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Influence of vermicomposting on solid wastes decomposition kinetics in soils*

NOURBAKHSH Farshid

(*Department of Soil Science, College of Agriculture, Isfahan University of Technology, Isfahan 84156-83111, Iran*)

E-mail: farshid@cc.iut.ac.ir

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Abstract: The effect of vermicomposting on kinetic behavior of the products is not well recognized. An incubation study was conducted to investigate C mineralization kinetics of cow manure, sugarcane filter cake and their vermicomposts. Two different soils were treated with the four solid wastes at a rate of 0.5 g solid waste C per kg soil with three replications. Soils were incubated for 56 d. The CO_2-C respired was monitored periodically and a first-order kinetic model was used to calculate the kinetic parameters of C mineralization. Results indicated that the percentage of C mineralized during the incubation period ranged from 31.9% to 41.8% and 55.9% to 73.4% in the calcareous and acidic soils, respectively. The potentially mineralizable C (C_0) of the treated soils was lower in the solid waste composts compared to their starting materials. Overall, it can be concluded that decomposable fraction of solid wastes has decreased due to vermicomposting.

Key words: Vermicompost, Manure, Sugarcane filter cake, Mineralization kinetics
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INTRODUCTION

Carbon storage in soils is particularly important because soils are the largest reservoir of organic C in terrestrial ecosystems, containing 3 times more C than the vegetation that they support (Rasse *et al*., 2005). The central role of soil organic matter in maintaining soil function and plant productivity in agroecosystems has long been recognized (Puget and Drinkwater, 2001). Accumulation of organic wastes has a negative impact on the environment, whereas transformation of these refuses through composting alleviates their potential toxicity in the environment and recycles organic fractions for agricultural purposes (García *et al*., 1991). Application of organic waste material to agricultural land has received considerable attention (Martinez and Tabatabai, 1997). Different sources of organic amendments including solid waste compost (Hachicha *et al*., 2006), municipal solid wastes (Montemurro *et al*., 2005) and biotechnology by-products (Martinez and Tabatabai, 1997) have been applied to enhance both crop yield and soil quality.

Composts from different sources can be used as organic amendments in soils, providing both organic matter and mineral nutrients, thus promoting physical and chemical properties of soils (Sáinz *et al*., 1998). The use of immature compost can cause phytotoxic effects as well as N deficiency to plants, which reduces plant yield (Bernal *et al*., 1998a). Several compost maturity indices have been established (Bernal *et al*., 1998b).

Vermicompost, another type of compost, which has attracted an increasing attention, is formed by earthworm activities from organic residues, mainly animal manures. Earthworms stabilize organic residues by producing earthworm casts, which are called vermicompost (Riffaldi and Levi-Minzi, 1983). Earthworm casts are soil conditioners that have a high nutrient bioavailability for plant growth. Devliegher and Verstraete (1997) have reported increased availabilities of P, Mg, Ca, Fe, Mn and Cu in soils introduced with an active population of *Lumbricus* sp.

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compared to the initial mineral concentrations.

Vermicomposting procedure changes the chemical compositions of the substrates that are subjected to earthworm activities. The ash contents of cattle, swine and ship manure vermicomposts increase compared to the initial substrates, whereas the amounts of organic matter, total N, total P, and pH values significantly decrease. Moreover, vermicomposting influences the C extractability by NaOH and $Na_4P_2O_7$, which was thought to be an indication of different organic matter quality in the earthworm casts. It has eventually concluded that vermicompost production procedure by action of earthworms changes the composition of humic substances in manures both quantitatively and qualitatively (Petrussi *et al*., 1988). There are some evidences revealing that vermicompost application can enhance both quantity and quality of plants (Gutiérrez-Miceli *et al*., 2007).

Different compositions of organic amendments in a wide range of plant residues, animal manures and sewage sludge influence their decomposition kinetics (Ajwa and Tabatabai, 1994). The decomposition kinetics of various types of organic wastes has been investigated, and it has been concluded that composting is the best way for obtaining maximum C stabilization, an important factor in soil conservation and reclamation (Bernal *et al*., 1998c). In an attempt to recognize the effects of plant residue quality on biodegradation kinetics, Nourbakhsh (2006) showed that a first-order kinetic model can differentiate plant residues possessing different concentrations of lignin and N. Furthermore, C mineralization kinetics in plant residue-amended soils under both non-saline and saline conditions was strongly influenced by the residue quality (Nourbakhsh and Sheikh-Hosseini, 2006).

Although mineralization kinetics of different composts has already been studied (Bernal *et al*., 1998c), little attention has been focused on vermicompost. Earthworm activities on solid wastes reduce the readily decomposable fractions of organic C (Riffaldi and Levi-Minzi, 1983) and, hence, it can be hypothesized that vermicompost decomposition in the soil may show different biodegradation kinetic behaviors compared to that of their starting materials. Therefore, the objective of this study was to identify the kinetic properties of C mineralization in two soils amended with cow manure and sugarcane filter cake (a solid waste derived from sugarcane processing factories) and their vermicompost in soils of contrasting properties.

MATERIALS AND METHODS

Soil sampling and vermicompost preparation

Two soil samples were collected from 0~15 cm depth of different climatic regions of Iran. The Shervedan soil was taken from Isfahan University of Technology research station in Shervedan, Iran (32°30′ N, 51°36′ E). The calcareous soil is under irrigated conventional corn (*Zea mays* L.) monoculture. The Langroud soil was collected from upland acid soils of northern Iran (37°18′ N, 50°15′ E). The acid soil is under permanent tea (*Camellia sinensis*) production. The Shervedan soil belongs to arid regions of central Iran with 120 mm mean annual precipitation, whereas Langroud is located in the humid part of northern Iran with 1300 mm mean annual precipitation. The physico-chemical properties of the soils are summarized in Table 1.

Cow manure (CM), cow manure vermicompost (V-CM), sugarcane filter cake (SFC) and sugarcane filter cake vermicompost (V-SFC) were provided by Safir Sabz Company, which commercially produces vermicompost in Iran. Briefly, vermicomposting process was performed by introducing 20 *Eisenia*

Table 1 General properties of the two soils and the four solid wastes studied

	Clay (%)	Silt (%)	Sand (%)	pH	EC (dS/m)	Organic C (g/kg)	N (g/kg)
Soils							
Shervedan	62	30	8	7.8	1.8	12.2	1.4
Langroud	20	18	62	4.7	0.4	31.5	1.9
Solid wastes							
CM	–	–	–	8.8	7.4	313.9	21.3
V-CM	–	–	–	8.4	3.0	158.9	21.2
SFC	–	–	–	8.2	3.2	238.4	13.8
V-SFC	–	–	–	7.7	3.3	181.4	18.0

CM: Cow manure; V-CM: Cow manure vermicompost; SFC: Sugarcane filter cake; V-SFC: Sugarcane filter cake vermicompost *foetida* earthworms per kg initial substrates under optimum moisture and temperature conditions in a 50-day vermicomposting period. The chemical compositions of the solid wastes are presented in Table 1.

Incubation experiment

To study the C mineralization kinetics, a factorial combination of the two soil types and the four types of organic amendments was prepared in three replications. Triplicates of 50 g soil samples were mixed thoroughly with solid wastes at the rate of 0.5 g solid waste C per kg soil. Moisture was adjusted at 50% water holding capacity. Control treatments without application of plant residues were also run. The soils were kept in sealed glass jars containing alkali solution vial (15 ml 1 mol/L NaOH) to trap CO_2-C respired. The jars were kept at 25 °C. The trapping alkali solution was replaced periodically after 1, 2, 3, 4, 7, 9, 11, 15, 22, 29, 36, 46 and 56 d of incubation. The CO_2-C trapped was measured by titrating the aliquot with 0.25 mol/L HCl following precipitation of carbonates by $BaCl_2$ solution (Alef, 1995).

A first-order kinetic equation was used to calculate the potentially mineralizable C (C_0):

$$C_m = C_0(1 - e^{-kt}),$$

where C_m (mg C/kg) is the organic C mineralized at any specific time, t (d), and k (d^{-1}) is the first-order rate constant. SYSTAT (Version 8.1) was used to calculate C_0 (mg C/kg), k and statistical analysis (Wilkinson, 1988).

RESULTS AND DISCUSSION

Expressed as a percentage of organic C in solid wastes, the cumulative amounts of C mineralized as CO_2-C in 56 d ranged from 31.9% to 41.8% for the Shervedan soil and from 55.9% to 73.4% for the Langroud soil, respectively (Table 2). In both soils, more CO_2-C evolution was observed in CM treatments compared to V-CM. The amounts of CO_2-C evolved at the end of 56 d of incubation for both soils in CM treatments were similarly 1.24 times greater than those of V-CM treatments (Table 2). The decomposition rate of SFC-treated Shervedan soil was 1.26 times greater compared to that of V-SFC in the same soil, whereas the rate of CO_2-C evolution for SFC was about 1.04 times greater than that of V-SFC treatment in the Langroud soil. The generally lower release of CO_2-C in the vermicompost-treated soils compared to their starting materials can be described by the fact that during the vermicompost production procedure, some parts of readily biodegradable C have been released through earthworms and microbial population respiration (Petrussi *et al*., 1988). It has been reported that the amounts of organic matter in cattle, swine and sheep manures decreased during vermicomposting process by 31.3%, 19.6% and 9.3%, respectively (Petrussi *et al*., 1988).

Table 2 Percentage of organic C evolved as CO_2-C from solid waste-treated soils in 56 d

Organic material	Organic C evolved (%)	
	Shervedan soil	Langroud soil
CM	39.6b* (0.99)**	73.4a (2.2)
V-CM	31.9d (0.64)	59.2b (1.24)
SFC	41.8a (0.96)	57.9b (1.51)
V-SFC	33.2c (0.60)	55.9c (0.95)

*Different letters in each column indicate significant difference (LSD, $P<0.05$); **Values in parenthesis are standard deviations. CM: Cow manure; V-CM: Cow manure vermicompost; SFC: Sugarcane filter cake; V-SFC: Sugarcane filter cake vermicompost

C mineralization kinetics

All data conformed well to the first-order kinetic model described earlier. In general, the amount of CO_2-C released from the solid waste-treated soils increased at a decreasing rate. This was seen as a rapid increase during the initial stages of incubation, followed by a slower release (Fig.1). In this study, the decomposition rate of the native soil organic C in the presence of organic material (priming effect) is assumed to be the same for each type of organic material. The same assumption has been made earlier by other researchers (Ajwa and Tabatabai, 1994; Trinsoutrot *et al*., 2000).

Potentially mineralizable C (C_0) of both soils significantly enhanced when treated with either of the solid wastes (Table 3). The C_0 values for the Shervedan soil ranged from 50.0 to 252.0 mg C/kg for control and SFC treatment, respectively. Greater C_0 values were obtained for the Langroud soils. The C_0 values in the Langroud soil ranged from 76.7 to 416.6

mg C/kg for the control and CM treatment, respectively. The higher C_0 values in the Langroud soil compared to those of the Shervedan soil can be attributed to greater percentages of the solid waste decomposed (Table 2). The percentages of solid waste C evolved as CO_2-C in the Langroud soil were greater than those of the Shervedan soil by 1.85, 1.85, 1.38 and 1.68 times for CM, V-CM, SFC and V-SFC, respectively (Table 2). In other word, application of similar solid wastes in the two soils created different levels of potentially mineralizable C (C_0). Since the Shervedan soil (the calcareous soil) is very rich in clay (Table 1), the organic matter from the wastes can be linked with the clay fraction, being less available for the microorganisms. The clay fraction acts as a kind of protection of the organic matter against microbial attack. Moreover, extracellular enzymes can be adsorbed on the clay surfaces, which may lead to a decrease in the enzyme kinetic parameters (Nannipieri *et al*., 2002).

The C_0 values indicate the biologically active fractions of solid wastes, which can be released as CO_2-C. The values, in turn, cannot reveal the decomposition rates of the solid wastes, because the kinetic rate constants are not involved in the C_0 values. Initially, the degradation rates of the wastes were slower in the Langroud (acidic) soil (Fig.1), but the potentially mineralizable C was greater than the Shervedan (calcareous) soil (Table 3), which means that the rate constants (k) must be much lower in the

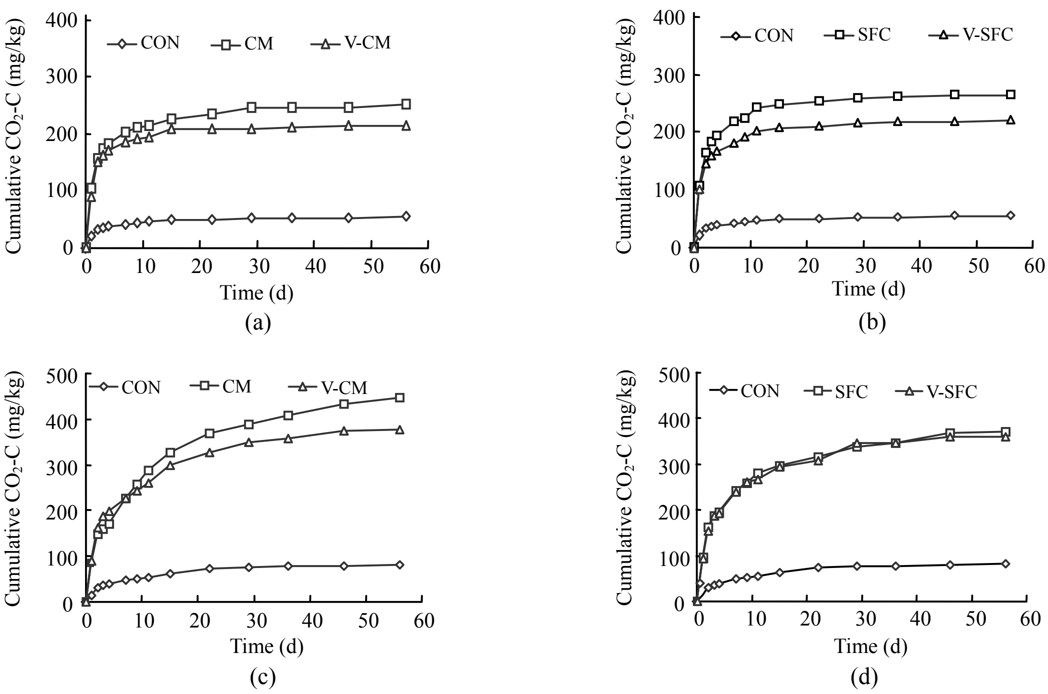

Fig.1 Cumulative evolution of CO_2-C from the Shervedan soil [(a) and (b)] and the Langroud soil [(c) and (d)] treated with cow manure (CM), cow manure vermicompost (V-CM) [(a) and (c)] and sugarcane filter cake (SFC), sugarcane filter cake vermicompost (V-SFC) [(b) and (d)], compared to control (CON)

Table 3 Potentially mineralizable C (C_0) and initial potential rates of CO_2-C evolution (kC_0) in the soils treated with the four solid wastes

Organic material	Shervedan soil			Langroud soil		
	C_0 (mg C/kg)	k (d^{-1})	kC_0 [mg C/(kg·d)]	C_0 (mg C/kg)	k (d^{-1})	kC_0 [mg C/(kg·d)]
Control	50.0e* (1.5)**	0.41d (0.0123)	20.5d (0.41)	76.7d (1.5)	0.15c (0.0045)	11.5d (0.23)
CM	232.4b (3.4)	0.49c (0.0122)	113.9b (1.71)	416.6a (9.4)	0.12d (0.0072)	50.0c (0.75)
V-CM	201.8d (4.3)	0.59a (0.0136)	119.1a (1.62)	346.6b (7.3)	0.19b (0.0039)	65.9b (2.64)
SFC	252.0a (7.3)	0.48c (0.0120)	121.0a (1.75)	336.6c (7.1)	0.22a (0.0033)	74.0a (2.52)
V-SFC	206.9c (4.1)	0.54b (0.0146)	111.8c (1.31)	332.8c (4.9)	0.22a (0.0031)	73.2a (2.64)

*Different letters in each column indicate significant difference (LSD, $P<0.05$); **Values in parenthesis are standard deviations. CM: Cow manure; V-CM: Cow manure vermicompost; SFC: Sugarcane filter cake; V-SFC: Sugarcane filter cake vermicompost

Langroud soil than in the Shervedan soil. Actually, the average value of k in the Shervedan soil was 2.8 times greater than that of the Langroud soil. A paired t-test indicates that k values for the Langroud soils are significantly lower than those of the Shervedan soil (data not shown).

It has been suggested that the product of C_0 and k (kC_0) is more accurate than C_0 to evaluate the decomposability of organic material in soils (Saviozzi *et al*., 1993). It has also been reported that the product kC_0 was sensitive to organic waste quality in an arid soil, amended with organic wastes of varying degrees of stability (Pascual *et al*., 1998). The term initial potential rate of mineralization has been chosen for the kC_0 values (Burket and Dick, 1998). In general, the kC_0 values of vermicomposted materials are lower than those of the original substrates. This finding can be explained by the lower decomposability of vermicomposted materials. Characterization of organic matter from animal manures before and after digestion by earthworms has shown that the digestion of manure by earthworm increased humification index and lowered the soluble fraction of organic C (Petrussi *et al*., 1988), which is thought to be more decomposable.

A paired t-test indicates that kC_0 values for the Langroud soils are significantly lower than those of the Shervedan soil (data not shown). This finding along with the significantly lower rate constant (k) values in the Langroud (acidic) soil (Table 3) indicates that the rate of decomposition of solid wastes in the Langroud soil is significantly slower than that of the Shervedan soil. Since the incubation conditions for both soils in terms of temperature and moisture have been identical, the different rates of decomposition can be related to intrinsic properties of the soils, which have induced dissimilar rates of decomposition. Taking the two soil properties into account, one can observe that the Langroud soil has an extremely acid condition (Table 1), which has the potential to inhibit the rates of decomposition compared to the Shervedan soil. It has widely been emphasized that the highest rates of mineralization can be occurred in the pH range of 6 to 8 (Tate, 2000). However, an adequate description of different initial potential rates of C mineralization in the soils needs more investigations.

CONCLUSION

Overall, the results clearly demonstrate that first-order kinetics can describe the kinetic behavior of vermicomposts decomposition in the soils. All types of solid wastes enhanced the amounts of CO_2-C released during the 56 d of incubation. The C_0 values of vermicompost-treated soils were generally lower than those treated with starting materials. The decomposition rate constants in acid soils were generally lower than the calcareous soil. It can be concluded that decomposable fraction of solid wastes has decreased due to vermicomposting. Moreover, the kinetics of solid waste decomposition in soil is influenced by the chemical properties of the soils.

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