific responses depend on the crop grown and the area used.[1,2] Besides the crop production, compost can be utilized as fertilizer for ornamental and urban arborisation species.[3] Fresh and dry matter accumulation have been used as indicator of the effectiveness application on plant growth of compost of biosolid, municipal solid waste and water hyacinth[4] and of vermicompost of green gram pods.[5] Amendment of soil with composted urban wastes significantly increased dry matter yields of red clover and cucumber plants, compared to treatments where soil was the only substrate.[6]

The application of compost to enhance crop yield is not yet a common practice in Brazil. However, it is increasing considerably because more solid waste municipal treatment plants are being built. While in

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developed countries the compost is originated from well-known urban waste composition (inorganic/organic matter ratio), the opposite occurs in Brazil and parameters are not necessarily suitable for Brazilian waste composition.[7] The composts are utilized mainly by horticulturists near the operation treatment plants. The presence of heavy metals in urban solid waste and cattle manure composts is a limiting factor that restrains their application.[8] Scientific data about the levels of potentially toxic metals present in compost and their effects in the environment are still scarcely discussed in the literature.

There is a lack of information about the chemical composition of compost as well as about the doses that should be applied to soil for the different plant species. Compost application to soil at elevated levels can limit lettuce yield due to the increase of soil salinity.[9] It was previously reported a great reduction in lettuce yield due to the application of doses above 60 t ha^{-1} of fresh urban waste in soil.[10] However, it has been established that decreasing plant metal uptake is a beneficial effect from the application of organic compost.[11] In some cases, high plant metal uptake has been noted with Pb being the greatest concern.[2] Current Brazilian legislation established maximum limits of some metals in food. However, there are no available regulations for land application of compost.

Soil properties such as pH, organic carbon content, electrical conductivity, and cation exchange capacity (CEC) are affected by the rate of urban solid waste compost applied.[12] Santos *et al.*[13] reported that the use of compost from the same community collected at different times and from different solid waste treatment plants might affect differently soil properties, such as the pH. The increase of compost dose might result in an inadequate soil pH for lettuce cultivation.

Lettuce, a vegetable of great consumption in Brazil, can be produced under different temperature ranges, which allows it to be market along all the year. This vegetable is one of the most efficient species in metal absorption.[14] Lettuce grown in soil amended with mine wastes accumulated significantly more metals than other species such as beans and tomato.[15]

This paper presents the results of a study in which Cu, Mn, Ni, Pb, and Zn accumulations were evaluated in lettuce grown in an oxisol amended with composted solid wastes at different times of application. The compost samples were collected from a big city and from a small city and applied to soil at increasing doses. The response of the plants to the metals based on the fresh and dry matter yield of leaves was also examined.

Experimental

The clayish soil was collected in the city of Sete Lagoas at the State of Minas Gerais, Brazil. The 20 cm layer at the soil surface was sampled and sieved to separate the particles smaller than 4 mm to be used for plant growth. The compost samples were obtained from municipal waste treatment plants in Rio de Janeiro (5,850,544 inhabitants), Rio de Janeiro State, and in Coimbra (6,443 inhabitants), Minas Gerais State, Brazil. The compost samples were air dried and passed through a 2 mm sieve.

The pH of the soil, compost samples and substrates (soil+compost) were measured in deionised water (solid/solution ratio = 1:2.5). The soil available P and K were extracted with the Mehlich-1 solution.[16] The soil and compost organic carbon were evaluated by the Walkley-Black method[17] while CEC was determined according to the method of EMBRAPA.[16] The compost available K was extracted with the Mehlich-1 solution. Particle size distribution in the soil was evaluated by the pipette method, using 0.1 mol L^{-1} NaOH solution as the dispersion agent. The total organic matter, total nitrogen and moisture contents of the compost samples were determined by the methods recommended by Kiehl.[18]

Available metals were extracted from the soil and compost samples with 0.005 mol L^{-1} DTPA (diethylene-triaminepentaacetic acid) in 0.01 mol L^{-1} $CaCl_2$, buffered at pH 7.3 with 0.1 mol L^{-1} TEA (triethanolamine) at a soil/solution or compost/solution ratio of 1:5. The extractions were performed at room temperature with continuous agitation for 2 h.[19] Total metals were extracted from the soil and compost samples by digestion with 10 mL of a HNO_3/ $HClO_4$ (5:1) mixture, and subsequently with 10 mL of a HF/$HClO_4$ (5:1).

The soil was limed,[20] the moisture content kept close to the field capacity and the material maintained in incubation during 15 days before the application of the doses of the composts. Individual soil subsamples were amended with compost at three different doses as follows: 0 t ha^{-1} (control), 35 t ha^{-1} (as suggested by the CFSEMG),[21] and 70 t ha^{-1} (double dose). The procedure was performed four times in order to obtain different times (0, 10, 20, and 30 days) of incubation for the soil and the compost mixture in the pot for plant growth.

The mixture of the compost with the soil was handmade in order to obtain better homogeneity. Each plastic pot was filled out with 4 dm^3 of the mixture (soil+compost). The doses of the composts in the pots were 0 g dm^{-3} (0 t ha^{-1}), 17.5 g dm^{-3} (35 t ha^{-1}) and 35 g dm^{-3} (70 t ha^{-1}). During the incubation period, it was added distilled water to the pots to keep the moistness close to the field capacity.

Lettuce (*Lactuca sativa L*) seedlings of the cultivar Regina de Verão were cultivated in plastic trays with the addition of distilled water during 18 days when the plants were transplanted to the pots. At the day of transplanting, the pots containing the three doses of composted urban solid waste (0, 35, and 70 t ha^{-1}) in the four incubation times (0, 10, 20, and 30 days) received 12.5 g of KH_2PO_4 and 1.1 g of $(NH_4)_2SO_4$ for each pot. Additionally, applications of 1.2 g of $(NH_4)_2SO_4$ were performed three times at different stages of the plant growth. Also, a solution of 25 mL containing the micronutrients B, Cu, Mn, Mo, and Zn were added as H_3BO_3 (1.59 g L^{-1}), $CuCl_2.2H_2O$ (1.14 g L^{-1}), $MnCl_2.4H_2O$ (4.22 g L^{-1}), $(NH_4)_6Mo_7O_{24}.4H_2O$ (2.16 g L^{-1}), and $ZnCl_2$ (2.67 g L^{-1}).

Forty one days after the transplanting, the plants were cut close to the soil and the leaves weighed for the determination of the fresh matter weight (FMW). The dry matter weight (DMW) was determined after drying the leaves to constant weight at 60 °C.

The dried leaves were ground and a 2 g sample was digested at 60 °C for 2 h with 20 mL of concentrated HNO_3 solution. The sample was further digested at 120 °C with 3 aliquots of 4 mL each of 30% (m/v) H_2O_2 solution and evaporated to near dryness. The extract was diluted with deionised water to 25 mL and the metal concentrations determined in three replicates.

The concentrations of Cu, Mn, Ni, Pb, and Zn were determined by flame atomic absorption spectrometry. The concentrations of the aforementioned metals were measured with a Carl Zeiss JENA atomic absorption spectrometer (model AAS3), by direct aspiration of the solutions into an air-acetylene lean flame. Background correction was used for Ni, Pb, and Zn determinations. The absorption lines of Cu at 324.8 nm, Mn at 279.5 nm, Ni at 232.0 nm, Pb at 217.0 nm, and Zn at 213.9 nm were used. A grating monochromator of 2604 grooves mm^{-1} (UV) was used and the value of the reciprocal linear dispersion was 1 nm mm^{-1}.

All glassware and materials were cleaned for metal analysis. Certified analytical grade reagents were used throughout. Analytical grade H_2O_2 (30% m/v), HNO_3 (65% m/v), HF (40% m/v) and $HClO_4$ (70% m/v) were used for digestion, with maximum heavy metal contents reported by the supplier being (in µg mL^{-1}): Cd < 0.01, Pb < 0.02 and Ni< 0.02. Blanks were run through all experiments. A midpoint check standard and calibration blank at the beginning, end and periodically was analyzed with each group of samples to certify that the instrument calibration has not drifted. To establish extraction efficiencies, our concurrent analyses of samples of Standard Sediments (National Institute of Standard & Technology no. 2704) gave the following total values, which are within the range of certified values: Cu = 94.5 (98.6 ± 5.0), Ni = 44.2 (44.1 ± 3.0), and Zn = 447 (438 ± 12) (in mg kg^{-1}); and Mg = 1.22 (1.20 ± 0.02) (in g kg^{-1}).

The treatments were disposed in a factorial 2 × 3 × 4, formed by two urban waste compost samples, from a big city and from a small city, three doses of compost (0, 35, and 70 t ha^{-1}), and four times of application (0, 10, 20, and 30 days), in a random block design, with four replications.

Analyses of variance and regression were used. The averages of the qualitative factor (compost type) were compared by the Tukey's test at the 5% level of probability. To the quantitative factors (application time and compost dose), the models were chosen according to the significance of the regression coefficients (t test at the 5% level of probability), and to the determination coefficients.

Results and Discussion

Soil and compost characteristics

The soil and compost characteristics are presented in Tables 1 and 2, respectively.

Fresh matter and dry matter yield

It has been reported that urban solid waste compost applied to oxisol results in linear increases in soil pH.[12] In the present work, the pH range varied from 5.2 to 6.3 (Table 3). The pH increment depends on the soil and the compost characteristics as well as on the dose and time of application. The application of the compost from Rio de Janeiro resulted, in general, in higher increase in the soil pH than that of Coimbra. The best range of soil pH for lettuce yield is between 5.7 and 7.0.[22] The pH values in the pots with soil amended with compost were in this range, except those in which the time of application was 30 days. Increasing the period of time between compost application and the plantation to 30 days resulted in soil pH values below the appropriate for lettuce cultivation.

Significant differences ($p<0.05$) were found for the FMW and DMW between plants grown with the composts from Rio de Janeiro and Coimbra (Table 4). The differences were observed when applying 35 and 70 t ha^{-1} of both composts, being higher for the compost of Coimbra at all times and doses used.

The increase of the time between the compost application and the plant transplantation resulted in pH

Table 1. Soil and compost characteristics

Soil Characteristic		Compost Source	
		Rio de Janeiro	Coimbra
pH in H_2O (1:2.5)	5.10	7.50	6.90
Organic carbon/(%, m/m)[a]	4.72	13.49	13.62
Total organic matter/(%, m/m)[b]	-	30.69	33.23
Total carbon/(%, m/m)	-	17.05	18.46
Available P/(mg dm^{-3})[c]	3.30	-	-
N total/(%, m/m)[d]	-	1.46	1.72
Available K/(mg dm^{-3})[c]	47.00	729	570
Exchangeable Al/($cmol_c$ dm^{-3})[e]	1.10	-	-
Exchangeable Ca/($cmol_c$ dm^{-3})[e]	1.50	7.00	9.30
Exchangeable Mg/($cmol_c$ dm^{-3})[e]	0.20	1.40	1.50
H + Al/($cmol_c$ dm^{-3})[f]	7.80	-	-
Sum of the bases/($cmol_c$ dm^{-3})	1.82	-	-
CEC/($cmol_c$ dm^{-3})	2.92	13.04	14.09
Base saturation/(%)	8.90	-	-
Al saturation/(%)	37.80	-	-
Sand/(%, m/m)	15	-	-
Silt/(%, m/m)	9	-	-
Clay/(%, m/m)	76	-	-
Texture	Clayish	-	-
C/N ratio	-	11.68	10.73
Moisture/(%, m/m)	-	14.10	30.39

[a]Walkley-Black method (Reference 17); [b]Ignition at high temperature; [c]Mehlich-1 extractant (Reference 16); [d]Kjeldahl method (Reference 18); [e]1 mol L^{-1} KCl exchangeable Ca and Mg; [f]0.5 mol L^{-1} pH 7.0 $Ca(CH_3COO)_2$ extractable acidity.

Table 2. DTPA extractable and total metal concentrations in soil and composted urban solid wastes (in µg g^{-1}, except Fe, in mg g^{-1})

Metal	Soil		Compost of Rio de Janeiro		Compost of Coimbra	
	Total[a]	DTPA extractable[b]	Total	DTPA extractable	Total	DTPA extractable
Fe	32.6	0.17	30.2	0.89	25.4	0.51
Zn	31.9	0.34	411	101	212	71.4
Cu	29.9	0.93	90.6	21.9	46.8	7.5
Mn	131	15.7	365	34.9	295	14.6
Ni	9.4	0.07	23.2	1.47	20.9	0.89
Cd	<0.1[c]	<0.1	1.9	0.5	0.6	<0.1
Na	782	-	11.1	-	2.3	-

[a]$HNO_3/HClO_4$ and $HF/HClO_4$ mixtures; [b]DTPA/TEA/$CaCl_2$ solution (Ref. 19); [c]Value preceded by < symbol indicate detection limit.

Table 3. pH of the soil+compost mixture after application of different doses of the Rio de Janeiro (CRJ) and Coimbra (CCb) solid waste composts at different times before transplanting the seedlings to the pots[a]

Compost	Time between the compost application and the transplanting (in days)			
	0	10	20	30
	0 t ha^{-1}			
CRJ	5.9 a	5.5 a	5.4 a	5.2 a
CCb	5.8 a	5.5 a	5.3 b	5.2 a
	35 t ha^{-1}			
CRJ	6.0 a	5.9 a	5.9 a	5.5 a
CCb	5.9 b	5.7 b	5.7 b	5.4 b
	70 t ha^{-1}			
CRJ	6.3 a	6.1 a	6.0 a	5.6 a
CCb	6.1 b	6.0 b	6.0 a	5.5 b

[a]Mean values followed by the same letter for each time of application and dose of the compost are not different at the 5% level according to the Tukey's test.

decrease (Table 3). As the pH decreased, there was a raise in the fresh and dry matter yields (Table 4). It seems that the increase in pH resulted in a decrease of nutrient supply to the plants. These results were not found when the compost doses were raised. As the doses of the composts increased, the pH of the soil+compost mixture increased (Table 3) and the fresh and dry matter yields also increased (Table 4). It seems that the composts have supplied nutrients to the plants in such a way that the supposed negative effect of the higher pH on micronutrient supply was overcome. Stringheta *et al.*[23] found a decrease in fresh and dry matter production of leaves and inflorescence of chrysanthemum due to the increase of pH and salt concentration of the substrate. The increase was attributed to the high proportion of conditioner consisting of urban solid waste compost (66.6%) and carbonized rice rusk

Table 4. Fresh and dry matter weight (g) of lettuce grown in the mixture soil+compost after application of different doses of the Rio de Janeiro (CRJ) and Coimbra (CCb) solid waste composts at different times before the transplanting of the seedlings to the pots[a]

Compost	Time between the compost application and the transplanting (in days)			
	0	10	20	30
	FMW			
	0 t ha^{-1}			
CRJ	163 a	181 a	192 a	180 a
CCb	164 a	180 a	194 a	179 a
	35 t ha^{-1}			
CRJ	198 b	225 b	229 b	218 b
CCb	210 a	234 a	247 a	235 a
	70 t ha^{-1}			
CRJ	232 b	245 b	245 b	227 b
CCb	256 a	259 a	277 a	260 a
	DMW			
	0 t ha^{-1}			
CRJ	9.6 a	10.5 a	10.9 a	10.4 a
CCb	9.7 a	10.3 a	10.9 a	10.3 a
	35 t ha^{-1}			
CRJ	11.2 b	12.1 b	12.4 b	11.9 b
CCb	11.6 a	12.6 a	13.2 a	12.6 a
	70 t ha^{-1}			
CRJ	12.5 b	13.0 b	13.1 b	12.3 b
CCb	13.5 a	13.6 a	14.3 a	13.6 a

[a]Mean values followed by the same letter for each time of application and dose of the compost are not different at the 5% level according to the Tukey's test.

(33.3%) that was added to soil and sand at a volume proportion of 4:2:1, respectively.

The application of the compost of Coimbra to the soil resulted in higher fresh and dry matter yield compared with the compost from Rio de Janeiro (Table 4). The largest FMW was 277 g when 70 t ha^{-1} of the compost of Coimbra were applied, 20 days before seedling. The difference in vegetal growth (Table 4) may have been due to the differences in the total and available metals concentrations between the composts of Coimbra and Rio de Janeiro (Table 2). The lack of significant differences in the treatments without compost (dose = 0 t ha^{-1}) reinforces it. These results suggest that the metals from the urban waste compost of Rio de Janeiro reached the plants in higher amounts as compared to those of Coimbra. This may explain the lower growth of the plants grown in the former. Special attention has to be given to Cd.

For the compost samples examined, the adjusted regression equations and the coefficients of determination related to the pH, FMW and DMW would be written as showed in Table 5.

In regard to the compost of Rio de Janeiro, the estimated times of application (TP) calculated from the regression equations (Table 5) to have maximum FMW values (194, 221, and 250 g) were 19.7 days for the control dose, 17.2 for the dose of 35 t ha^{-1} and 14.8 days for the dose of 70 t ha^{-1}. For the compost of Coimbra, the estimated times of application to have maximum FMW (193, 234, and 276 g) were equal to those found for the Rio de Janeiro compost in the three doses. At the fixed times, there were linear increments of the FMW with the increase of the compost proportion. The highest yield was obtained from the dose of 70 t ha^{-1}.

The heavy metal mobility in soil and availability to the plants are affected by the physical-chemistry characteristics of soil, such as pH, organic matter content, CEC, redox conditions, as well as the type of clay mineral.[24] At low soil pH, the presence of toxic trace elements at critical levels can limit plant productivity. The availability of nutrients and toxic metals to plants might enhance during the incubation of the mixture soil+compost. The mineralization of the organic matter and the soil pH decrease can contribute to the increase of toxic metal availability, certainly affecting plant yield.

When organic residues are applied to soil, the decomposition process starts immediately due to the presence of microorganisms. Variations in pH, temperature, humidity, aeration and C/N ratio affect the organic residue decomposition.[25,26] The soil pH plays an important role in micronutrient availability. The more acid is the soil, larger is the solubility and the availability of micronutrients,[27] except Mo. Plants grown in soil with pH near neutral absorb less heavy metal than that in acid soil.[28]

Table 5. Regression equations and coefficients of determination related to pH, fresh matter production (FMW) and dry matter production (DMW) as a function of compost doses (DOS) and time of application (TA) for the composts of Rio de Janeiro (CRJ) and Coimbra (CCb)

Dependent variable	Equation	R^2
pH (CRJ)	$\hat{Y}$ = 5.76704 + 0.00748214**DOS - 0.00940005**TA - 0.000333332**TA^2	0.91
pH (CCb)	$\hat{Y}$ = 5.70323 + 0.00627678**DOS - 0.00929168**TA - 0.000279166**TA^2	0.90
FMW (CRJ)	$\hat{Y}$ = 162.585 + 1.00107**DOS + 3.20511**TA - 0.0814667**TA^2 - 0.0113461**DOSxTA	0.96
FMW (CCb)	$\hat{Y}$ = 164.683 + 1.25239**DOS + 2.86415**TA - 0.071346**TA^2 - 0.00368783*DOSxTA	0.97
DMW (CRJ)	$\hat{Y}$ = 9.65833 + 0.0409857**DOS + 0.133229**TA - 0.0034**TA^2 - 0.000453213**DOSxTA	0.97
DMW (CCb)	$\hat{Y}$ = 9.82971 + 0. 0486429**DOS + 0.113263**TA - 0.00297292**TA^2	0.96

*Significant at 5% of probability (*t* test); ** Significant at 1% of probability (*t* test).

In regard to the DMW using the compost from Rio de Janeiro, the best adjusted equation was quadratic for the factor time at the established dose, while it was linear for the dose at the established time (Table 5). Also, related to the compost from Rio de Janeiro, the estimations of the maximum dry matter weights were 10.96, 12.11, and 13.29 g obtained from the estimated times of application of 19.6, 17.3, and 14.9 days, at the doses of 0, 35, 70 t ha^{-1}, respectively. For the compost from Coimbra, the estimations of the maximum DMW were 10.91, 12.61, and 14.31 g, at the doses of 0, 35, and 70 t ha^{-1}, respectively, obtained from the estimated time of 19.05 days.

The DMW enhanced linearly and positively due to the increase of the doses of both composted urban solid wastes at the established times (Table 5). There was not a reduction in the DMW even in the highest dose. The effect was similar to that observed in the FMW.

Increased dry matter yields of Swiss chard and basil due to high Cu compost application treatments (20, 40, and 60%, by volume) to soil was reported by Zhejazkova and Warman.[29] Crescent doses of compost applied to soil leads to linear increases of Ca, K, Mg, and P.[30] Among the improvements in soil conditions due to compost addition to soil, the most significant alteration is the increase of the organic matter content.[31] Compost application to soil is only beneficial when it is completely ripe at the time of application. The C/N ratio of compost in this condition should vary from 10:1 to 14:1.[18] The values found in this research study are within this range (Table 1).

Amendment of soil with 10 or 50% vermicompost significantly increased dry matter yields of red clover and cucumber plants, compared to treatments where soil was the only substrate.[6]

Seedling emergence of the clover *T.fragiferum L.* cv. 'Salina' was in general higher under urban compost treatment than under inorganic and control treatments. This specie also showed higher dry matter production with the use of urban compost than with other fertilizer.[32]

Metal concentrations in lettuce leaves

The adjusted regression equations and the coefficients of determination related to metal concentrations in the lettuce leaves, as a function of doses of the compost applied at different times, can be seen in Table 6.

In the case of the compost of Rio de Janeiro, the highest Zn concentrations in the leaves were obtained in the estimated times of 16.9, 19.2, and 21.5 days, respectively, for the doses of 0, 35, and 70 t ha^{-1} (Table 6). Increasing the doses at a fixed time resulted in enhanced Zn concentration in the leaves. Calculations from Table 6 indicate that the estimated highest Zn concentration (90.04 mg kg^{-1}) was found when 70 t ha^{-1} were applied, 21.5 days before the transplanting. The calculated correspondent Zn concentration in the fresh matter was of 4.88 mg kg^{-1}. In the best conditions for dry matter yield (70 t ha^{-1} and 14.9 days), the Zn concentration was 87.91 mg kg^{-1}.

For the compost of Coimbra, the highest Zn concentration occurred with the time 18.3 days for all doses (Table 6). The calculated highest Zn concentration was 69.00 mg kg^{-1} in 18.3 days, being applied 70 t ha^{-1}. At this fixed time, Zn concentration enhanced with the increase of the compost doses applied. The calculated correspondent concentration of fresh matter was 3.61 mg kg^{-1}. The maximum Zn concentration established by the Brazilian legislation for fresh food is 50 mg kg^{-1}.[33]

High levels of P can reduce Zn absorption by plants due to the antagonistic Zn-P interaction.[34] Interactions with other nutrients can also reduce absorption, such as Zn-Fe, Zn-Cu, Zn-N and Zn-Ca.[35] It was previously reported a reduction in

Table 6. Regression equations and coefficients of determination related to Zn, Cu, Mn, Pb, and Pb concentrations in the lettuce leaves, as a function of compost doses (DOS) and time of application (TA) for the composts of Rio de Janeiro (CRJ) and Coimbra (CCb)

Dependent variable	Equation	R^2
ZnLL (CRJ)	$\hat{Y}$ = 37.1382 + 0.427691**DOS + 1.6824**TA - 0.0499023**TA^2 + 0.00654735**DOSxTA	0.91
ZnLL (CCb)	$\hat{Y}$ = 39.2207 + 0.33162**DOS + 0.716247**TA - 0.0195377*TA^2	0.95
CuLL (CRJ)	$\hat{Y}$ = 6.13634 + 0.0478337**DOS + 0.0516538**TA	0.97
CuLL (CCb)	$\hat{Y}$ = 6.05444 + 0. 0421634**DOS + 0.0144113*TA + 0.00106665**TA^2 +0.000298398**DOSxTA	0.97
MnLL (CRJ)	$\hat{Y}$ = 122.51 + 1.02913**DOS + 1.75775**TA	0.94
MnLL (CCb)	$\hat{Y}$ = 116.591 + 0.344754**DOS + 0.79093**TA + 0.0298903**TA^2 + 0.0111044**DOSxTA	0.99
PbLL (CRJ)	$\hat{Y}$ = 2.19222 + 0.0314527**DOS - 0.023689**TA + 0.000943845**TA^2 + 0.000866276**DOSxTA	0.97
PbLL (CCb)	$\hat{Y}$ = 1.8322 + 0.0205053**DOS + 0.0205837**TA + 0.000321559**DOSxTA	0.97
NiLL (CRJ)	$\hat{Y}$ = 1.4738 + 0.014135**DOS + 0.0504385**TA - 0.00117385**TA^2 + 0.000462295**DOSxTA	0.97
NiLL (CCb)	$\hat{Y}$ = 1.00491 + 0.0121648**DOS + 0.021991**TA + 0.000324761**DOSxTA	0.98

*Significant at 5% of probability (t test); ** Significant at 1% of probability (t test).

Zn absorption by plants in response to high levels of Cd and P.[36] It has been reported that Cu(II) strongly inhibit Zn(II) absorption.[37] The authors suggested that these ions compete for the same sites in the uptake by plants. The leaf concentrations of the metals Cu, Mn, Ni, and Pb increased as the time between compost application and seedling transplantation increased from 0 to 30 days (Tables 7 and 8). For Zn, the leaf concentration increased from 0 to 20 days and decreased from 20 to 30 days (Table 7). It seems that the lower leaf Zn concentrations at the greater time were due to a competition with other metallic cations in the ionic root uptake of the lettuce plants. This might have been the cause of the yield response as the time between compost application and transplanting was increased from 20 to 30 days (Tables 3 and 4). The Zn deficiency reduces the leaf expansion and the growth of the plants.[38]

Table 7. Concentrations of Zn, Cu and Mn (μg g^{-1}) in the dry matter of lettuce leaves grown in the mixture soil+compost after application of different doses of the Rio De Janeiro (CRJ) and Coimbra (CCb) solid waste composts at different times before the transplanting of the seedlings to the pots[a]

Sample	Time between the compost application and the transplanting (in days)			
	0	10	20	30
		Zn		
		0 t ha^{-1}		
CRJ	36.07 a	43.67 a	44.87 a	42.98 a
CCb	35.82 a	42.77 a	44.49 a	43.61 a
		35 t ha^{-1}		
CRJ	58.89 a	72.67 a	76.70 a	69.10 a
CCb	54.41 a	59.17 b	59.86 b	57.14 b
		70 t ha^{-1}		
CRJ	63.00 a	77.45 a	94.48 a	79.91 a
CCb	62.53 a	65.35 b	68.50 b	63.17 b
		Cu		
		0 t ha^{-1}		
CRJ	6.19 a	6.35 a	6.99 a	7.49 a
CCb	6.10 a	6.39 a	6.92 a	7.14 b
		35 t ha^{-1}		
CRJ	8.12 a	8.45 a	9.26 a	9.77 a
CCb	7.49 a	7.53 b	8.34 b	9.80 a
		70 t ha^{-1}		
CRJ	9.31 a	9.83 a	10.41 a	10.86 a
CCb	9.99 a	9.76 a	10.07 b	10.79 a
		Mn		
		0 t ha^{-1}		
CRJ	122.31 a	134.20 a	143.19 a	173.45 a
CCb	117.20 a	123.56 b	139.92 a	166.50 b
		35 t ha^{-1}		
CRJ	163.09 a	185.85 a	208.68 a	226.68 a
CCb	130.80 b	147.49 b	170.69 b	195.27 b
		70 t ha^{-1}		
CRJ	192.04 a	208.90 a	222.39 a	237.98 a
CCb	138.19 b	158.65 b	182.64 b	210.86 b

[a]Mean values followed by the same letter for each time of application and dose of the compost are not different at the 5% level according to the Tukey's test.

The critical concentrations of Zn deficiency in the aerial part of plants range from 15 to 20 mg kg^{-1} (dry matter).[38] The critical concentrations of Zn toxicity range from 200 to 500 mg kg^{-1} (dry matter), depending on the species and age of the plant.[39] Lettuce cultivation well nurtured accumulated from 94 to 116 mg kg^{-1} of Zn in the dry matter of leaves.[40]

Significant differences ($p < 0.05$) were found for Zn concentrations in most of the treatments with compost (Table 7). The highest Zn concentrations in the dry matter of lettuce leave where found when the compost of Rio de Janeiro was applied. Since the compost from this city presented higher total and available metal concentrations comparatively to Coimbra (Table 2), the former had a larger potential for supplying the metals to the plants than the latter.

For the compost from Rio de Janeiro, the Cu concentration in the lettuce leaves increased linearly with the time at a fixed dose and with the doses at a fixed time (Table 6). The highest Cu concentration was 10.86 mg kg^{-1} in dry matter at the time of 30 days and dose of 70 t ha^{-1}, corresponding to 0.58 mg kg^{-1} in the fresh matter. For the compost from Coimbra, the best adjusted equation was linear for the factor dose, while a quadratic effect was found in relation to the time.

Table 8. Concentrations of Pb and Ni (μg g^{-1}) in the dry matter of lettuce leaves grown in the mixture soil+compost after application of different doses of the Rio De Janeiro (CRJ) and Coimbra (CCb) solid waste composts at different times before the transplanting of the seedlings to the pots[a]

Sample	Time between the compost application and the transplanting (in days)			
	0	10	20	30
		Pb		
		0 t ha^{-1}		
CRJ	2.14 a	2.19 a	2.34 a	2.51 a
CCb	1.86 b	1.96 a	2.23 a	2.36 a
		35 t ha^{-1}		
CRJ	3.21 a	3.39 a	3.46 a	3.82 a
CCb	2.66 b	2.46 b	3.45 a	3.66 a
		70 t ha^{-1}		
CRJ	4.53 a	4.81 a	5.58 a	6.71 a
CCb	3.25 b	3.79 b	3.91 b	4.55 b
		Ni		
		0 t ha^{-1}		
CRJ	1.59 a	1.71 a	1.91 a	2.06 a
CCb	1.02 b	1.19 b	1.38 a	1.62 b
		35 t ha^{-1}		
CRJ	2.05 a	2.44 a	2.89 a	2.88 a
CCb	1.45 b	1.84 b	2.11 b	2.61 b
		70 t ha^{-1}		
CRJ	2.28 a	3.37 a	3.74 a	3.78 a
CCb	1.82 b	2.25 b	2.88 b	3.03 b

[a]Mean values followed by the same letter for each time of application and dose of the compost are not different at the 5% level according to the Tukey's test.

The smallest Cu concentration (6.10 μg g^{-1}, dry matter) was found in the treatment without application of the compost from Coimbra at the zero time (Table 7). When using the compost from Coimbra, the highest Cu concentration was 10.79 mg g^{-1} in the dry matter at the time of 30 days and dose of 70 t ha^{-1}, corresponding to 0.56 mg g^{-1} in the fresh matter. The highest limit of Cu concentration established by the Brazilian legislation for fresh food is 30 μg g^{-1}.[33]

In the best conditions of dry matter yield for the application of the compost from Rio de Janeiro (70 t ha^{-1} and 14.9 days), and from Coimbra (70 t ha^{-1} and 19.1 days), the calculated correspondent concentrations in the dry matter were 10.26 and 10.07 μg g^{-1}, respectively (Table 6).

Copper concentrations ranging from 3.19 to 13.61 μg g^{-1} in the dry matter of lettuce leaves have been reported.[41] They also reported increased Cu concentrations with the elevation of the doses of urban solid waste compost applied.

The critical concentrations of Cu deficiency in vegetables range from 1 to 3.5 μg g^{-1} (dry matter), while critical concentrations of Cu toxicity in most of plant species range from 15 to 30 μg g^{-1}.[42] In the dry matter of lettuce, Cu concentration varied from 5.9 to 13.9 μg g^{-1}.[40]

Gallardo-Lara *et al.*[43] reported that the application of composted urban wastes led to an increase of Cu concentration in lettuce compared to the control, but it was only significant when the higher ratio of municipal solid waste compost (80 t ha^{-1}) was used. The application of 60 t ha^{-1} of compost to soil for lettuce cultivation increased Cu concentration in leaves up to 32.44 μg g^{-1} in the dry matter.[44] They noticed toxicity symptoms including necrosis points at the leaf edges. However, Rodd *et al.*[45] reported that municipal solid waste compost applied at higher ratios as compared to normal agronomic ratios did not increase Cu and Zn concentrations in tissues at levels considered harmful to boot-stage in barley and wheat.

It has been reported increased concentrations of Cu (68.2 μg g^{-1}), Pb (11.2 μg g^{-1}), and Zn (10.6 μg g^{-1}), in lettuce leaves due to the application of sewage sludge to soil.[46] The Cu and Zn concentrations found in the present work are in agreement with the values reported by those authors. The metal concentrations in plant leaves grown in soil amended with sewage sludge and compost depend on the metal concentrations in these materials and in the degree of ripeness, as well as on the type of soil, what hinders comparisons. The addition of high ratios of relatively immature Cu rich compost may not always increase Cu concentration in plants.[29]

For both composts, the increase of Mn concentration in lettuce leaves occurred as a function of the time at a fixed dose, as well as a function of the doses at a fixed time (Table 6). For the compost from Rio de Janeiro, the best adjusted equation was linear for the two factors (application time and compost dose), while for that from Coimbra it was quadratic in relation to the time and linear to the dose (Table 6).

Maximum limit of manganese concentration in fresh vegetables is still not established by the Brazilian legislation. Deficiency of manganese occurs in plants in the range from 15 to 30 μg g^{-1} (dry matter) and the critical concentrations for Mn toxicity range from 100 to 650 mg kg^{-1} (dry matter).[39] Furlani *et al.*[40] found Mn concentrations ranging from 95 to 154 μg g^{-1} in lettuce leaves (dry matter).

The highest Mn concentrations in lettuce leaves grown with both composts (238 μg g^{-1} for Rio de Janeiro and 211 μg g^{-1} for Coimbra) were found in the treatment where 70 t ha^{-1} was applied, 30 days before seedling (Table 7). These Mn concentrations in the dry matter correspond to 12.90 and 11.02 μg g^{-1} in the fresh matter. Reports show that the increase of the doses of composts results in higher Mn concentrations in soil.[47,48]

The best conditions for dry matter yield, dose 70 t ha^{-1} and time 14.9 days for Rio de Janeiro compost and 70 t ha^{-1} and 19.1 days for Coimbra compost, corresponded to calculated Mn concentrations in the dry matter equal to 220.79 and 181.45 μg g^{-1}, respectively. The high Mn concentrations (Table 7) found in the lettuce leaves are due to the high concentrations present in the soil and composts used in this work (Table 2).

For both composts, the increase of Pb concentrations in lettuce leaves occurred as a function of the time at a fixed dose as well as a function of the dose at a fixed time (Table 6).

For the compost from Rio de Janeiro, the highest Pb concentration in the dry matter of lettuce was 6.71 μg g^{-1} at the time of 30 days and dose of 70 t ha^{-1}, which corresponds to 0.36 μg g^{-1} in the fresh matter. For the compost produced in Coimbra, the highest Pb concentration was 4.55 μg g^{-1} in the dry matter and 0.24 μg g^{-1} in the fresh matter, obtained from the same conditions as described above (Table 8). Addition of Cd and Pb to nutrient solution significantly reduced the fresh and dry matter yield of lettuce leaves and roots.[49] They found that higher concentrations of Cd and Pb in nutrient solution implied in increased accumulations of these metals in plants.

Increased Pb concentration in leaves due to the elevation of the dose of compost has also been described in the literature.[50] It was reported that Pb concentrations reached up to 3.39 μg g^{-1} in the dry matter in lettuce cultivation when 30 t ha^{-1} of composted urban solid waste was applied to soil. Lead concentration in plants can reach 8 mg kg^{-1} in the dry matter without presenting phytotoxic effects.[51]

The maximum limit of Pb tolerance in fresh foods is 0.50 μg g^{-1}.[52] In 10 lettuce cultivars fertilized with composted urban solid waste, the Pb concentration exceeded that value and ranged from 0.63 to 3.02 μg g^{-1}.[53] Lead concentration commonly found in plant tissues is 3 μg g^{-1}.[54]

In the best conditions of dry matter yield for the compost from Rio de Janeiro (70 t ha^{-1} and 14.9 days), and for the Coimbra compost (70 t ha^{-1} and 19.1 days), the Pb concentrations in the leaves were 5.16 and 4.09 μg g^{-1}, respectively.

It can be seen in Table 6 for Ni that the best adjusted equation was quadratic for the factor time at a fixed dose, while it was linear for the dose at a fixed time, in respect to the compost of Rio de Janeiro. Nickel concentrations in the leaves increased until the estimated times of 21.5, 28.4, and 35.3 days, respectively, for the doses of 0, 35, and 70 t ha^{-1} (Table 6).

Increasing the dose of the compost from Rio de Janeiro resulted in higher Ni concentration in the leaves of the plant (Table 8). In the conditions of maximum production, the Ni concentration in the leaves was 3.44 μg g^{-1} in the dry matter. The highest Ni concentration, 3.78 μg g^{-1} in the dry matter was found in the treatment where 70 t ha^{-1} was applied, 30 days before transplanting. The calculated correspondent Ni concentration in the fresh matter was 0.21 μg g^{-1} .

For the compost from Coimbra, the best adjusted equation was linear for the two factors time of application and compost dose). Nickel concentrations in the leaves enhanced with the increase of the time of application at a fixed dose, as well as with the elevation of the dose in a fixed time (Table 6). The highest Ni concentration in the dry matter (3.03 μg g^{-1}) was found in the treatment where 70 t ha^{-1} was applied, 30 days before transplanting, corresponding to 0.16 μg g^{-1} in the fresh matter (Table 8). The maximum Ni concentration established by the Brazilian legislation for fresh food is 5 μg g^{-1}.[33] Applying 70 t ha^{-1} of compost in soil 19.1 days before transplanting resulted in highest DMW. In this case, the Ni concentration was 2.71 μg g^{-1}.

Nickel is an essential micronutrient. However, its concentration in dry matter of plant tissues is usually low (around 2 μg g^{-1}). Phytotoxical effects can occur with critical concentration of 11 μg g^{-1}.[55] Jordão *et al.*[56] found that the Cu, Cr, Ni, and Zn concentrations in the leaves and roots of the leguminous *Stilozobium aterrimum* and *Cajanus cajan* were close to the values commonly found in plants. These results were reported for plants grown in eroded oxisol amended with vermicompost of cattle manure that was previously applied to purify electroplating wastes containing heavy metals.

Conclusions

The increase of the doses of composted urban solid wastes applied to soil resulted in enhanced fresh and dry matter weights of lettuce. At the fixed doses, the application of different times between compost addition and the plantation caused significant differences in fresh and dry matter weights. Copper, Mn, Ni, Pb, and Zn concentrations in lettuce leaves augmented with the increase of compost doses. However, metal concentrations remained within the range normally found in plants and were not higher than the maximum limits allowed by the Brazilian legislation. The compost from the small city (Coimbra) showed better characteristics to be used as organic fertilizer than that of the big city (Rio de Janeiro), since it led to higher yields, with lower metal concentrations in the vegetable tissues. The results also have shown that the application of the composts from Rio de Janeiro and Coimbra to soil did not cause any visible phytotoxic effects on lettuce.

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