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Use of municipal solid waste compost to reclaim limestone quarries mine spoils as soil amendments: Effects on Cd and Ni

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ABSTRACT

The use of composted municipal solid waste (MSWC) in restoration of quarries in Mediterranean environments was checked in order to evaluate the mobility of Cd and Ni in a technosol. The experiment was done simulating a topsoil (0–30 cm) formed by limestone outcrops and the addition in the 0–15 cm of MSWC. The availability for plants of these heavy metals in the soil and their presence in the leachates were checked. The availability for plants was low in these conditions for both. Cd and Ni presented a different behavior where the main different was that Ni was easily lixiviated and its mobility seems to be more important than Cd in the calcareous soil profile. In general, the retention of Cd in this limestone material seemed to be more important. The environmental risk due to the presence of both heavy metals in the compost used in this technosol was very low even though in the beginning of the experiment the availability for plants and the presence in the leachates were very reduced in these conditions.

1. Introduction

The use of compost from municipal solid waste (MSW) in degraded soils may be an important means of organic matter recovery (Gigliotti et al., 1996). Compost amendment may improve the physical, chemical and biological properties of impoverished soils by supplying organic matter (Iovieno et al., 2009; Jordão et al., 2006; Karaca, 2004) and can be used in soil restoration and in quarries reclamation. In addition, composting is a good alternative to landfilling and incineration, thereby reducing CO_2 and atmospheric pollutant emissions (Baldantoni et al., 2010).

However the use of municipal solid waste compost (MSWC) may have some negative effects on the environment, such as an increase in soil content of potentially toxic elements, like heavy metals and nitrates (Jordão et al., 2003). These heavy metals may be retained by soil components in the soil horizons near the surface, or may either precipitate or co-precipitate as sulfides, carbonates, oxides or hydroxides with Fe, Mn and Ca (Dowdy and Volk, 1983). In arid zones, carbonate effectively immobilizes heavy metals by providing an adsorbing or nucleating surface, and by buffering pH at values at which metals hydrolyze and precipitate. The mobility of trace metals reflects their capacity to pass through one soil compartment into another where the element is bound less energetically, the ultimate compartment being the soil solution which determines their bioavailability (Davis et al., 1988). Cd and Ni are considered pollutants for plants causing nutritional disorders and affecting plant development (Moral et al., 1994; Navarro-Pedreño et al., 1997) as well as for terrestrial animals (EPA, 2005). The application of organic wastes to the soil includes the possible detrimental effects on water quality from leaching, erosion, or runoff losses.

From the ecological point of view, the restoration of extensive areas degraded by mining activities and the use of their own waste materials are required (Jordan et al., 2006; Jordán et al., 1998; Ram et al., 2006; Tedesco et al., 1999). These materials do not possess the necessary fertility to ensure a successful process of restoration. Therefore, it requires the addition of organic amendments to achieve efficient substrate (Jordán et al., 2008). Technosols are one of the latest additions to the World Reference Base for Soil Resources (IUSS Working Group WRB, 2007). This new reference soil group contains a large range of artifacts and materials of natural and anthropic origin. They include a variety of refuse-based soil-like mine spoils, landfills, cinders, or sludge, whose properties and pedogenesis are dominated by their technical origin (Novo et al., 2013).

An adequate technosol selection, based on its nature and intrinsic properties, can constitute a valuable and cost-effective solution for soil remediation and waste management (Novo et al., 2013) and may be an adequate resource for mining restoration. Sewage sludge application in restoration has demonstrated its efficiency in previous studies (Albiach et al., 2001; Jordán et al., 2008; Pond et al., 2005) although the use of MSW may produce similar effects. However, the use of MSWC has to preserve the conservation of the environment with less risk of contamination of surface water and groundwater.

For those reasons, the present work has the objective to evaluate the presence, availability and leaching of two dangerous heavy

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metals (Cd and Ni) for ecological systems in technosols prepared from limestone outcrops using municipal solid waste compost (MSWC) as amendment.

2. Materials and methods

In order to study the mobility of Cd and Ni through the topsoil profile, an experiment was conducted that attempts to reproduce the behavior of different heavy metals (Legret et al., 1988). The experiment was carried out under controlled conditions inside a greenhouse (20 °C and 50% relative humidity). 36 columns with a height of 30 cm, from PVC pipe and an internal diameter of 10.5 cm, were prepared. Each column was cut into two sections: 0–15 and 15–30 cm. In the case of limestone quarries, it may be possible to add higher amounts of waste without causing environmental problems or food pollution. This type of application must be compatible with environmental security by avoiding displacement of dissolved pollutants to drainage. A mineral residue from limestone outcrops was amended with 30 and 90 t of MSWC/ha. The soils in the columns were irrigated with 100 mm (1000 m^3/ha) of water every two weeks (Navarro-Pedreño et al., 2004). Four samples of soil were taken during the experiment with an interval of four weeks between each. Three columns were chosen per treatment and control treatment in each sampling period (9 columns), separated into the different layers. At the same time, the leachates that accumulated from each column were also collected. Cadmium (Cd) and nickel (Ni) were analyzed in leachates collected at the bottom of the columns (Navarro-Pedreño et al., 2004). Available metals for plants were determined by diethylene triamine pentaacetic acid (DTPA) extraction following the Lindsay and Norvell method (1978).

Cd and Ni in DTPA extracts were determined by inductively coupled plasma mass spectroscopy (ICP) and atomic absorption spectrophotometry (AAS) with a graphite furnace (GF), depending on the amount of the heavy metal in the samples analyzed. The Cd and Ni in leachates were determined by atomic absorption spectrophotometry (AAS) with a graphite furnace (GF) (Knudsen et al., 1982; Xiu et al., 1991).

Statistical analysis (mean, confidence interval (C.I.) based in the Student's t-test at 95% and ANOVA F test) was used to determine the statistical significance of the treatments and differences between means.

3. Results

The main characteristics of the calcareous mineral residue used in these columns experiment are shown in Table 1 and the composition of the MSW compost used is in Table 2. The main characteristics of the mineral residue, more than it is constituted by limestone, are the sandy texture and its very low organic matter content.

Table 1
Characteristics of limestone outcrops' residue used.

Variables	Data[a]
Sand (20<∅<2000 μm)	70.1%
Silt (2<∅<20 μm)	20.6%
Clay (<2 μm)	9.3%
pH in water (1:2.5)	8.84
Electrical conductivity (E.C.) (1:5)	275 dS/m
Oxidizable organic matter (O.M.)	1.8 g/kg
Phosphorus (P)[b]	1.75 mg/kg
Potassium (K)[c]	25.1 mg/kg
Sodium (Na)[c]	75.8 mg/kg
Calcium (Ca)[c]	2.18 g/kg
Magnesium (Mg)[c]	27.3 mg/kg
Iron (Fe)[b]	1.19 mg/kg
Manganese (Mn)[b]	2.60 mg/kg
Copper (Cu)[b]	0.13 mg/kg
Zinc (Zn)[b]	0.46 mg/kg

[a] Amounts in dry matter basis.
[b] Available (P: Burriel–Hernando procedure; metals: Lindsay–Norvell procedure).
[c] Exchangeable (ammonium acetate extraction).

Table 2
Composition of MSW compost.

Variables	Amounts[a]
pH in water (1:2.5)	6.9
Electrical conductivity (E.C.) (1:5)	705 dS/m
Oxidizable organic matter (O.M.)	416 g/kg
Phosphorus (P)	4610 mg/kg
Potassium (K)	2100 mg/kg
Sodium (Na)	1010 mg/kg
Calcium (Ca)	60 mg/kg
Magnesium (Mg)	45 mg/kg
Iron (Fe)	9800 mg/kg
Manganese (Mn)	177 mg/kg
Copper (Cu)	89 mg/kg
Zinc (Zn)	186 mg/kg
Nickel (Ni)	18.8 mg/kg
Cadmium (Cd)	0.8 mg/kg

[a] Amounts on a dry matter basis.

In these technosols (upper part of the column), composed of limestone outcrops and the addition of MSWC in two amounts, the available Ni extracted with DTPA (Table 3) showed significant variations due to the treatments applied in the top of the column (control treatments MSW0, MSW3 and MSW9) but between 15 and 30 cm, and there were no significant differences between treatments MSW3 and MSW9. The most important amount of Ni extracted was detected after 8 weeks and after that, available Ni content decreases along the time of the experiment.

There is a significant increase in available Cd after MSWC application in the top level (Table 4). In the columns treated with MSWC there is a decrease in extractable cadmium with depth (between 0 and 15 and 15 and 30 cm).

Tables 5 and 6 show the results of Ni and Cd respectively in the leachates. There are significant differences in Ni concentration in leachates from columns treated with MSWC and not treated (MSW0). It can be observed that a high mobility of this element diminishes along time. The highest amount of Ni in waters was detected at the beginning of the experiment.

Cd in leachates only presents significant differences in its concentration due to the MSW9 treatment. No significant differences were found in the presence of Cd in leachates except in the first sampling period. This behavior was different than that showed by Ni.

4. Discussion

The availability of Ni and Cd was favored by the presence of the compost although the substrate was limestone outcrops. However, this availability was too low to be of importance in quarries reclamation and natural recovery of vegetation in Mediterranean environments would not be affected by this type of technosol. About soil heavy metal content, data varied according to the metal and the applied fertilizer. Cherif et al. (2009) found significant increases in soil heavy metal

Table 3
Available Ni content in soil (μg/kg).

Depth	Treat.	4 weeks		8 weeks		12 weeks		16 weeks	
		Mean	CI	Mean	CI	Mean	CI	Mean	CI
0–15	MSW0	24.7a	0.9	35.2a	1.3	7.8a	1.8	9.3a	0.4
	MSW3	526.6b	29.8	634.5b	28.9	450.1b	9.9	546.3b	24.4
	MSW9	827.0c	50.6	1016.6c	16.4	721.2c	37.8	763.7c	31.3
15–30	MSW0	30.7a	1.3	35.8a	0.9	8.1a	1.2	6.5a	0.7
	MSW3	268.5b	20.2	221.6b	24.2	160.9b	12.1	161.6b	17.9
	MSW9	224.8b	28.0	169.5c	6.4	142.5b	7.9	141.0b	4.9

Values with a different letter are significantly different ($P < 0.05$).
CI = Confidence Interval.