

# CATION RELEASE DYNAMICS IN SOILS AMENDED WITH MUNICIPAL SOLID WASTE COMPOST

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## 1 INTRODUCTION

The use of municipal solid waste (MSW) compost as a soil amendment is a feasible option for increasing the SOM contents, as well as a sustainable waste management strategy. In addition to increasing soil organic carbon, a fertilizing effect has often been observed after application of MSW compost to agricultural soil (Giusquiani et al. 1988; Hargreaves et al. 2008). Given that part of the nutrients are present in organic forms, the gradual release of plant nutrients after mineralization is another of the expected advantages of the use of MSW compost as an agricultural soil amendment (Frossard et al. 2002; He et al. 2005). Although the effect of compost on the concentration, availability and dynamics of soil N and P has been widely studied, studies evaluating the effect on Ca, Mg, and K are still scarce. Most existing literature does not report the evolution of those nutrients throughout the short period following compost addition. However, this point deserves more attention because, if the mineralization process is responsible for the gradual release of nutrients from compost, their concentrations should increase after compost addition. However, when field experiments in cropped soils are conducted, it is difficult to establish the evolution of the added nutrients, due to the effects of plant uptake, leaching, modifications in the plant roots environment and in the soil nutrient pools, etc.

In this work two laboratory experiments were performed with MSW compost-amended soils, in order to describe the evolution of available Ca, Mg and K in closed systems, free from potential disturbance due to leaching or nutrient uptake by plants. The main objective was to determine the extent of nutrient release from MSW compost, relating this effect to the initial composition of compost, on the one hand, and microbial nutrient immobilization, on the other hand.

## 2 MATERIALS AND METHODS

### 2.1 Soils and composts

Composite samples from the top 10 cm of Ap horizons of agricultural soils developed on granite (Gr), schist (S) and gabbro (G) were collected. The three soils were located near each other at 43° N and 8° W, near to Santiago de Compostela (A Coruña, Spain). Once in the laboratory, the soils were sieved through a 4-mm mesh, and stored under 4°C until utilization in the incubation experiments. The soils on schist and granite had a sandy-loam texture, while the soil on gabbro was loamy; all the soils were acidic, with pH values between 5.1 and 5.8. The soil developed on gabbro showed the highest C concentration, more than twice the C of the other two soils.

Two municipal solid waste (MSW) composts supplied by industrial waste treatment facilities in Galicia were used. MSW1 is compost obtained by anaerobic fermentation of the biodegradable fraction of MSW, separated before collection, followed by an aerobic composting step, to stabilize the incompletely digested residue. MSW2 is an aerobic MSW compost obtained from source separated biodegradable fraction of MSW. For the analysis of the general properties of the composts, the Spanish version of the European CEN (European Committee for Standardization) methods for the characterization of soil amendments and substrates was followed. Briefly, pH and electrical conductivity (EC) were determined in aqueous extracts (substrate/extractant ratio: 1/5 v/v) of fresh samples. Total organic matter (OM) was determined by weight loss on ignition of dried ground samples at 450°C, and total organic C (TOC) calculated multiplying OM by a factor of 0.58. Total N was measured by Kjeldahl digestion and steam distillation. Total nutrients were extracted after digestion in a sandbox with concentrated HCl and HNO<sub>3</sub> (3:1 ratio), water-soluble nutrients were extracted with distilled water, and available nutrients were

extracted with  $\text{CaCl}_2$ -DTPA solution. The exchangeable cations were determined in 1N  $\text{NH}_4\text{Cl}$  extracts following the method of Gillman et al. (1983). The elemental concentrations in all extracts were measured by flame atomic absorption/emission spectroscopy (Varian 220FS). Total carbonates were measured in a Bernard calcimeter according to the method described by Guitián and Carballas (1976).

## 2.2 Incubation Experiments

Two incubation experiments were performed with fresh soil samples collected at two different times of the year, in order to study the effect of different microbial activity on nutrient dynamics. The first incubation was run with soils collected in March 2006, when microbial activity is expected to be at its minimum, and the second one was conducted with soils collected in May 2006, when the activity of microorganisms is supposed to be at its maximum in temperate soils in the Northern hemisphere (Leirós et al. 1999). Each soil was incubated alone and mixed with each compost at 2.5% dry weight (roughly equivalent to  $60 \text{ t ha}^{-1}$ , a high rate which is closer to those of restoration studies than to agricultural rates).

Prior to the first incubation, which lasted three months, the moisture of the soils was adjusted approximately to 70% of their field capacity. For the incubation, 25-gram samples of the soil or mixtures of soil and compost were placed in 100-mL incubation vessels, three replicates per treatment. The jars were hermetically sealed and incubated at 25°C for ninety days. The moisture of the samples was maintained constant during the experiment by replacing the weight losses with distilled water. Available Ca, Mg and K were extracted in 1M  $\text{NH}_4\text{AcO}$  at pH 7, filtered, and the extracts analyzed by flame atomic absorption/emission spectroscopy (Varian FS220).

The second incubation was similar to the first one but lasted five months. Available Ca, Mg, K were determined as explained above. After the incubation, the samples were fumigated with chloroform, and the available nutrients released (Ca, Mg, K) were also analyzed in the fumigated soils to determine the differences between the fumigated and non-fumigated soils (nutrient flux).

## 3 RESULTS AND DISCUSSION

The main properties of the composts are shown in Table 1. MSW1 had higher contents of total Mg and K compared to MSW2, whereas MSW2 was the richest in Ca and P. Despite the differences existing in the total concentrations, the available (soluble in  $\text{CaCl}_2$ -DTPA) and water-soluble fractions were similar for both composts. Both composts had significant amounts of essential plant nutrients, with Ca as the most abundant nutrient, as it is typical for urban waste composts (He et al. 2005; Hargreaves et al. 2008). However, total concentrations are not indicative of the short-term nutrient availability to crops. In fact, the nutrients present in compost may exist in different forms, both organic and inorganic, with different solubility. The different extractions performed on the composts showed that K was almost completely available, as it was mainly present as an exchangeable cation or in water-soluble forms. Calcium and Mg were less water-soluble than K, and also had a lower fraction of their total concentrations in exchange sites. For Ca, this is explained by the presence of significant quantities of carbonates in both composts, which are not dissolved in water or in ammonium chloride.

TABLE 1 Composts properties. Numbers in brackets represent percentage of the total concentrations.

	MSW1	MSW2		MSW1	MSW2
pH	8.4	8.2	<b>Water-soluble nutrients (<math>\text{mg kg}^{-1}</math>)</b>		
EC ( $\text{dS m}^{-1}$ )	2.3	2.4	<b>Ca</b>	605 (0.8)	542 (0.7)
OM ( $\text{g kg}^{-1}$ )	487	397	<b>Mg</b>	131 (1.7)	100 (2.0)
Total C ( $\text{g kg}^{-1}$ )	283	230	<b>K</b>	1507 (25)	1594 (33)
Total N ( $\text{g kg}^{-1}$ )	17	15	<b><math>\text{CaCl}_2</math>-DTPA-soluble nutrients (<math>\text{mg kg}^{-1}</math>)</b>		
C/N	17	15	<b>Mg</b>	1072 (14)	876 (17)
Carbonates ( $\text{g kg}^{-1}$ )	163	169	<b>K</b>	3816 (63)	3315 (70)
<b>Total nutrients (<math>\text{mg kg}^{-1}</math>)</b>			<b>Exchangeable nutrients (<math>\text{mg kg}^{-1}</math>)</b>		
<b>Ca</b>	72464	80412	<b>Ca</b>	6940 (9.6)	4860 (6.0)
<b>Mg</b>	7783	5054	<b>Mg</b>	778 (10)	583 (12)
<b>K</b>	6082	4763	<b>K</b>	4575 (75)	5044 (106)

After addition to the soil, both composts significantly increased the K, Ca and Mg concentrations with respect to the control soils in the two incubations, in general without differences in their respective effects (Tables 2-3). Ca was the element whose available content was most increased in the soils amended with the composts, from

values about 700 mg kg<sup>-1</sup> up to values around 1000-1500 mg kg<sup>-1</sup> (i.e. a two-fold increase of the non-amended soil concentration). Bearing in mind that the composts were added at a rate of only 2.5% of the total soil weight, both composts had a notable role as an available Ca source, which could not be immediately predicted from their water-soluble concentrations (Table 1). This effect was probably due to the dissolution of compost carbonates because of the acidic pH of the three soils. Similarly, the composts increased the available K concentrations by approximately 150-200 mg kg<sup>-1</sup> (i.e. a 100% increment for the granite and gabbro soils, and a 50% increment for the schist soil). The available Mg was also increased in the soils after the amendment, although to a lesser extent than Ca and K (about 20-30 mg kg<sup>-1</sup>, which represents approximately a 50% increment with respect to the soils concentrations).

TABLE 2 Available nutrient concentrations (mg kg<sup>-1</sup>) during the first incubation. Different letters within the same column for each element mean statistically significant differences at p<0.05 in the Duncan's test.

	Day	S	S+MSW1	S+MSW2	G	G+MSW1	G+MSW2	Gr	Gr+MSW1	Gr+MSW2
Ca	0	750bc	1442a	1663cd	718a	1585a	1343a	517ab	1131a	1193a
	15	754bc	1579ab	1457ab	765b	1549a	1474ab	544ab	1422a	1387b
	30	700a	1464a	1566abc	712a	1644a	1690bc	494a	1231a	1239ab
	45	707ab	1585ab	1436a	708a	1509a	1631bc	512ab	1479a	1272ab
	60	769c	1657ab	1624bc	773b	1707a	1824c	569b	1284a	1339ab
	90	877d	1842b	1827d	874c	2018b	2125d	661c	1630a	1763c
	Day	S	S+MSW1	S+MSW2	G	G+MSW1	G+MSW2	Gr	Gr+MSW1	Gr+MSW2
Mg	0	50ab	77a	77bc	61c	94ab	86a	34a	63ab	61a
	15	51b	78a	75ab	58b	89a	88ab	35ab	64ab	66ab
	30	50ab	79a	78bc	57b	89a	91ab	35ab	61a	64ab
	45	46a	77a	74a	54a	89a	93ab	34a	68b	65ab
	60	51b	83a	79c	59bc	97b	93ab	37b	65ab	66b
	90	49ab	79a	78bc	57b	95ab	95b	36ab	66ab	73c
	Day	S	S+MSW1	S+MSW2	G	G+MSW1	G+MSW2	Gr	Gr+MSW1	Gr+MSW2
K	0	400b	527a	534ab	162b	313cd	322bc	145bc	279bcd	300a
	15	397b	538ab	541ab	155b	282ab	308ab	143b	268ab	300a
	30	420bc	565ab	618c	150b	299bc	324bc	124a	273bc	296a
	45	350a	498a	499a	123a	267a	290a	120a	253a	275a
	60	461d	599b	561abc	159b	320cd	348c	153c	292d	333b
	90	447cd	602b	573bc	153b	332d	315ab	150bc	288cd	341b

TABLE 3 Available nutrient concentrations (mg kg<sup>-1</sup>) during the second incubation. Different letters within the same column for each element mean statistically significant differences at p<0.05 in the Duncan's test.

	Day	S	S+MSW1	S+MSW2	G	G+MSW1	G+MSW2	Gr	Gr+MSW1	Gr+MSW2
Ca	0	953a	1652a	1443a	1055a	1759a	1684a	561a	1171a	956a
	30	1112c	1758a	1777bc	1200c	1985ab	2020b	564a	1257ab	1258bc
	60	1007ab	1738a	1630ab	1090ab	2011ab	1978b	555a	1333ab	1170ab
	90	1027abc	1822a	1742bc	1144bc	2147b	1978b	556a	1218a	1393bc
	120	1055bc	1825a	1935c	1286d	2213b	2273c	620a	1400b	1472c
	150	994ab	1730a	1708abc	1193c	2018ab	1883b	620a	1332ab	1373bc
	Day	S	S+MSW1	S+MSW2	G	G+MSW1	G+MSW2	Gr	Gr+MSW1	Gr+MSW2
Mg	0	63a	98c	96cd	113b	140ab	141b	42a	68a	59a
	30	63a	90ab	96bcd	107a	146b	149bc	39a	65a	65a
	60	64a	92bc	93bc	106a	150b	157c	39a	67a	64a
	90	65a	98c	100d	139c	167c	174d	41a	66a	66a
	120	59a	86ab	91b	117b	142b	151bc	37a	62a	63a
	150	59a	83a	85a	108a	127a	128a	38a	63a	64a
	Day	S	S+MSW1	S+MSW2	G	G+MSW1	G+MSW2	Gr	Gr+MSW1	Gr+MSW2
K	0	457a	645c	658b	198a	432a	444b	172b	318a	317a
	30	462a	584b	574a	194a	402a	373a	120a	266a	315a
	60	485a	603b	629ab	221ab	444a	416b	173b	320a	310a
	90	440a	605b	622ab	222ab	437a	429b	187b	310a	303a
	120	487a	586b	612ab	238b	422a	430b	173b	301a	304a

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150    437a    549a    586a    220ab    397a    368a    164b    287a    280a

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Over the incubation time, the nutrient concentrations were rarely increased with respect to those observed immediately after the amendment was applied (day 0). Four main mechanisms could explain this result: (1) the main part of the compost nutrients was already in available forms; (2) a significant fraction of the nutrients added is immediately taken by the soil microbial biomass, thus reducing the available pool; (3) a major fraction of the total elements in the compost existed in insoluble inorganic forms that were not affected by organic matter mineralization; and (4) a major fraction of the total elements in the compost existed in organic forms which were not mineralized in the course of the experiment. It has to be noted that mineralization of the compost was very low during the incubation time (under 5% of TOC for all treatments in both incubations), one more reason to discard this mechanism as a source of nutrients, at least in the short-term.

The first hypothesis seems to be the most plausible to explain the behaviour of K. The availability of this element in the composts was very high, so all compost K will be released to the soil in available forms immediately after compost addition. Thus, further modifications due to the mineralization of compost or other soil processes were not expected. The first hypothesis could also explain the behaviour of Ca, although in this case, the quick dissolution of carbonates after addition to the acid soils would be the cause of its high availability.

Regarding the second hypothesis, although microbial biomass has been demonstrated to retain variable concentrations of nutrients in soil (Jenkinson and Ladd 1981), significant increments of available Ca, Mg or K concentrations were not detected in the fumigated soils (data not shown). Therefore, the microbial biomass did not contain a significant fraction of K, Ca or Mg, so microbial immobilization must be discarded for these elements.

To explain the behaviour of Mg, the third hypothesis must be considered, as it seems that Mg is present in inorganic forms of low solubility. Co-precipitation in insoluble forms or inclusion into the crystalline lattice of mineral components could be the main mechanisms to explain the low Mg availability, although its presence in highly stable complexes with organic matter cannot be excluded.

#### 4 CONCLUSIONS

The addition of MSW compost to schist, granite and gabbro soils produced immediate increments in the soil available Ca, Mg, and K. The nutrient supply of the composts for these elements followed the sequence Ca > K > Mg, a result that cannot be predicted from the results of the chemical extractions used for assessing the availability of nutrients in compost. The incubation of compost-amended soils in the laboratory, in general, did not produce further changes after the initial increases in the concentrations of these elements. Thus, it seems that the fertilizing effect of compost in the short or mid term relies mostly on its soluble and carbonate-associated nutrient content, and less on the cation release upon organic matter mineralization. In conclusion, to adequately predict the availability of the compost nutrients in the soil-plant system and the fertilizing effect of compost, it is necessary to know the major forms of each element in compost.

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