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Carbon mineralization in an arid soil amended with thermally-dried and composted sewage sludges

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Abstract

Soil amendment with sewage sludge (SS) from municipal wastewater treatment plants is nowadays a common practice for both increasing soil organic matter and nutrient contents and waste disposal. However, the application of organic amendments that are not sufficiently mature and stable may adversely affect soil properties. Composting and thermal drying are treatments designed to minimize these possible deleterious effects and to facilitate the use of SS as a soil organic amendment. In this work, an arid soil either unamended or amended with composted sewage sludge (CSS) or thermally-dried sewage sludge (TSS) was moistened to an equivalent of 60% soil water holding capacity and incubated for 60 days at 28 °C. The C–CO_2 emission from the samples was periodically measured in order to study C mineralization kinetics and evaluate the use of these SS as organic amendments. In all cases, C mineralization decreased after the first day. TSS-amended soil showed significantly higher mineralization rates than unamended and CSS-amended soils during the incubation period. The data of cumulative C–CO_2 released from unamended and SS-amended soils were fitted to six different kinetic models. A two simultaneous reactions model, which considers two organic pools with different degree of biodegradability, was found to be the most appropriate to describe C mineralization kinetics for all the soils. The parameters derived from this model suggested a larger presence of easily biodegradable compounds in TSS-amended soil than in CSS-amended soil, which in turn presented a C mineralization pattern very similar to that of the unamended soil. Furthermore, net mineralization coefficient and complementary mineralization coefficient were calculated from C mineralization data. The largest losses of C were measured for TSS-amended soil probably due to an extended microbial activity. The results obtained thus indicated that CSS is more efficient for increasing total organic C in arid soils.

Keywords: Sewage sludge; Composting; Thermal drying; Carbon mineralization; Model fitting; Organic amendment

1. Introduction

During the last years the amount of sewage sludge (SS) from urban wastewater treatment plants has increased steadily with consequent environmental and economic problems related to its disposal (Albiach et al., 2001). The high organic matter (OM) content of SS has favoured a growing interest in its use as a soil organic amendment, especially in arid and semi-arid Mediterranean areas. The soil organic matter (SOM) content in these areas is typically low and tends to decrease for different reasons like inappropriate cultivation practices, erosion or climatic conditions (Pascual et al., 1999; Garcia-Gil et al., 2000).

However, before land application, SS should be subjected to appropriate treatments, designed to enhance the stability of OM and to avoid a number of harmful effects on soil properties as well as many health hazards that may result from an inadequate use (Senesi and Brunetti, 1996; Plaza et al., 2003). One common treatment for this purpose is composting, a biological process of aerobic decomposition that degrades labile organic matter to water vapour, CO_2, ammonia, inorganic nutrients and stable organic material containing humic-like substances (Senesi, 1989). Composting allows to obtain an environmentally-safe and agronomically-advantageous soil organic amendment, but has important requirements of time (over three months) and space (for

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the composting piles). An alternative and relatively newer process is the so called “thermal drying” by which SS is treated by intense heating (over 300 °C). Thermal drying inactivates pathogens and volatile chemicals and leads to a sanitized final product in pellets in relatively short time, with low odours and good handling characteristics but without maturation process.

From an environmental and agronomical point of view, a correct management of the SS in agriculture relies mainly on two aspects: efficient increase of the SOM and adequate match of the release of mineral nutrients to crop demand. Therefore, the knowledge of C mineralization dynamics in SS-amended soils is of intrinsic interest. The effects of composted sewage sludge (CSS) on soil properties and C mineralization have been the focus of intensive research, but only a limited number of investigations have dealt with the effects of thermally-dried sewage sludge (TSS), and even fewer studies have been conducted on C mineralization in soils amended with TSS. Thermally-dried sewage sludge is richer in N and soluble organic carbon (e.g., aminoacids and carbohydrates) than CSS, two factors that can stimulate the soil microbial metabolism and consequently the mineralization of C.

Even if carried out over short time periods, the use of laboratory methods involving incubation of soil-waste mixtures under controlled conditions can supply accurate information about C mineralization dynamics. In addition, C mineralization data obtained can be fitted to kinetic models, which allow calculating the fraction of potentially mineralizable C and its mineralization rate and, therefore, the real benefits of applying these organic wastes to soil (Saviozzi et al., 1993; Bernal et al., 1998). The first-order model by Stanford and Smith (1972) is the most widely used, although many other models have been also postulated. These include linear (Levi-Minzi et al., 1990) and non-linear regression expressions (Smith et al., 1980; Talpaz et al., 1981; Boyle and Paul, 1989; Murwira et al., 1990; Campbell et al., 1991), and first-order equations with parameters related to groups of substrates of various degrees of stability (Molina et al., 1980; Jones, 1984; Lindemann and Cardenas, 1984; Murayama et al., 1990). These mathematical descriptions of C release patterns can provide useful indices and allow the testing of hypotheses concerning the involved mechanisms.

The aim of this work was to describe comparatively the dynamic and kinetics of C mineralization in an arid soil amended with either TSS or CSS and in the same soil unamended. These results can be used to evaluate the degree of maturity and stability achieved in both organic amendments and, therefore, their environmental safety and agronomic efficiency.

2. Materials and methods

2.1. Soil and sewage sludge

The CSS used in this work was collected from a mixture of three SS originated from three municipal wastewater treatment plants in Madrid (Spain) metropolitan area, which has been subjected to a windrow composting process for three months. The TSS sample was collected from the wastewater treatment plant SUR in Madrid metropolitan area where the SS is dried in a process that use hot air at temperatures ranging from 380 °C to 450 °C. The soil sample used in this experiment is characterized by a sandy loam texture (sand, 580 g kg^{-1}; silt, 240 g kg^{-1}; clay, 180 g kg^{-1}) and was taken from the arable layer (Ap horizon, 0–20 cm depth) of a Typic Haploxeralf (Soil Survey Staff, 2003), which is located in the experimental farm “La Higueruela” (Toledo, Spain). The main chemical properties of the CSS, TSS and soil are included in Table 1.

2.2. Incubation experiment

Carbon mineralization was studied in an aerobic incubation experiment carried out in a closed system. A hundred grams of air-dried and 2-mm sieved sample of soil homogeneously mixed with CSS or TSS, according to the field rates of 80 Mg ha^{-1} (assuming a soil bulk density of 1.5 g mL^{-1} for the top 20 cm), were placed in 500 mL hermetically sealed flasks. Also 100 g of soil without any amendment were run as control. Water was added to an equivalent of 70% of the soil water holding capacity and flasks were introduced in a thermostated bath at 28 °C for 60 days. There were four replicates for each treatment. The quantity of C–CO_2 released was measured daily over the first eleven days and thereafter at days 13, 15, 17, 20, 23, 26, 29, 34, 39, 44, 48, 54 and 60. For this purpose a forced stream of CO_2-free-air was circulated during 2 h through the flasks and then bubbled into a solution of 0.1 M NaOH, where CO_2 displaced from the flasks was trapped in. Then, excess alkali in this solution was back-titrated with standard 0.2 N HCl after precipitating carbonate with 1.5 M $BaCl_2$ solution (Polo et al., 1983).

2.3. Kinetic models

Six different models have been used in this experiment to describe the C mineralization in the samples studied.

The first model referred herein as zero-order (Seyfried and Rao, 1988) is expressed by the function:

$$C_t = kt + \text{intercept} \quad (1)$$

where C_t is the cumulative organic carbon mineralized (mg C–CO_2 kg^{-1}) at time t (days), k (mg kg^{-1} day^{-1}) is a zero-order

Table 1
Main chemical properties (±standard errors) of soil, composted sewage sludge (CSS) and thermally-dried sewage sludge (TSS) used in the experiment

	Soil	CSS	TSS
pH (H_2O)	5.7±0.1	7.1±0.1	7.0±0.1
Electrical conductivity (*d*S m^{-1})	0.05±0.01	3.90±0.01	1.50±0.02
Total organic carbon (g kg^{-1})	7.2±0.1	181.0±0.2	296.0±0.2
Total extractable carbon (g kg^{-1})	1.4±0.2	53.4±0.2	87.7±0.3
Humic acids carbon (g kg^{-1})	0.7±0.1	21.0±0.3	24.8±0.2
Fulvic acids carbon (g kg^{-1})	0.6±0.1	32.4±0.3	62.9±0.3
C/N	8.0±0.1	7.6±0.2	8.3±0.2
Total N (g kg^{-1})	0.9±0.1	23.9±0.1	35.6±0.1
P (g kg^{-1})	0.09±0.01 [a]	13.90±0.02 [b]	13.43±0.02 [b]
K (g kg^{-1})	0.20±0.01 [a]	5.02±0.07 [b]	4.29±0.05 [b]

[a] Available content.
[b] Total content.