SJSS
SPANISH JOURNAL OF SOIL SCIENCE

Magnetic susceptibility and trace element distribution in compost size fractions

Susceptibilidad magnética y distribución de elementos traza en fracciones granulométricas de composts

Susceptibilidade magnética e distribuição de elementos vestigiais em frações granulométricas de compostados

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Received: 03.10.2013 | **Revised:** 10.03.2014 | **Accepted:** 24.04.2014

ABSTRACT

Magnetic susceptibility can be used for assessing anthropogenic pollution in solid matrices, including soils and composts. This work studies the distribution of trace elements and magnetic susceptibility in the different size fractions of six composts, for the development of measures aimed at reducing compost pollution at the production stage. The results showed that magnetic susceptibility decreased with increasing particle size in all composts, and the same was true for most trace element concentrations. Magnetic susceptibility was significantly correlated with Fe, as well as with Cu, Zn, Pb, Cr and Ni, which proves the relationship between the presence of ferric particles and trace element contamination in compost. Our results suggest that the association of trace elements and magnetic susceptibility is a characteristic feature in municipal solid waste composts.

RESUMEN

La susceptibilidad magnética es una propiedad que se puede utilizar para evaluar la contaminación de origen antrópico en matrices sólidas, incluyendo suelos y compost. En este trabajo se estudió la relación entre la distribución de elementos traza y la susceptibilidad magnética en distintas fracciones granulométricas de seis compost, con el objetivo de desarrollar medidas para la reducción de la contaminación durante la etapa de la producción del compost. En general, tanto la susceptibilidad magnética como las concentraciones de elementos traza metálicos se redujeron en las fracciones más gruesas con respecto a las más finas. Se encontraron correlaciones positivas significativas de esta propiedad con las concentraciones de Fe, Cu, Zn, Pb, Cr y Ni, lo que demuestra la relación entre la presencia de partículas férricas y la contaminación con elementos traza en el compost. Los resultados sugieren que esta relación es característica de los compost de residuos sólidos urbanos.

RESUMO

A susceptibilidade magnética é uma propriedade que se pode utilizar para avaliar a contaminação de origem antrópica en matrizes sólidas, incluindo solos e compostados. Neste trabalho estudou-se a relação entre a distribuição de elementos vestigiais e a susceptibilidade magnética em distintas frações granulométricas de seis compostados, com o objetivo de desenvolver medidas para a redução da contaminação durante as etapas de produção do compostado. Em geral, tanto a susceptibilidade magnética como as concentrações de elementos vestigiais metálicos baixam nas frações mais grosseiras relativamente às mais finas. Encontraram-se correlações positivas significativas desta propriedade com as concentrações de Fe, Cu, Zn, Pb, Cr e Ni, o que prova a relação entre a presença de partículas férricas e a contaminação com elementos vestigiais no compostado. Os resultados sugerem que esta relação é característica dos compostados de residuos sólidos urbanos.

DOI: 10.3232/SJSS.2014.V4.N2.06

1. Introduction

The application of organic amendments such as compost to agricultural land has a number of beneficial effects including restoring soil fertility by increasing the soil organic matter content, supplying plant nutrients and improving the soil physical condition (Hargreaves et al. 2008; Diacono and Montemurro 2010). However, composts may contain high concentrations of potentially toxic trace elements such as Cu, Zn or Cr, in particular municipal solid waste (MSW) composts (Smith 2009). The presence of pollutants in this type of compost is mostly related to the inadequate separation of biodegradable fractions from metal-rich non-degradable or inert materials when the mechanically-sorted organic fraction is used for their production instead of the separately collected waste (Haug 1993). As a consequence of their potential adverse effects on plant growth and the associated environmental risks, trace element contents in MSW compost are the main restriction to their agronomic use, and considerable efforts are currently devoted to the study of their concentrations and distribution.

One of the techniques that have recently gained attention in the field of pollution assessment is the measurement of magnetic susceptibility, due to the simplicity of measurement and the fact that it is a non-destructive technique. Magnetic susceptibility is the degree of magnetization of a material in response to an applied magnetic field, and it is a typical feature of soil iron oxides (Thompson and Oldfield 1986). Its utilization in the environmental field is based in the fact that many inorganic pollutants are associated by sorption processes with magnetic particles such as iron oxides, and so it can be used as a proxy for detecting anthropogenic pollution in solid matrices including soils and composts (Knab et al. 2001; Wang and Qin 2005; Spiteri et al. 2005; Yoshida et al. 2003). In a previous work (Paradelo et al. 2009), we found significant positive correlations between magnetic susceptibility and trace element concentrations in composts from different origins, and we demonstrated their relationship with ferric particles when the application of a magnet reduced simultaneously the magnetic susceptibility and trace element content. The objective of this work is to further explore this link by studying the distribution of trace element concentrations and magnetic susceptibility in the different size fractions of six composts. This knowledge could lead to the proposal of new measures for trace element correction during compost production.

KEY WORDS
Composting, soil pollution, magnetic methods

PALABRAS CLAVE
Compostaje, contaminación, métodos magnéticos

PALAVRAS-CHAVE
Compostagem, contaminação, métodos magnéticos

2. Material and Methods

The composition of five municipal solid waste composts and a manure vermicompost, most of which was used for our previous study (Paradelo et al. 2009), was investigated. These were the following: MSWC1 is a compost obtained by anaerobic fermentation of the biodegradable fraction of municipal solid waste (MSW) separated before collection, followed by an aerobic composting step to stabilize the incompletely digested residue. MSWC2 and MSWC3 are aerobic MSW composts obtained from the source-separated biodegradable fraction of MSW; all MSW composts were provided by industrial composting facilities located in A Coruña (Spain). MSGW is a commercial compost obtained from the source-separated biodegradable fraction of MSW mixed with green waste, and MGSS is compost from municipal garden trimmings mixed with sewage sludge; they both were supplied by an industrial composting facility located in Catalunya (Spain). MV is a mixed manure vermicompost supplied by a local producer in Galicia (Spain), and it was included in the set for comparison purposes. For the analysis of the composts, the Spanish version of the European methods for the characterization of soil amendments and substrates (AENOR 2001a, 2001b, 2001c) was followed. The general properties of the composts are shown in Table 1. All the composts were alkaline (pH values 7.3-9.2) and presented similar TOC contents (217-298 g kg^{-1}), whereas salinity was the highest for the three composts produced from unblended MSW (MSWC1-MSWC3).

For the size distribution study, four size fractions were separated after sieving 400 g of air-dried compost through the following meshes: 0.5, 2, and 5 mm. Each fraction was weighed, ground in an agate mortar (< 500 µm), and analysed for total Fe, Cu, Zn, Pb, Cr and Ni after wet digestion with aqua regia (AENOR 2002). The specific mass magnetic susceptibility of the fractions was measured using a magnetic susceptibility meter MS2 linked to a MS2B dual frequency sensor (Bartington Instruments Ltd.); the measures were performed at low frequency.

Table 1. Properties of the composts. EC: electric conductivity; OC: total organic carbon

	MSWC1	MSWC2	MSWC3	MSGW	MGSS	MV
pH	8.4	8.2	8.7	9.2	7.3	7.9
EC (dS m^{-1})	2.3	2.4	5.1	1.2	1.4	0.7
OC (g kg^{-1})	280	230	220	248	298	217
C/N	17	15	12	14	15	21
Fe (g kg^{-1})	16.1	24.4	15.0	14.4	24.4	18.6
Mn (mg kg^{-1})	302	455	223	322	406	624
Cu (mg kg^{-1})	325	829	356	52	688	144
Zn (mg kg^{-1})	608	1149	646	200	896	689
Pb (mg kg^{-1})	188	223	200	62	180	33
Cr (mg kg^{-1})	80	77	42	17	68	23
Ni (mg kg^{-1})	57	75	47	25	71	27

3. Results

The trace element distributions among compost size fractions (Table 2) were not homogeneous, as already observed in several works (Veeken and Hamelers 2002; Smith 2009). The highest concentrations of Fe appeared in the finer fractions (< 2 mm) for MSWC1, MSWC2, MSWC3 and MGSS, whereas MV and MSGW had the highest concentrations in the > 5 mm fraction. Copper concentrations increased in the finer fractions in all the composts except MSGW. All composts showed a consistent trend of increasing Zn concentration with decreasing particle size. For Pb, in general the fractions under 2 mm were richer than the fractions over 2 mm, with the exception of the compost MV, for which no differences existed. The distribution for Cr was similar to that of Fe, whereas Ni was overall evenly distributed in the different size fractions for all the composts.

Table 2. Trace element concentrations in composts' size fractions

MSWC1	> 5 mm[a]	2-5 mm	0.5-2 mm	< 0.5 mm
Fe (g kg^{-1})	-	11.7	18.2	22.2
Cu (mg kg^{-1})	-	657	683	758
Zn (mg kg^{-1})	-	731	907	969
Pb (mg kg^{-1})	-	377	489	588
Cr (mg kg^{-1})	-	31	46	56
Ni (mg kg^{-1})	-	56	67	76
MSWC2	> 5 mm	2-5 mm	0.5-2 mm	< 0.5 mm
Fe (g kg^{-1})	12.6	14.4	21.9	23.1
Cu (mg kg^{-1})	450	584	624	620
Zn (mg kg^{-1})	569	703	864	914
Pb (mg kg^{-1})	232	252	351	325
Cr (mg kg^{-1})	43	50	54	85
Ni (mg kg^{-1})	52	57	64	76
MSWC3	> 5 mm	2-5 mm	0.5-2 mm	< 0.5 mm
Fe (g kg^{-1})	6.3	7.3	10.2	12.3
Cu (mg kg^{-1})	175	205	243	265
Zn (mg kg^{-1})	316	374	462	468
Pb (mg kg^{-1})	103	109	141	153
Cr (mg kg^{-1})	24	20	21	28
Ni (mg kg^{-1})	23	24	33	34
MSGW	> 5 mm	2-5 mm	0.5-2 mm	< 0.5 mm
Fe (g kg^{-1})	20.7	9.0	13.1	13.7
Cu (mg kg^{-1})	49	45	46	52
Zn (mg kg^{-1})	110	129	156	179
Pb (mg kg^{-1})	74	63	73	97
Cr (mg kg^{-1})	56	13	12	18
Ni (mg kg^{-1})	30	18	19	20

MGSS	> 5 mm	2-5 mm	0.5-2 mm	< 0.5 mm
Fe (g kg^{-1})	4.2	5.7	8.7	12.0
Cu (mg kg^{-1})	21	42	52	56
Zn (mg kg^{-1})	87	135	172	187
Pb (mg kg^{-1})	50	55	83	98
Cr (mg kg^{-1})	10	13	12	21
Ni (mg kg^{-1})	10	14	12	17
MV	> 5 mm	2-5 mm	0.5-2 mm	< 0.5 mm
Fe (g kg^{-1})	21.1	16.8	15.0	17.3
Cu (mg kg^{-1})	60	118	134	143
Zn (mg kg^{-1})	243	523	623	645
Pb (mg kg^{-1})	40	30	38	30
Cr (mg kg^{-1})	25	24	19	24
Ni (mg kg^{-1})	26	22	24	26

[a] the amount of this fraction in MSWC1 was not sufficient for the determinations.

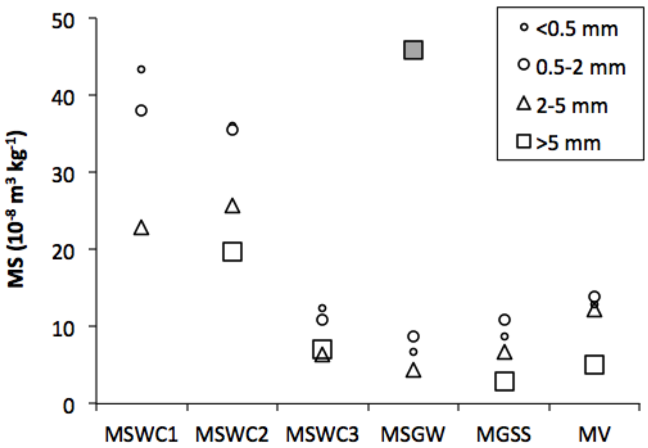

Figure 1. Magnetic susceptibility (MS) of the composts' size fractions.

In general, magnetic susceptibility decreased with increasing particle size, as shown in Figure 1. This trend was very clear for the MSW composts, for which the highest magnetic susceptibility values were found in the < 0.5-mm fraction, followed by the 0.5-2-mm fraction, and then the 2-5 and 5-mm fractions. The trend was less clear in the composts MGSS and MSGW, which include green waste in their composition, although the size fractions under 2 mm still presented higher magnetic susceptibility values than the coarser fractions. It must be noted that there is a marked enrichment in the 5-mm fraction of the compost MGSS, probably due to the unexpected presence of an iron particle in the sample, which is confirmed by the high Fe, Ni and Cr contents of this fraction. Finally, no differences in magnetic susceptibility between size fractions were observed in the manure compost. These results suggest that the association of trace elements and magnetic susceptibility is a characteristic feature of municipal solid waste composts.

Significant positive correlations were found between magnetic susceptibility and Fe (R^2=0.50**, p<0.01, not shown in the Figure), and total trace element concentrations (Figure 2) for Cu (MS=3.9+0.044•[Cu]; R^2=0.88***, p<0.001), Zn (MS=-2.1+0.038•[Zn]; R^2=0.84***, p<0.001), Pb (MS=3.9+0.071•[Pb]; R^2=0.85***, p<0.001), Cr (MS=-0.9+0.57•[Cr]; R^2=0.77***, p<0.001) and Ni (MS=-2.8+0.54•[Ni]; R^2=0.90***, p<0.001). These relationships were clearer for those samples with the highest trace element contents; this is at concentrations above 200 mg kg^{-1} for Cu, Pb and Zn, and above 30 mg kg^{-1} for Cr and Ni.

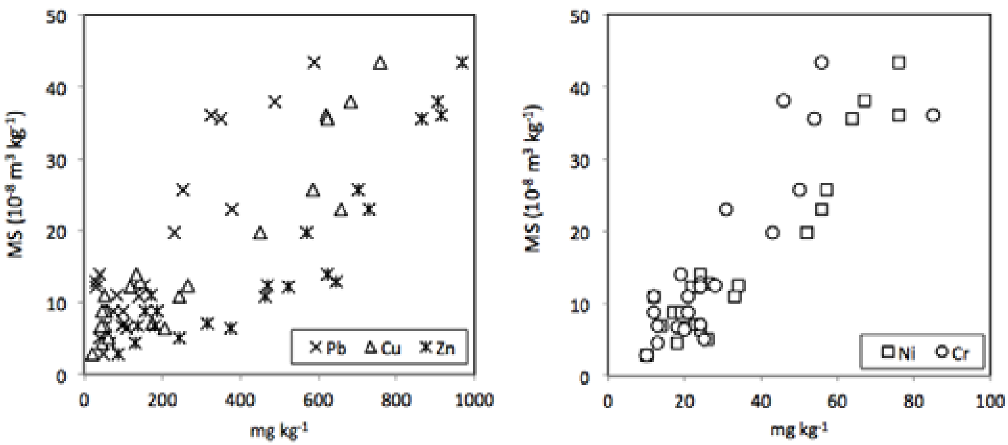

Figure 2. Relationships between trace element contents and magnetic susceptibility (MS) in the compost size fractions.

The correlation between trace element concentration and magnetic susceptibility does not necessarily mean that all trace elements are exclusively associated with ferric particles in the final composts. This may be true for Cr and Ni, which are present in Fe alloys, as confirmed by the low solubility of these elements in the composts (Paradelo et al. 2011). For the other elements, the correlations suggest that metallic particles are their main origin and source. These elements enter the compost pile at the beginning of composting, associated with ferric particles and/or oxides, and afterwards some of them (Cu, Pb, Zn) can migrate due to changes in the physicochemical conditions during the composting process, thereby changing their distribution within the compost fractions (in particular in the organic fraction). In consequence, the fraction associated with metallic particles in the finished composts could be lower than at the beginning of the process, even though high correlations with magnetic susceptibility remain, showing their common origin. The migration of elements from the original source points out the difficulties existing for reducing trace element concentrations in compost by mechanical procedures, particularly when they are associated with fine compost particles, and emphasizes the importance of an adequate separate collection in order to minimise metal concentration in MSW composts. For practical purposes, the association of trace elements with metallic particles opens the door to a potential utilization of magnetic separators in combination with mechanical screening as a method for reducing metal contamination in compost at the production stage.

4. Conclusion and Perspectives

Magnetic susceptibility and trace element concentrations decreased with increasing particle size in six composts produced from different feedstocks, mainly urban wastes. The significant correlations found between trace element contents and magnetic susceptibility demonstrate the link between ferric particles and trace element contamination in compost, and suggest that it is a characteristic of municipal solid waste composts. The association between magnetic particles and trace elements opens the possibility of using magnetic separators to reduce metal contamination in composts.

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