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RELATIONSHIPS BETWEEN CARBON MINERALISATION AND PHYTOTOXICITY OF IMMATURE COMPOST IN SOIL

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ABSTRACT

The organic-C mineralisation process of samples at different stages of the composting process was studied in incubation with soil. In a pot experiment, phytotoxicity of these samples mixed with soil was tested, using ryegrass, in a growth chamber. The composting samples were collected from a mixture of brewing yeast and lemon tree prunings at the following stages of composting: initial mixture (C_I); after 4, 7, 9 and 13 weeks (C_4, C_7, C_9, C_{13}); and at 28 weeks, mature compost (C_M). The composting samples were added at a rate of 2 % (w/w) to an agricultural calcareous soil (clay loam Xerollic Calciorthid). Immature composting samples led to a high rate of CO_2-C production (C_4, C_7, C_9, C_{13}), and reduced plant growth with respect to control soil, although these samples gave adequate values of germination index. Good significant relationships were found between organic-C mineralisation from composting samples and plant growth, which may indicate that CO_2 production in soil was the main factor determining the latent phytotoxicity of immature compost.

Key words: Carbon mineralisation, compost maturity, phytotoxicity.

INTRODUCTION

Composting is considered a suitable process for recycling of organic wastes, and their transformation into organic fertilisers suitable for agricultural purposes. However the addition of immature compost to soil often produces phytotoxicity and alteration of the microbial population (Barberis and Nappi, 1996). Toxic substances, such as polyphenols, ammonium and organic acids, present in the organic material or as intermediate degradation products of the organic matter in soil (latent phytotoxicity) can be responsible for the phytotoxicity, together with a high electrical conductivity, heavy metals or pathogens. Moreover, fresh wastes or immature compost can promote a fast rate of organic matter mineralization in soil producing high concentration of CO_2 (Bernal et al., 1998a), anaerobic conditions and thus a lack of oxygen for the plant roots in soil. Therefore O_2 consumption or CO_2 production are indicative of compost stability and maturity (Hue and Liu, 1995; Bernal et al., 1998a). The determination of compost quality, by a maturity test based in soil-plant systems, is necessary to detect potential harmful effects of immature compost on plants (Brinton et al., 2001). The aim of this work was to study the relevance of the CO_2 released from the organic matter mineralisation of immature compost in soil and its latent phytotoxicity.

MATERIALS AND METHODS

Two by-products, lemon tree prunings and brewing waste (yeast and malt from the fermentation process), were composted by the Rutgers static composting system (García-

Gómez et al., 2002). The mixture was prepared using 2.5% brewing waste and 97.5% lemon tree prunings (dry weight). Samples were taken from different stages of the composting process (Table 1): the initial phase (0 weeks T=21 °C, C_1), the thermophilic phase (4 weeks T=55 °C, C_4), the end of the thermophilic phase (7 weeks T=50 °C, C_7), at the mesophilic phase (9 weeks T=29, C_9), the end of the active phase (13 weeks T=31 °C, C_{13}) and mature compost (28 weeks T=27 °C, C_M). The soil used was an agricultural, clay loam, calcareous soil (52 % $CaCO_3$), low in organic matter (1.91 %) and nitrogen (1.1 g kg-1), classified as Xerollic Calciorthid (American Soil Taxonomy). Some characteristics were: pH 7.8, electrical conductivity 0.28 dS m^{-1}, total-P 0.4 g kg^{-1}, total-K 0.4 g kg^{-1}, cation exchange capacity 12.3 $cmol_c$ kg^{-1}, clay 28 %, silt 49 %, sand 23 %, and water-holding capacity (WHC) 335 g kg^{-1}.

The carbon mineralisation process was studied in an incubation experiment with soil. Ten-gram samples of soil were thoroughly mixed with 200 mg portions of the composting samples. Soil controls were run without any amendment. Deionised water was added to the soil-composting sample mixture and the soil samples in order to bring their moisture content to 60 % of their WHC. The incubation vessels were closed, but to maintain adequate oxygen levels they were opened periodically. The incubations were carried out with three replicates per treatment, in a temperature-controlled incubator at 28 °C, for 70 days. The CO_2 evolved was trapped into 10 ml of 0.1 M NaOH in small tubes, which were placed on top of the soil in the incubation vessels. Empty vessels were used as blanks. After 1, 2, 3, 6, 10 and 14 days, and then weekly to 70 days, the CO_2 evolved was measured by titration of the NaOH solution with 0.1 M HCl in an excess of $BaCl_2$. Data concerning CO_2-C evolution in soil were fitted to a first-order kinetic function by the non-linear least-square technique (Marquardt-Levenberg algorithm), using the Sigma-Plot computer programme: $C_m = C_0 (1\text{-}e^{-kt})$

Where C_m is the carbon mineralised (%TOC) at time t (day), C_0 and *k* are the potentially mineralisable C (%TOC) and rate constant (day^{-1}). The statistical significance of curve fitting, residual mean square (RMS) and F-values were calculated.

Pots of 250 g were used for the experiment with plants, and the composting samples were added to the soil at the rate of 2% (w/w, dry weight basis), as in the incubation experiment. Each treatment was replicated four times, giving a total of 28 pots. The moisture of the soil was adjusted to 60 % of the WHC with deionised water. Ryegrass (*Lolium perenne L.*) was sown at a rate of 0.5 g seed per pot (47.6 g/m^2), in pots having a 7.5 cm upper diameter and a height of 5 cm, with drainage holes in the base. After germination, pots were placed in a growth chamber at 25 °C day, 20 °C night, with a 16-h photoperiod. The relative humidity was kept at 70 % throughout. The plants were watered with deionised water. The above-ground parts of the plants were cut three times, at 28-day intervals. Dry weights were determined, and the total nitrogen concentration was analysed by automatic microanalysis.

RESULTS AND DISCUSSION

The organic-C mineralisation of the composting samples decreased as the composting period was extended (Table 2). The C_I released the highest amount of CO_2-C in the soil because the fresh organic wastes have a high proportion of easily degradable organic matter. The value of C_m from C_I was within the range found for untransformed wastes (21-62 % TOC) such as plant materials, animal manures and sewage sludges (Ajwa and

Tabatabai, 1994), but lower values were obtained for the other samples at different composting times. The potentially mineralisable-C, calculated using the first-order kinetic model (Fig. 1), followed the same trend as C_m, indicating that the proportion of degradable TOC was reduced during composting, and the organic matter had been stabilised. The greatest difference in both C_0 and C_m was between C_1 and C_4 samples, suggesting that the most labile organic matter was degraded during the thermophilic phase of composting. The differences in C_0 and C_m between samples at the end of the active phase (C_{13}) and the mature compost (C_M) indicate that, during maturation, stabilisation of the TOC prevailed over mineralisation, as both materials had similar concentrations of TOC.

The addition of composting samples with different transformation times to soil affected plant growth, mainly at the first cut (Fig. 2), as found by Bernal et al. (1998b), who indicated the relevance of compost maturity for obtaining a good quality compost. The decrease in yield could be due to nitrogen deficiency, as immature compost can lead to N-immobilisation in the soil (Bernal et al., 1998b). However the concentrations of N in the plant tissue were not different statistically in the treatments and control, being 11.1-12.0 mg kg^{-1} (first cut), 10.8-14.3 mg kg^{-1} (second) and 12.9-16.6 mg kg^{-1} (third). The yield increased with the composting time of the samples (Fig. 2), being greatest in the treatment with the mature compost. Therefore, the low yield obtained with the immature compost should be due to phytotoxicity. The C_1 sample had a low germination index (Table 1) which indicated the presence of phytotoxins in the fresh wastes. However, GI values for C_7, C_9, and C_{13} were adequate (>50 %, Table 1), so the low yield in soil may be due to the production of intermediate phytotoxins during degradation of the organic matter in soil (latent phytotoxicity), as well as high CO_2-C production, with a decrease in the O_2 level in the soil. The yields in the second and third cuts varied less between treatments, increasing with the most transformed samples, due to the nutrients supplied. The less transformed samples had values more similar to the control soil, which indicated that the phytotoxicity was reduced.

Plant yield, expressed as a percentage of control soil, correlated at $P<0.05$ with the C-mineralisation (C_m, %TOC), r=-0.906 after 28 days for the first cut, r=-0.880 after 56 days for the second cut, and r=-0.859 at the end of the incubation for the third cut. Therefore, the production of CO_2 by C-mineralisation was responsible for the phytotoxicity of the composting samples. Brinton et al. (2002) found that the CO_2-respiration of compost correlated well with plant growth when compost at different degrees of maturation was used in growing media for container plants. They concluded that apart from other factors, oxygen depletion as a result of immature compost use was associated with negative effects upon plant. In the present work, composting samples were used as an organic fertiliser in soil, at only 2 % (w/w), but this proportion was enough to show CO_2-production by C-mineralisation as factor responsible for latent phytotoxicity.

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Table 1. Main characteristics of the organic materials at different composting time. EC electrical conductivity; OM organic matter; TOC total organic carbon; TN total nitrogen; GI germination index. (nd: no determined).

Sample	Composting time (weeks)	pH	EC dS m^{-1}	OM %	TOC g kg^{-1}	TN g kg^{-1}	C/N	NH_4^+-N mg kg^{-1}	NO_3^--N mg kg^{-1}	GI %
C_I	0	6.6	2.56	89.8	454.7	13.4	33.8	590	nd	0.1
C_4	4	7.9	1.93	81.9	459.1	15.0	30.6	120	nd	nd
C_7	7	8.3	1.72	78.4	450.0	20.1	22.5	360	nd	87.5
C_9	9	8.3	1.86	83.4	446.1	18.4	24.2	300	0	nd
C_{13}	13	8.6	1.39	77.4	414.3	19.4	21.4	240	150	75.9
C_M	25	8.6	2.58	74.6	416.0	24.9	16.7	150	870	89.3

Table 2. Organic C mineralised from the different composting samples (C_m, % of TOC) and parameter values of the first-order kinetic model, potentially mineralisable-C (C_0), rate constant (K), residual mean square (RMS) and F-value. Standard deviation in brackets (n=3).

Sample	C_m (% TOC)	C_0 (% TOC)	k (day^{-1})	RMS	F
C_I	24.7 (0.87)	22.8 (0.45)	0.123 (0.0097)	4.35	627
C_4	13.3 (0.27)	12.6 (0.30)	0.094 (0.0081)	1.50	601
C_7	13.8 (0.62)	13.4 (0.44)	0.059 (0.0055)	1.51	690
C_9	11.9 (0.86)	12.1 (0.31)	0.064 (0.0050)	0.93	924
C_{13}	8.9 (0.47)	9.1 (0.23)	0.075 (0.0061)	6.96	771
C_M	5.4 (0.10)	5.0 (0.11)	0.100 (0.0081)	2.36	647

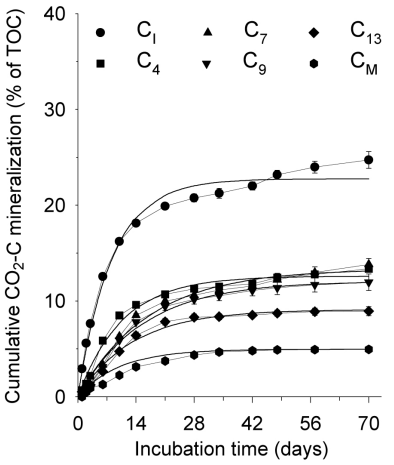

Figure 1. Cummulative CO -C mineralisation of the composting samples. Symbols are experimental data and lines represent fitted curves. Vertical lines are the standard errors of the means.

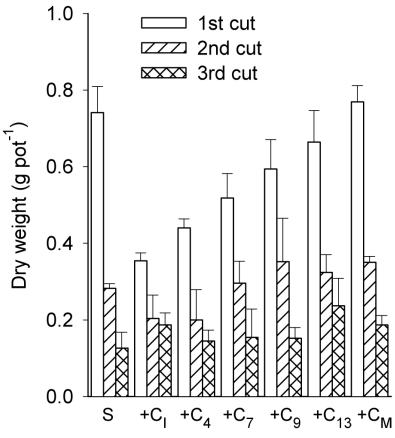

Figure 2. Yield of ryegrass from soil and soil amended with the different composting samples.