

Fate of carbon and nitrogen from plant residue decomposition in a calcareous soil

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ABSTRACT

Carbon and nitrogen transformations in soil are microbially mediated processes that are functionally related. The fate of C and N was monitored in a clay-textured soil (Typic Haplocambid) which was either unamended (control) or amended with various plant materials at the rate of 10 g residue C/kg soil. To evaluate C mineralization, soils were incubated for 46 days under aerobic conditions. Nitrogen mineralization/immobilization was evaluated at the end of eight-week incubation experiment. All CO₂ evolution data conformed well to a first-order kinetic model, $C_m = C_0 (1 - e^{-Kt})$. The product of K and C₀ (KC₀) was significantly correlated with some chemical and biochemical properties of the plant residues, including N concentration ($r = 0.83, P < 0.001$), C:N ($r = -0.64, P < 0.05$) and lignin:N ($r = -0.81, P < 0.001$). Among the plant residue composition characteristics, N concentration ($r = 0.96, P < 0.001$), C:N ($r = -0.69, P < 0.01$) and lignin:N ($r = -0.68, P < 0.01$) were significantly correlated with the net rates of N mineralization/immobilization ($N_{m/i}$).

Keywords: transformation of C and N; calcareous soil; plant residue quality

The importance of soil organic C in maintaining soil functionality and as one of the major C pools interacting with atmospheric CO₂ has been acknowledged (Puget and Drinkwater 2001). Plant parts with different biochemical composition would be expected to show different C mineralization kinetics. Increased understanding of residue decomposition and its associated N mineralization may improve the management of cover crops in agroecosystems (Quemada and Cabrera 1995). Paré and Gregorich (1999) suggested that low input agricultural systems emphasize the use of legume residues as a source of N for crop production.

The soil N availability will change depending on the amount of N mineralized or immobilized during the decomposition of crop residues. Fertilizer recommendation procedures usually ignore or simply guess at the amount of N that will mineralize from decomposing crop residues (Vigil and Kissel 1991). Because of the complexity of N mineralization, several researchers used computer simulation models as tools for learning more about the process of organic N turnover. In most of these models the C:N ratio, the N concentration of the residue or both are used to control the N mineralization rate. On the other hand,

contradictory results were obtained for the effects of lignin and polyphenol effects on N mineralization rates (Vigil and Kissel 1991).

The objective of this study was to investigate the association of the kinetic parameters of C mineralization and net rates of N mineralization/immobilization with the initial composition of plant residue in a calcareous soil.

MATERIAL AND METHODS

The soil sample was taken from 0–15 cm, Shervedan Research Station, Isfahan University of Technology, Isfahan, Central Iran. The soil was clayey (576 g/kg clay and 59 g/kg sand) with pH 8.1, containing 18.01 organic C and 1.96 g/kg total N. The soil was calcareous (394 g/kg calcium carbonate equivalent), non saline (ECe = 0.97 dS/m) and non-sodic (SAR = 1.42). The soil sample was passed through a 2-mm sieve, air-dried for 48 hours at 22°C and kept in sealed containers at 4°C before analyses and incubation experiments.

Wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.) and corn (*Zea mays* L.) roots and shoots were sampled one week prior to harvest. Alfalfa

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(*Medicago sativa* L.) and clover (*Trifolium repens* L.) roots and shoots were sampled before flowering and the four tree leaves including oak (*Quercus brantii* Lindl), apple (*Malus pumila* L.), plane (*Platanus orientalis* L.) and oleaster (*Elaeagnus angustifolia* L.) trees were sampled late in the autumn. Plant residues were washed with running tap water, rinsed three times with distilled water, then dried at 65°C for 24 h, passed through a 1-mm sieve and kept in sealed glass containers until analyses and/or incubation experiments. Hemicellulose, cellulose and lignin contents were determined in triplicate samples sequentially (Van Soest et al. 1991).

To study the C mineralization kinetics, triplicates of 50 g soil samples were mixed thoroughly with plant residues at the rate of 10 g residue C/kg soil. Moisture was adjusted at 50% water holding capacity. A control treatment without application of plant residues was also done. The soils kept in sealed glass jars containing trapping alkali solution vial (15 ml, 1M NaOH) to trap CO₂-C respired. The jars were kept at 25°C. The alkali solution was replaced periodically at 1, 2, 3, 4, 5, 6, 7, 9, 11, 13, 15, 18, 21, 29, 37 and 46 days after incubation. The CO₂-C trapped was measured by titrating the aliquot with 0.25M HCl following precipitation of carbonates by saturated BaCl₂ in the presence of phenolphthalein (Alef 1995).

A first order kinetic equation was used to calculate the potentially mineralizable C (C₀):

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

where: C_m is the organic C mineralized at specific time *t*, and K is the first order rate constant. Curve Expert (version 1.3) was used to calculate C₀ and K.

To determine the net N mineralization/immobilization rates, 100 g soil sample were mixed thoroughly with plant residues at the rate of 10 g residue C/kg soil. Moisture was adjusted at 50% water holding capacity and incubated at 25°C for 8 weeks. A control treatment without application of plant residues was also done. During the incubation, the container was weighed every other day and the lost weight was replaced by addition of distilled water. The experiment was conducted with three replications. At the end of the incubation period, soils were shaken with 2M KCl, for 1 hour and passed through filter paper Whatman No. 42. The extracts were kept at -20°C until analyses. The NH₄⁺ and NO₃⁻ of the extracts were measured by steam distillation procedure (Keeney and Nelson 1982). The following equation was used to calculate the net rates of N mineralization/immobilization.

$$N_{m/i} = (NH_4^+ + NO_3^-)_f - (NH_4^+ + NO_3^-)_i$$

where: N_{m/i} is the net rate of N mineralization or immobilization. Positive and negative values of N_{m/i} considered as net N mineralization and net N immobilization, respectively. (NH₄⁺ + NO₃⁻)_f

Table 1. Initial composition of the fourteen plant materials (in %)

Plant	Total C	Total N	Cellulose	Hemicellulose	Lignin	C:N	Lignin:N
Clover roots	47.5 (2.2)	1.59 (0.05)	24.97 (2.1)	11.32 (1.7)	2.70 (0.6)	29.9	1.70
Clover shoots	40.5 (1.6)	2.57 (0.10)	15.83 (1.6)	4.33 (0.3)	1.97 (0.3)	15.8	0.77
Wheat roots	42.1 (1.6)	0.63 (0.09)	37.31 (3.6)	26.21 (1.8)	6.03 (0.5)	66.8	9.57
Wheat shoots	41.3 (1.7)	1.84 (0.08)	23.44 (3.1)	23.05 (1.5)	0.83 (0.6)	22.4	0.45
Barley roots	39.4 (1.7)	0.69 (0.06)	36.17 (3.5)	22.58 (1.7)	4.66 (0.4)	57.1	6.75
Barley shoots	41.7 (1.6)	1.66 (0.08)	25.24 (2.7)	23.4 (1.7)	0.84 (0.1)	25.1	0.51
Corn roots	46.5 (1.9)	0.50 (0.06)	40.86 (3.4)	26.3 (2.1)	4.29 (0.5)	93.0	8.58
Corn shoots	44 (1.8)	1.04 (0.12)	25.61 (2.7)	25.4 (2.3)	3.34 (0.4)	42.3	3.21
Alfalfa roots	45.7 (1.8)	1.23 (0.09)	25.86 (2.9)	10.65 (1.2)	5.57 (0.6)	37.2	4.53
Alfalfa shoots	38 (1.7)	2.98	10.89 (1.6)	6.98 (0.8)	2.81 (0.4)	12.7	0.94
Oleaster leaves	45 (1.6)	1.48	12.74 (1.8)	5.2 (0.6)	3.77 (0.4)	30.4	2.55
Apple leaves	42 (2.8)	1.03	15.75 (2.4)	11.94 (1.5)	8.89 (0.3)	40.8	8.63
Plane leaves	39.5 (1.7)	1.13	17.21 (2.5)	10.35 (1.5)	11.52 (0.9)	35.0	10.19
Oak leaves	37 (1.8)	0.95	21.30 (1.8)	15.47 (1.9)	16.06 (1.2)	38.9	16.90

Table 2. Pearson linear correlation coefficients between decomposability and initial chemistry of the plant materials

	KC ₀	N _{m/i}	N	C:N	Lignin	Lignin:N
KC ₀	1					
N _{m/i}	0.88***	1				
N	0.83***	0.96***	1			
C:N	-0.64*	-0.69**	-0.83***	1		
Lignin	-0.72**	-0.54*	-0.45	0.20	1	
Lignin:N	0.81***	0.68**	0.67	0.55*	0.92***	1

P* < 0.05; *P* < 0.01; ****P* < 0.001

and (NH₄⁺ + NO₃⁻)_i are the final (after 8 weeks of incubation) and initial (before incubation) concentrations of total inorganic N (mg N/kg soil), respectively.

RESULTS AND DISCUSSION

The initial compositions of various residues are summarized in Table 1. There were considerable differences in chemical quality of the residues. The N concentration of the plant residues ranged from 0.50 to 2.98% (Table 1). The lowest and the highest N concentrations were observed in corn roots and alfalfa shoots, respectively. The C:N ratio was lowest in alfalfa shoots (12.7), with a range of 12.7 to 93.0 for the other plant residues. Corn roots possessed the highest C:N ratio (93.0). The average value of C:N ratio in the cereal (wheat, barley and corn) roots (72.4) was higher than that of legume roots (33.5).

Cereal roots and shoots had the highest hemicellulose content (Table 1). A similar pattern was observed for cellulose content except that cereal shoots had a higher cellulose content than their roots. The lignin concentration ranged between 0.83 and 16.06%. Lignin and N concentrations in the plant residues were not significantly correlated, a pronounced correlation was however observed between lignin:N ratio and N concentration (Table 2).

The pattern of CO₂-C evolution against time for the soil treated with the wheat and alfalfa roots and shoots is shown (Figure 1). Results showed that, in general, the amount of CO₂-C initially released rapidly during the first 10 days followed by a slower evolution during the rest of incubation period. A relatively more consistent release of CO₂-C was observed in the control treatment

(Figure 1). The findings are consistent with the results of Ajwa and Tabatabai (1994). 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 the organic material. The same assumption has been made previously by other researchers (Ajwa and Tabatabai 1994).

Many researchers have used KC₀ as an index of residue biochemical quality and decomposability, because both values of rate constant (K) and potentially mineralizable C (C₀) are involved (Pascual et al. 1998). Campbell et al. (1991) proposed this product as a useful factor to explain and understand the quality of soil organic matter. In the present study, lignin content of the plant residues was negatively associated with the KC₀ values (*r* = -0.72, *P* < 0.001) revealing that the plant residues that have higher contents of lignin are less decomposable and are more resistant to biodegradation. Lignin is known to be resistant

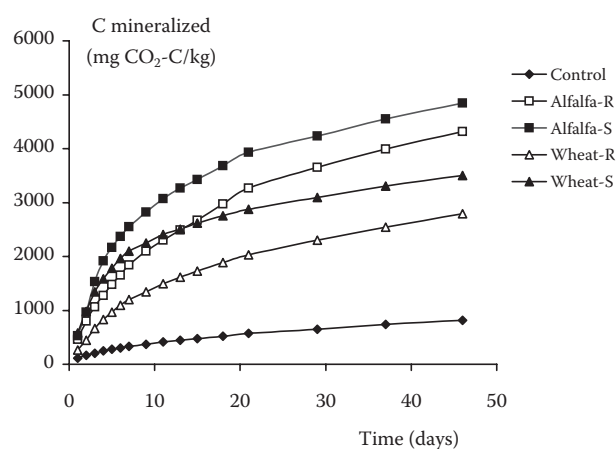


Figure 1. Cumulative carbon dioxide release from soils treated with or without residues (R – roots, S – shoots)

to microbial degradation (Melillo et al. 1982) and forms complexes with proteins present in cell wall (Reeves 1993). On the other hand, N concentration of the plant residues and the KC_0 values was significantly correlated ($r = 0.83$, $P < 0.001$) indicating that residues with higher N contents are more sensitive to biodegradation. The correlation between KC_0 values and N content was much stronger than that of C:N ratios (Table 2).

Net N mineralization/immobilization rates ($N_{m/i}$) during the 8-week period of aerobic incubation ranged between -59.7 to 622.2 mg N/kg for apple tree leaves and alfalfa shoots, respectively. Net immobilization rates of N were observed for the four tree leaves, corn, wheat and barley roots. Other plant residues showed net N mineralization. The net rates of N mineralization or immobilization were significantly correlated with the N concentration in the residues ($r = 0.957$, $P < 0.001$), and associated negatively with C:N ratios ($r = -0.69$, $P < 0.01$) and lignin contents ($r = -0.54$, $P < 0.05$) (Table 2).

To conclude, plant residue decomposition under specific conditions of temperature and moisture is a function of a plant chemical and biochemical quality. Lignin and N contents of the plant residues play an important role in their decomposition. The value of lignin:N can be considered as an index of biodegradability. Lastly, this research was done under laboratory conditions where the residue was ground and mixed with the soil. It is certain that morphological properties of the residues and their contact with the soil also affect residue decomposition rates (Angers and Recous 1997). Studying the effect of residue morphology on the association of C and N transformations in soil warrants further research.

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