Rate of mineralisation of biosolids in calcareous soils: effect of the soil type and of the biosolids treatment

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Abstract

This work studies the mineralisation dynamics of different biosolids as organic amendments for calcareous soils, using different scenarios based on soil texture and biosolids characteristics. For this, an incubation controlled experiment was carried out during 240 days, using two calcareous soils with different textures (clay-loam and sandy-loam, respectively) and seven different biosolids obtained after different wastewater treatments and stabilisation methods, to establish the maximum rate of C mineralisation in optimal conditions. The C mineralisation was influenced by the soil texture, being higher in the soil with the lower clay content. Effluent treatment and especially biosolids stabilisation affected the C mineralisation dynamics including significant soil-type dependence for biosolids stabilisation.

Introduction

Biosolids production in Spain was around 1,206,000 tons in 2009, with a rate of rise of 41% in the period 2000-2009, constituting the use in agricultural soils one of the main alternatives of management, this option increasing in a 120% during the period 2000-2009. Agricultural application of sewage sludge has become the most widespread method of disposal, since it is the most economical technique to reduce the amount of sewage sludge and offers the opportunity to recycle beneficial plant nutrients and organic matter to soil for crop production [1]. However, biosolids also show a heterogeneous composition that makes necessary the study of several factors prior to their application into agricultural soils, such as the content in potentially harmful substances and the degree of stability and the rate of mineralisation of their organic matter [2]. The stability of biosolids and their C dynamics in amended soils depend on several factors (organic matter fractionation and nature) related to biosolids origin and also to the characteristics of the amended soil. The information obtained from decomposition studies in biosolids-treated soils may be useful for assessing nutrient availability, and for optimising the biosolids application rate to agricultural soils, aspects that imply agricultural and environmental benefits. Therefore, the main objective of this research was to establish the mineralisation dynamics of different biosolids in several scenarios depending on the type of biosolids and on the type of soil amended.

Material and Methods

Experimental design

In a randomized incubation experiment, two soils (S1 and S2) with different textures (clay-loam and sandy-loam, respectively) were amended with seven different types of commercial biosolids using an application rate of 25 g biosolids d.w. kg^{-1} soil, and incubated in aerobic conditions during 240 days. An unamended soil of each type was also incubated and used as control treatment (C). The soils used were S1, a calcareous clay-loam Xerofluvent [3] collected from Orihuela (Alicante, Spain) and S2, a calcareous sandy-loam Haplocalcid [3] from Guardamar del Segura (Alicante, Spain). The soils were sampled at each field site, collecting a composite soil sample from the soil surface (0–25 cm). After removal of vegetation, bigger roots and stones, the collected soils were air-dried and crushed to pass through a 2 mm sieve. The different biosolids used (SW1, SW2, SW3, SW4, SW5, SW6 and SW7) were obtained after using different wastewater treatments and stabilisation methods. The main characteristics of these materials are shown in Table 1. The evolution of oxidisable organic C, soil respiration, and cumulative CO_2 emissions from the amended soils were determined at 0, 8, 24, 60, 120 and 240 days of incubation.

Table 1. Main characteristics of the biosolids used in this experiment (dry weight basis).

Parameter	Biosolids						
	SW1	SW2	SW3	SW4	SW5	SW6	SW7
Effluent treatment	AS	AT&EA	AS	EA	EA	EA	AS
Sludge stabilisation	anaerobic	aerobic	aerobic	aerobic	aerobic	aerobic	anaerobic
pH	6.24	6.01	5.99	7.03	5.95	6.08	6.19
EC (dS/m)	2.40	3.64	2.46	4.25	3.16	1.99	3.28
OM (%)	62.6	67.2	66.6	60.7	72.1	64.4	71.3
Coox (%)	18.1	21.4	17.3	17.0	18.3	17.4	17.9
TKN (%)	3.45	4.79	4.87	4.24	6.38	4.51	6.67
C/N ratio	9.85	6.52	7.29	7.09	6.25	7.24	6.05
P (g/kg)	16.9	19.1	16.7	17.0	19.0	17.1	19.2
K (g/kg)	1.83	4.39	4.32	3.54	6.11	3.93	9.90

EA: Extended aeration; AS: Activated sludge; EC: electrical conductivity; OM: total organic matter; Coox: oxidisable organic C; TKN: total Kjeldahl nitrogen.

Analytical methods and statistical analysis

The analytical determinations in the amended soils and in the biosolids were carried out according to the methods described by Bustamante et al. [4]. Cumulative CO_2 emissions calculated by summing up all CO2 evolved during incubation, was taken to represent the amount of C mineralised [4]. Data concerning cumulative emissions of CO_2 from the amended soils were fitted in the first order kinetic model generally used for organic C mineralisation [4]: $C_m = C_o(1–e^{-Kt})$ where Cm is the mineralised C (%C) at time t (days), Co is the amount of potentially mineralizable C (%C) and k is the first-order mineralisation rate constant (days^{-1}). Residual mean square (RMS) and F-values were calculated to compare the fittings of different functions and the statistical significance of curve fitting. This model was chosen as the best fit for the amended soils because it gave a randomised distribution of the residuals together with the lowest value of RMS and high F-value (data not shown).

Results and discussion

The incorporation of the biosolids into the soils induced a sustainable increase in the contents of the oxidisable organic C (Coox) compared to those observed in the control treatment (C), these pools being higher in the most fine-textured soils (Figs. 1a and 1b).

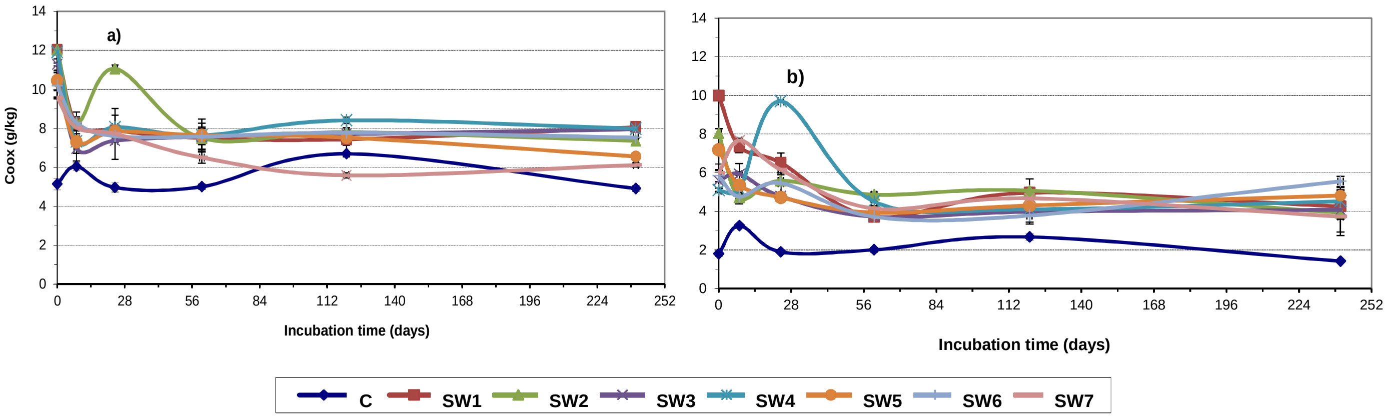

Figure 1. Evolution of the oxidisable organic C in the unamended and amended soils S1 (clay-loam soil) a) and S2 (sandy-loam soil) b).

The initial decrease in the contents of Coox was related to the quick degradation of organic labile pools, especially associated to the initial high activity of microbiota in optimal conditions [4]. During the experiment, the most complex organic pools degradation induced relative increases on Coox content, linked to the formation of secondary labile compounds [4]. The cumulative CO_2–C evolution throughout the incubation experiment for all the treatments followed a first-order kinetic model, as it is shown in Figure 2.

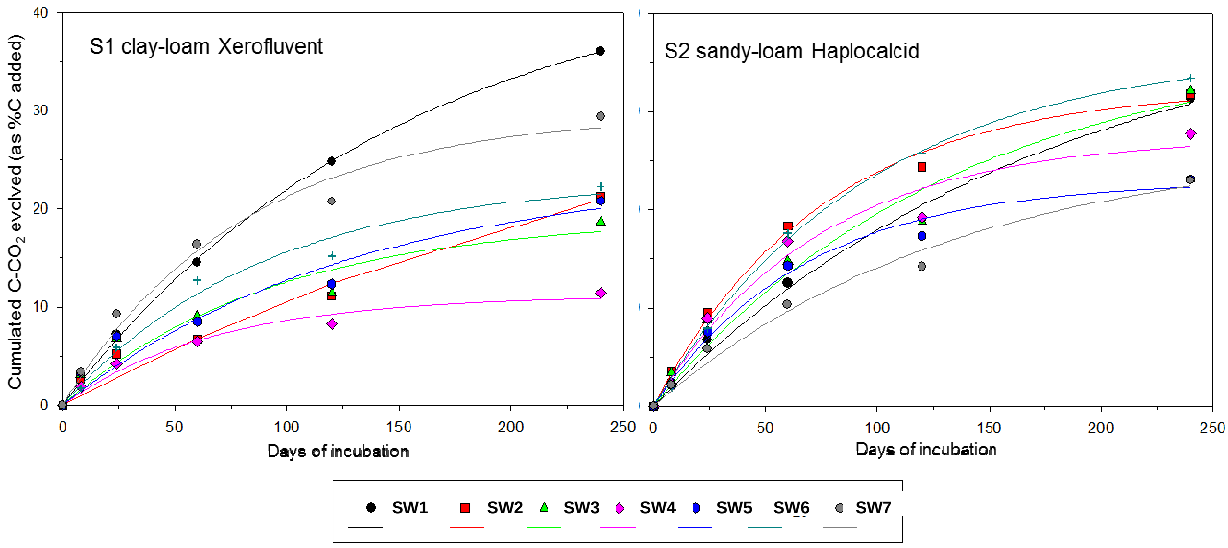

Figure 2. Evolution of cumulative CO_2–C from the wastes (% of total organic C added) (lines represent curve-fitting) in the different soils studied.

Although all equations were significant at $P < 0.001$, in general, the results of S2 fitted better the equation than the results obtained for S1, which showed lower F and higher values for the standard estimation error (SEE) (Table 2). In general, the lowest values of the C mineralised values after 240 days (C_{240}) and rate of Coox mineralisation, as the K and C_o x K values showed, were observed in the clayey-loam soil in all the amended soils, which indicates the influence of the soil type on the mineralisation process of the organic matter resent in the different biosolids considered. This fact was also observed by Bustamante et al. [5] in an experiment using different textured soils amended with winery and distillery wastes.

Table 2. Mean soil respiration rates during incubation and estimated C mineralisation parameters.

Biosolids	C_{240} (%C)	C_o (%C)	*K* (days^{-1})	C_o x K	R^2	*F*	SEE
	S1 clay-loam Xerofluvent soil						
SW1	36.04 (0.14)	45.15 (1.28)	0.0067 (0.0003)	0.30	0.9992	6616***	0.383
SW2	20.92 (0.23)	39.56 (2.06)	0.0031 (0.0023)	0.12	0.9562	110***	1.588
SW3	17.66 (0.55)	19.15 (3.24)	0.0106 (0.0041)	0.20	0.9141	54**	1.933
SW4	10.84 (0.74)	11.16 (0.97)	0.0148 (0.0033)	0.17	0.9630	131***	0.810
SW5	20.03 (0.38)	23.86 (5.57)	0.0076(0.0035)	0.18	0.9193	58**	2.077
SW6	21.54 (0.56)	23.10 (1.99)	0.0112 (0.0022)	0.26	0.9785	229***	1.259
SW7	28.31 (0.69)	29.80 (2.22)	0.0125 (0.0023)	0.37	0.9796	241***	1.585
	S2 sandy-loam Haplocalcid soil						
SW1	30.79 (0.39)	41.34 (5.01)	0.0057 (0.0012)	0.24	0.9904	515***	1.146
SW2	31.14 (0.72)	32.50 (1.23)	0.0132 (0.0012)	0.43	0.9944	883***	0.931
SW3	31.01 (0.47)	37.12 (6.33)	0.0075 (0.0025)	0.28	0.9614	125***	2.296
SW4	26.46 (0.69)	27.50 (2.43)	0.0136 (0.0030)	0.37	0.9685	155***	1.894
SW5	22.30 (0.71)	22.96 (1.34)	0.0148 (0.0022)	0.34	0.9845	318***	1.128
SW6	33.39 (0.05)	36.28 (1.05)	0.0105 (0.0007)	0.38	0.9979	2400***	0.614
SW7	22.41 (0.46)	27.00 (3.46)	0.0074 (0.0018)	0.20	0.9793	238***	1.223

***, **: Significant at a $P<0.001$, $P<0.01$, respectively; standard error in brackets. SEE: standard error of estimation.

In order to classify the influence on the mineralisation parameters as a consequence of the soil type, the treatment of the effluent (activated sludge, extended aeration or both) and the type of stabilisation of the biosolid (aerobic and anaerobic), an univariate general linear model was performed. Due to the lack of data for all the combinations, ET x BS x S and ET x BS interactions were not analysed (Table 3). As it is shown in Table 3, the treatment of the effluent based on extended aeration seems to reduce the mineralisation process of the biosolids. This fact may be related to the lower amount of labile compounds in this kind of biosolids, obtained after aerobic stabilisation procedures. The type of soil affected the mineralisation maximum value, with an increase of about 27% for sandy-loam soils (S2), ranged between 11 and 36% for the clay-loam soil and between 23 and 33% for the sandy-loam, respectively. This fact was also observed by Bustamante et al. [5], who observed that clay content protect organic matter to biodegradation.

Table 3. Results of the univariate general linear model depending on soil type, effluent treatment and type of biosolid stabilisation.

Variable	Options			Sign.
Effluent treatment (ET)	**Activated sludge (AS)**	**Ext. aeration (EA)**	**Both**	
	27.7b	22.4a	26.0ab	4.2*
Biosolids stabilisation (BS)	**aerobically**	**anaerobically**	**Sign.**	
	23.5a	29.4b	5.8*	
Soil (S)	**S1**	**S2**	**Sign.**	
	22.2a	28.3b	11**	
	Sign.			
ET x BS x S	nd			
ET x BS	nd			
ET x S	0.39 ns			
BS x S	21***			
BS x S	**S1**	**S2**	**Sign.**	
aerobically	18.2a	28.9b	50***	
anaerobically	22.2a	28.3b	4.7*	

nd: not determined due to the lack of specimens; ns: not significant.

Biosolids stabilisation (BS) clearly affected the mineralisation dynamics, the anaerobically stabilised biosolid being the most easily degradable materials. In this sense, soil type significantly affected this behaviour (BS x S = 21***), especially for aerobic biosolids, probably due to the need of optimum conditions (e.g. light textured soils) to decompose the most recalcitrant organic compounds present in aerobic biosolids, also associated to extended aeration (EA) procedures.

Conclusion and perspectives

The addition of the biosolids studied to the different soils supposed an increase of the C pools in both types of soils, this effect being less notable in the sandy-loam soils. The C mineralisation was influenced by the soil texture, being higher in the soil with lower clay contents. In our study, effluent treatment and especially biosolids stabilisation affected the C mineralisation dynamics including significant soil-type dependence for biosolids stabilisation. However, more research must be carried out in order to extend these conclusions in wider biosolids-soil scenarios.

Acknowledgments

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