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ORIGINAL RESEARCH

Physicochemical and biochemical properties of an acid soil under potato culture amended with municipal solid waste compost

Marta Domínguez[1,2] · Remigio Paradelo Núñez[1] · Juan Piñeiro[3] · María Teresa Barral[1]

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Abstract

Purpose A field trial was conducted on a silty-loam soil under potato culture in NW Spain, to assess the effect of municipal solid waste (MSW) compost in a heavily fertilized acid soil.

Methods Three doses of compost (0, 30 and 60 Mg compost ha^{-1} soil) or inorganic fertilization (~ 140 N: 120 P_2O_5: 240 K_2O kg ha^{-1} soil) were assayed. The effects of compost on soil physical, chemical (nutrient status and potentially toxic trace elements) and biochemical properties were evaluated after 1 and 5 months.

Results Compost addition at the highest dose decreased bulk density and increased soil porosity and soil stability against water erosion. Soil pH, total organic C and N, cation exchange capacity and available P, Ca, Mg and K were also higher in compost-amended soils, whereas no effect on NH_4^+-N and NO_3^--N was observed. Compost significantly increased soil microbial biomass and dehydrogenase activity. Due to the high nutrient status in the control soil, potato yield was not increased by compost or inorganic fertilization. A negative consequence of compost addition was the increased extractability of trace metals such as Zn, Cu, Pb and Ni, although their total concentrations in soil or in potato tubers did not increase with respect to the control.

Conclusions Overall, results show that positive effects of MSW compost can be expected even in rich soils that do not need fertilization for maintaining their productive function in the short-term. These positive effects prove the benefits of recycling urban wastes in agricultural soils as a sustainable way of waste management.

Keywords Organic amendments · Soil quality · Microbial biomass · Heavy metals

Introduction

Agricultural activities may result in a decrease in soil organic carbon (SOC) in cultivated soils in comparison with their non-cultivated counterparts when losses are not sufficiently compensated by inputs. Tillage and the progressive replacement of organic amendments by inorganic fertilizers are among the processes that have contributed to the loss of soil organic matter (SOM) in cropped soils. Given the key role of organic matter in soil functions and agricultural sustainability, the maintenance of appropriate soil organic matter levels is essential to ensure soil quality and sustainability of soil use (Barral et al. 2009). Urban wastes and in particular municipal solid waste (MSW) are interesting sources of organic matter for agricultural soils now that urban areas are increasing at expenses of rural areas. Through composting, urban wastes can be transformed in safe soil amendments (Farrell and Jones 2009) that have been demonstrated to be of use in low-fertility, degraded or low-quality soils, where nutrient and organic matter inputs are necessary to restore productivity (Hargreaves et al. 2008; Park et al. 2011; Paradelo 2013; Rady et al. 2016). Notwithstanding, the problem with urban wastes is growing and compost use should be envisaged also for agricultural soils that do not necessarily need an increasing of fertility or organic matter content. In this case, potential negative effects of urban wastes, such as

✉ Remigio Paradelo Núñez
remigio.paradelo.nunez@usc.es

1 Departamento de Edafoloxía e Química Agrícola, Facultade de Farmacia, Universidade de Santiago de Compostela, Praza Seminario de Estudos Galegos S/N, Campus Sur, 15782 Santiago de Compostela, Spain

2 Fomento de Construcciones Y Contratas, Planta de Tratamiento de Residuos de Lousame, Servia (Lousame), A Coruña, Spain

3 Centro de Investigaciones Agrarias de Mabegondo (CIAM), Apdo. 10, A Coruña, Spain

excess nutrient leaching or accumulation of potentially toxic elements, must be taken into account.

This is the case of composts produced from urban wastes such as MSW that may be the cause of negative effects when added to soil due to the presence of high concentrations of potentially toxic trace elements (Smith 2009; Lopes et al. 2011; Paradelo et al. 2011). Among these, Pb, Cu, and Zn often reach high concentrations in composts due to the inadequate separation of MSW biodegradable fractions from non-degradable or inert materials rich in metals, as well as to their presence in vegetables and other human food materials (Chaney et al. 2001), and they could be accumulated in soils up to excessive levels after repeated compost applications. Consequently, concern about the risk of soil pollution by contaminants has led to the development of European and national guidelines controlling the use of these materials (Barral and Paradelo 2011).

When working with degraded systems, where soil fertility must be restored before any other consideration, these potential drawbacks can be considered a minor concern. In turn, if MSW composts are to be used in fertile soils with soil functions other than plant production in mind, environmental issues gain relevance. In this sense, the general objective of this work was to know what happens in very fertile and organic matter-rich soils: whether, in this case, the potential advantages of composts beyond plant yield have more weight than the associated risks. Thus, we have evaluated the effects of the application of municipal solid waste compost on the properties of an agricultural soil under an Oceanic climate throughout the cycle (5 months) of a potato (*Solanum tuberosum* L.) culture, in comparison with soil receiving inorganic fertilization. Physical, chemical and biochemical properties have been assessed, as well as crop yield and potential transfer of heavy metals to the edible parts of potatoes.

Materials and methods

Site description and treatments

The field trial site was located in the CIAM Agricultural Research Station in Mabegondo (A Coruña, Spain), at 43º 15′N and 8º 16′W. The site (120 m above the sea level) is a nearly flat area of c.a. 540 m^2 on weathered biotite schist. Climate is Oceanic, with a mean annual temperature of 12.3 ºC, mean annual rainfall of 1169 mm and annual evapotranspiration of 766 mm. The soil was a silty-loam Eutric Cambisol (IUSS Working Group WRB 2014), with 25% sand and 19% clay, acid (pH in water 5.6 and 5.0 in 0.1N KCl), rich in organic matter (3.4% OM, 0.19% total N) and nutrients (443 mg kg^{-1} and 293 mg kg^{-1} for available K_2O and P_2O_5 respectively, and 1865 and 76 mg kg^{-1} for available CaO and MgO, respectively). The 10 months previous to the beginning of the experiment the plot remained uncultivated and was disk-harrowed twice, in autumn and spring.

The field trial comprised four replicates of four treatments (two doses of compost, one dose of inorganic fertilizer and a control), applied to subplots of 8 × 4.2 m, set out in a Latin square design. The application of 30 and 60 Mg compost ha^{-1} (fresh weight) will be referred to as SC1 and SC2, respectively. The application of inorganic fertilizer N:P:K (12:12:24) at a dose 1000 kg ha^{-1}, commonly used for potato culture in the region, plus NH_4NO_3 at a dose of 100 kg ha^{-1} soil will be referred to as SIF. Control plots without compost or inorganic fertilizer will be referred to as S. The treatments assayed in the experience are summarized in Table 1.

The compost employed in the trial was produced by an industrial composting plant, through aerobic transformation of separately collected organic fraction of municipal solid waste (MSW), and its characteristics are indicated in Table 2. The pH was near neutrality, the C/N ratio 13 is indicative of maturity, available K and Ca are present in high concentrations (29.1 and 14.9 g kg^{-1}, respectively), whereas Mg and P are less abundant (3.3. and 5.8 g kg^{-1}, respectively). The total Zn and Pb concentrations were in the range proposed by the Spanish regulation for class C compost (Ministry of Agriculture 2005), while for the other metals class B requirements would be fulfilled. Therefore, the compost would be classified as "C compost" and should not be employed at rates higher than 5 Mg dry matter ha^{-1} $year^{-1}$. Most concern is about Zn that has been commonly regarded as the metal with the highest availability in MSW composts (Paradelo et al. 2011, 2017).

Plots with organic amendment received 540 or 1080 kg total N ha^{-1}, from which only about 10% is considered to be available for a first culture (Hadas and Portnoy 1994). Based on available nutrient concentrations, the addition of

Table 1 Treatments assayed in the field trial and total amounts of nutrients added

Key	Type	Fertilizer/Amendment	Rate (Mg ha^{-1})	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
S	Control	None	–	–	–	–
SC1	Organic	MSWC	30	540	135	653
SC2	Organic	MSWC	60	1080	270	1306
SIF	Inorganic	NH_4NO_3 + NPK 12:12:24	0.1 + 1.0	141	120	240

MSWC municipal solid waste compost

Table 2 Characteristics of the compost

			Total ($mg\ kg^{-1}$)		Available[a] ($mg\ kg^{-1}$)
pH in H_2O	7.5	Fe	11,039	Fe	981
OM ($g\ 100\ g^{-1}$)	51.9	Zn	519	Zn	263
Total N ($g\ 100\ g^{-1}$)	2.4	Mn	295	Mn	164
C/N	13	Pb	192	Pb	51
K_2O ($g\ kg^{-1}$)	29.1	Cu	101	Cu	14
CaO ($g\ kg^{-1}$)	14.9	Ni	25	Ni	5
MgO ($g\ kg^{-1}$)	3.3	Cr	22	Cr	2
P_2O_5 ($g\ kg^{-1}$)	5.8	Cd	1	Cd	< 0.3

Concentrations are expressed on a dry weight basis. Moisture of fresh compost was 25%

[a]Extracted in EDTA at pH 4.65

30 and 60 t ha^{-1} compost also contributed 653 and 1306 kg ha^{-1} of K_2O, and 135 and 270 kg ha^{-1} of P_2O_5, whereas inorganic fertilization provided 141 kg ha^{-1} N, 120 kg ha^{-1} P_2O_5 and 240 kg ha^{-1} K_2O. One month after the application of the amendments and fertilizers the soil was tilled to 20 cm depth, and potatoes (Kennebec cultivar) were planted 1 week later, in June 2001.

Sampling

The soil was sampled 30 (1 month) and 150 days (5 months) after compost application; the last sampling was just before potato harvesting. Six subsamples were randomly collected from the top 15 cm of the central strips of subplots and mixed to constitute a composite sample representative of each subplot. Samples were transported in crush-proof plastic boxes to the laboratory, where they were sieved (< 5 mm) and stored at 4 ºC before the analysis. Biochemical analyzes, as well as NH_4^+-N and NO_3^--N determinations, were carried out on field-moist soils, within 2 weeks of sampling. Chemical and physical analyzes were carried out on air-dried subsamples.

For potato harvesting, a 0.40 m buffer zone was established along the outer rim of each plot to minimize the edge effect. Potatoes were harvested outside this buffer area and yield was recorded.

Soil analysis

The physicochemical properties of the soils were determined as per Guitián and Carballas (1976). Soil pH was determined in water and 0.1M KCl suspensions (1:2.5 w/v) with a glass electrode. Organic C was analyzed by dichromate oxidation and titration with ferrous ammonium sulfate. Total *N* was determined by the Kjeldahl method. Inorganic *N* (NH_4-N + NO_3-N) was determined by extraction in 2M KCl, followed by steam distillation (Keeney and Nelson 1982). Cation exchange capacity (CEC) was determined in 1M NH_4OAc (Gillman et al. 1983) and available Ca, Mg and K determined by flame atomic absorption/emission spectroscopy (Varian SpectrAA 220FS, Varian Inc., Palo Alto, US). Available P was extracted in NH_4F–HCl (Bray and Kurtz 1945) followed by colorimetric determination of the phosphomolybdic complex. Total Mn, Cr, Cu, Ni, Pb and Zn were analyzed by flame atomic absorption spectroscopy, after digestion in microwave oven with HNO_3, HCl and HF. Quality control of total element analyzes was performed by analyzing triplicate samples of a certified reference material (sewage sludge amended soil CRM-143) from the Community Bureau of Reference. The method of Lakanen and Erviö (1971) was used to extract NH_4OAc/EDTA-soluble metals that were analyzed by flame atomic absorption spectroscopy.

Bulk density was determined in three undisturbed soil cores dried at 105 ºC, and total porosity was calculated from particle density and bulk density. Particle density was determined in ground (< 50 μm) dry soil by the pycnometer method, using toluene as the filling liquid. The aggregate size distribution was determined after ten minutes of dry shaking in a sieving machine at medium intensity, from the weight fraction of aggregates retained on sieves with mesh size of 2 and 1 mm, the top threshold of clods being 5 mm (Burke et al. 1986). Aggregate stability was determined by wet sieving following the method of Kemper and Rosenau (1986). The aggregate resistance to raindrop impact was determined by evenly spreading 50 g of soil sieved between 4 and 0.25 mm on a sieve of mesh size 0.25 mm. The soil was subjected to 30 min of artificial rainfall simulated by ejecting water at an exit pressure of 0.25 kg cm^{-2} from an oscillating sprinkler at 2.5 m high over the soil. The simulated rain had a mean drop diameter 1.25 mm, intensity 45 mm h^{-1} and a kinetic energy 14.38 J m^2 mm^{-1}. From the results of duplicate experiments, the proportion of soil loss was calculated (g m^{-2} min^{-1}).

Microbial biomass C (MBC) was determined by the chloroform fumigation-extraction method (Vance et al. 1987). Dehydrogenase activity was determined by the reduction of 2,3,5-triphenyltetrazolium chloride (TTC) to triphenylformazan (TPF) following the method proposed by Tabatabai (1982).

Plant analyzes

The tubers were analyzed for their nutrient and total heavy metal concentrations, after microwave oven digestion of the potato tuber (dried at 70 ºC) in concentrated HF + HNO_3 + H_2O_2 and measuring of element concentration in the extracts by flame atomic absorption spectrometry (Varian SpectrAA 220FS, Varian Inc., Palo Alto, US).

Statistical analyzes

Linear regression model analysis and one-way ANOVA were performed to assess the significance of the differences between the treatments and the control soil, using the R statistical package for MacOSX (version R 3.1.3; R Core Team 2015).

Results and discussion

Soil physical properties

The addition of compost significantly decreased soil bulk density and increased porosity at the highest dose, whereas at the low rate there was no effect (Table 3). Although aggregate size and aggregate stability did not change with compost application, soil loss under simulated rainfall did decrease in comparison with the control soil, even at the lowest compost dose. These modifications are overall positive to plant growth, because they are associated to higher moisture and water retention by the soils, as well as for other soil functions such as protection against erosion or a better habitat for microorganisms. Although increases in aggregate stability have also been commonly observed in compost-amended soils (Hargreaves et al. 2008; Diacono and Montemurro 2010), this was not the case in our study. The high aggregate stability of these basic schist soils is due to the abundance of poorly crystalline Fe/Al (hydr)oxides (Arias et al. 2016) and can explain the lack of effect observed after the addition of compost.

Soil chemical properties

The chemical properties of the treated and control soils during the experiment are shown in Table 4. A significant increase in pH in KCl took place for the SC2 treatment, 5 months after the addition of compost. This pH increase is

Table 3 Physical properties of the soils after the experiment

Key	Fertilizer/Amendment	Dry bulk density g cm^{-3}	Total porosity %	Aggregate size distribution			Aggregate stability %	Soil loss g m^{-2} min^{-1}
				> 2 mm %	1–2 mm %	< 1 mm %		
S	None	1.31	49	35	29	36	29	63
SC1	MSWC	1.27	50	33	29	38	30	39*
SC2	MSWC	1.16*	54*	29	29	42	31	39*
SIF	NH_4NO_3+NPK	–	–	–	–	–	–	–

Statistically significant differences ($P<0.05$) with respect to the control are indicated by an asterisk

– Not determined on the SIF plots

Table 4 Chemical properties of the soils during the experiment

Key	Fertilizer / Amendment	pH_w		pH_{KCl}		TOC (g kg^{-1})		N (g kg^{-1})		C/N		CEC (cmol$_c$ kg^{-1})	
		Jul	Nov	Jul	Nov	Jul	Nov	Jul	Nov	Jul	Nov	Jul	Nov
S	None	5.7	5.9	5.2	5.4	15	11	1.3	1.3	12	9	9.9	9.7
SC1	MSWC	5.8	6.3	5.6	6.0	19	14	1.7*	1.6*	10	9	11.4	10.9
SC2	MSWC	6.1	6.8	6.1	6.5*	22*	20*	2.3*	2.2*	10	9	17.3*	15.8*
SIF	NH_4NO_3+NPK	5.4	5.5	5.0	5.1	14	12	1.4	1.3	11	9	9.3	10.1
		NH_4-N (mg kg^{-1})		NO_3-N (mg kg^{-1})		P_2O_5 (mg kg^{-1})		K_2O (mg kg^{-1})		CaO (mg kg^{-1})		MgO (mg kg^{-1})	
		Jul	Nov	Jul	Nov	Jul	Nov	Jul	Nov	Jul	Nov	Jul	Nov
S	None	1.3	1.1	33.6	21	369	395	1166	1160	1384	1363	78	69
SC1	MSWC	1.7	2.6	69.7*	46	489	512	1563	1661*	1958	1979	129*	119*
SC2	MSWC	2.2	3.9	105*	67	621*	603*	1973*	1916*	3184*	2913*	195*	154*
SIF	NH_4NO_3+NPK	13.9*	2	94*	76	437	449	1375	1414	1298	1262	6	65

Statistically significant differences ($P<0.05$) with respect to the control are indicated by an asterisk

TOC total organic carbon, *CEC* cation exchange capacity, *Jul* sampling at July, *Nov* sampling at November commonly observed when acid soils are amended with urban waste composts (Hargreaves et al. 2008; Paradelo and Barral 2017), and is a consequence of the buffering capacity of organic matter and the presence of carbonates in municipal solid waste in this case (Vassilev et al. 1999; Paradelo et al. 2011). This liming effect is extremely important in these acid soils with variable charge and a high P fixation capacity. On the one hand, increase of pH contributes to the reduction of Al toxicity by decreasing the amount of exchangeable Al. On the other hand, higher pH means lower positive charge, and therefore, lower phosphate fixation, what is positive in terms of fertility. Additionally, liming can also contribute to increase OC sequestration in these soils by two mechanisms: increasing C protection by aggregates due to improved stability of clay assemblages and clay-organic matter bonds; and indirectly by increasing the return of C inputs to soil as a consequence of higher plant productivity in limed soils (Paradelo et al. 2015).

SOC contents were higher in the soils with the highest compost dose SC2 both in July and November, whereas total N concentrations were higher in SC1 and SC2 treatments (Table 4). Simultaneous increases in both parameters caused the C/N ratio not to change significantly with treatments. Thus, compost addition increased organic matter concentrations even in these soils that were not previously poor, compared to most agricultural soils in Europe. These soils developed on basic rocks under Oceanic climate have a great potential for sequestering OC due to the presence of poorly crystalline Fe and Al compounds that highly stabilize organic matter (García-Rodeja et al. 1987), and indeed non-agricultural soils developed on these materials often present SOC concentrations over 50 g kg^{-1} (Calvo de Anta et al. 2015). Thus, the addition of urban waste composts is an interesting option for increasing SOC sequestration and N contents.

Nutrient concentrations and cation exchange capacity for the treated and control soils are also shown in Table 4. Cation exchange capacity was higher for SC2, what can be related to its higher OC concentration that contributes with negative charged surfaces responsible for cation exchange. Regarding available nutrients, only the inorganic fertilization produced significant increases in NH_4-N, 1 month after the application, in comparison with control soils. Nevertheless, this effect was lost at the harvest time, suggesting intense absorption of this nutrient by the crop. Nitrate (NO_3-N), which represents the major part of inorganic N at the two sampling times, was higher for all the treatments in comparison with the control soil in the first sampling, but not in the second one, corroborating the intensive use of inorganic N by the crop and/or losses by leaching. The available P concentration was higher in SC2 in comparison with SIF and control soil, as was the available K_2O, and the same was true for available Ca and Mg. Thus, compost addition increased the concentrations of essential plant nutrients (N, P and K), in line with the capacity of compost for NPK supply that has been demonstrated in other studies (Hargreaves et al. 2008; Diacono and Montemurro 2010; Barral et al. 2011). This shows that, in addition to their effect as organic amendments, increasing or maintaining SOM contents, MSW composts used at concentrations similar or slightly higher than those usual for manure in the region are a valuable source of nutrients. However, in view of the high nutrient content of MSW composts, attention has to be paid to potential N and P losses through leaching. Under the climatic conditions of these oceanic regions, when these amendments are added to nutrient-rich soils, as is the case for the studied soil, excess N and P may be lixiviated from soils to water bodies. Here, the risk associated to N would be more important that in the case of P, according to the large increment in available nitrate in the compost-amended soil (Table 4). Thus, both the dose of compost and the moment of application to agricultural soils are decisive factors to reduce or avoid N leaching.

Soil biochemical properties

The addition of MSW compost had favorable effects on soil biological activity, as it increased dehydrogenase activity at both doses, although biomass-C content was only higher for SC2 (Table 5). This is in agreement with results from several experiments that have demonstrated that soil biological properties such as microbial biomass C and enzymatic activities are significantly improved by compost addition (Paradelo et al. 2007, 2009b; Hargreaves et al. 2008; Diacono and Montemurro 2010). This effect of compost on biological activity is attributed to an increase in substrate availability to decomposer microorganisms, since they use organic carbon for energy trough respiration or for assimilation into their tissues. Better conditions for microorganisms and microbial activity are positive beyond the productive function of soil, as they will increase biodiversity and influence the biogeochemical cycles that are dependent on organic matter decomposition (Ros et al. 2006; Diacono and Montemurro 2010).

Potato yield

Despite all the improvements in soil conditions, potato yield did not increase with fertilization as it would be expected (Table 5). The positive effects of MSW compost (at least at the highest dose) on nutrient contents, porosity, stability against water erosion and biological activity were not reflected in the potato yield, but neither were found in the plots receiving inorganic fertilization. Several factors can explain this fact: (1) the increase in soil pH due to compost is not necessarily positive for potato, which is well adapted

Table 5 Soil biological activity, potato yield and metal plant uptake: potato tuber composition

Key	Fertilizer/Amendment	Soil		Potato yield (Q ha^{-1})	Potato			
		Dehydrogenase activity (mg TPF kg^{-1} day^{-1})	Microbial biomass C (mg kg^{-1})		Fe (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})
S	None	77	65	58.9	49	4.8	7.8	14.1
SC1	MSWC	104	120*	53.9	55	5.1	9.7	15.2
SC2	MSWC	132*	254*	49.8	73	5.3	9.4	17.9
SIF	NH_4NO_3+NPK	67	70	58.8	89	5.4	7.9	12.6

Ni, Pb, Cr, and Cd concentrations were under the detection limits. Statistically significant differences ($P<0.05$) with respect to the control are indicated by an asterisk

to acid soils; (2) the soil used had already a high fertility status, which met the requirements for potato growth without additional fertilization or amendment as shown by nutrient analyses of the control unfertilized plots (Table 4), and this could mask any positive short-term effect of compost; and (3) it has been noted that the best agronomic performance of MSW compost is often obtained as a slow-release nitrogen fertilizer and that it is less effective in the first year of application (Diacono and Montemurro 2010). The combination of these three facts explains why no increase in potato yield has been observed in our short-term study.

Heavy metals in soil and plant

In what concerns potentially toxic trace elements, which is the most studied risk in soils amended with urban wastes, the elements that were present at higher concentrations in the MSW compost employed here were Zn and Pb (Table 2), as commonly observed in compost studies (Smith 2009; Lopes et al. 2011; Paradelo et al. 2011; Rajaie and Tavakoly 2016). The total concentrations of metals in the compost-amended soils were not modified, as shown in Table 6 (there were no differences in soil metal composition from June to November, so only November data are shown). In turn, a significant increase in available Cu, Ni, Pb, and Zn was observed for the highest compost dose, the latter two elements being more problematic due to their higher potential toxicity. This availability increase is in agreement with what has been observed in similar soils (Paradelo and Barral 2017; Paradelo et al. 2018). Previous laboratory studies with several Galician soils and composts have shown that the risk related to heavy metals in compost-amended soils is mostly due to Cu, Pb, and Zn and that among them, the highest environmental risk is that of Zn, that is the element with the highest concentrations in readily available soluble forms (Paradelo and Barral 2017; Paradelo et al. 2018). From a more general point of view, the quality of MSW compost could be substantially improved in what concerns metal contents with a more efficient source-separation of wastes, given that these elements reach the organic fraction of urban wastes during contact with ceramics, plastics, printed paper, and metallic particles (Haug et al. 1993; Paradelo et al. 2009a).

These observations obtained from soil analyses need to be complemented by studies on plant uptake. In this sense, the analysis of potato tubers in this study has shown that there was no additional metal transference to plant due to compost amendment (Table 5), despite the increase in metal availability. This fact is likely due to the liming effect of compost, since metal uptake is generally lower as soil pH increases (Smith 2009). These results show that, at least in the short-term, the risk associated to the use of MSW compost as organic amendment in these fertile agricultural soils is low. However, the long-term effects of repeated

Table 6 Trace element contents in the soils in November (total and available)

Key	Fertilizer/amendment	Total (mg kg^{-1})						Available (mg kg^{-1})				
		Cu	Pb	Zn	Co	Ni	Cr	Cu	Pb	Zn	Co	Ni
S	None	40	156	102	66	71	77	2.2	3.9	1.3	0.7	0.3
SC1	MSWC	39	157	105	66	73	74	2.7	5.9	3.6	0.7	0.4
SC2	MSWC	41	154	126	59	68	74	3.4*	11.3*	9.2*	0.8	0.5*
SIF	NH_4NO_3+NPK	39	157	98	66	74	73	2.2	3.7	1.2	0.8	0.3

Total Cd and available Cr and Cd concentrations were under the detection limits in all cases. Statistically significant differences ($P<0.05$) with respect to the control are indicated by an asterisk applications of compost on the transference of toxic elements to plants could be different and should be studied in longer field experiments.

Conclusions

The addition of a MSW compost to a fertile, organic matter-rich soil at doses of 30 or 60 Mg ha^{-1} produced a series of modifications in the soil physical, chemical and biological properties in comparison with soils receiving inorganic fertilization and with untreated control soils, although it did not influence potato yield. Positive effects for soil functions include increases of organic matter and porosity, correction of acid soil pH and increase in microbial activity. Higher available concentrations of Cu, Pb, and Zn were observed in compost-amended soils, but neither total metal concentrations in soil nor metal uptake by potato were increased by compost addition. Overall, the positive effects observed prove the benefits of recycling urban wastes in agricultural soils as a sustainable way of waste management. To achieve a safe application of MSW compost and to obtain the maximum beneficial effects without the detrimental effects of the accumulation of heavy metals in the environment after repeated amendment, it is recommended that compost quality be optimized by better source-separation of waste.

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