Carbon and Nitrogen Mineralized from Leaves and Stems of Four Cover Crops

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ABSTRACT

Increased understanding of surface residue decomposition may improve cover crop management in no-till systems. Most decomposition studies of cover crop residues have been conducted with samples composed of a mixture of leaves and stems. Because leaves and stems have different composition, however, they would be expected to show different mineralization kinetics. The objective of this work was to study C and N mineralization from isolated stems, isolated leaves, and a mix of leaves and stems of wheat (*Triticum aestivum* L.), rye (*Secale cereale* L.) oat (*Avena sativa* L.), and crimson clover (*Trifolium incarnatum* L.). Cecil loamy sand soil (clayey, kaolinitic, thermic Typic Kanhapludult) was packed into acrylic plastic cylinders, adjusted to 55% water-filled porosity, treated with either leaves, stems, or a mix of both (1-cm pieces) on the surface, and incubated at 35 °C for 160 d. Air samples for CO_2 and N_2O determinations were taken periodically and NH_3 evolved was trapped during the first 16 d. Soil columns were leached periodically and leachates were analyzed for N (total and inorganic) and total C. The dynamics of C and N mineralization of a mix of leaves and stems was different from the patterns predicted from isolated leaves and isolated stems. These results indicate a strong interaction between stems and leaves during early stages of decomposition, which may be relevant for predicting N mineralization from cover crop residues. The best predictors for N mineralization were residue C/N ratio and the reciprocal of residue N concentration.

CROP RESIDUE DECOMPOSITION at the soil surface is important in no-till systems. Increased understanding of surface residue decomposition and its associated N mineralization may improve the management of cover crops in these systems.

Some studies from the early 1980s suggested that plant parts with different chemical composition would be expected to show different mineralization kinetics (Harper and Lynch, 1981; Lespinat et al., 1976). More recently, Collins et al. (1990), in a 30-d incubation experiment, showed that when a mix of wheat parts (stems, leaves, leaf sheaths, and chaff) decomposed together, cumulative CO_2 evolution was larger than that predicted by adding cumulative CO_2 evolved from individual components. They hypothesized that decomposition of the mix was stimulated by fungal hyphal extensions from residue components with high substrate concentration to adjacent components with low substrate concentration. If that hypothesis is correct, interaction between the mineralization dynamics of different plant parts might be relevant in determining the release of nutrients to soil.

No attempt has been made to compare N mineralized from isolated cover crop parts with N mineralized from a mixture of the different plant parts. However, a large difference in N content among green manure parts has been shown. Frakenberger and Abdelmagid (1984) studied kinetic parameters of N mineralization rates of leguminous crop parts (stem, leaves, and roots) incorporated into soil and concluded that individual constituents of plant residues are a variable source of N. In a field decomposition study with litter bags, the release of N from roots, leaflets, and stems + petioles of beans (*Vicia faba* L.), timothy (*hleum pratense* L.), and different clovers (*Trifolium repens* L., *T. pratense* L., *T. subterraneum* L.) differed greatly (Müller et al., 1988).

Somewhat contradictory results have been reported when studying the chemical characteristics of plant residues that control the decomposition process. Nitrogen content and C/N ratio have been broadly mentioned as useful indicators (Iritani and Arnold, 1959; Bartholomew, 1964; Jansson and Persson, 1982; Frankenberger and Abdelmagid, 1985). Other studies have reported lignin or lignin/N ratio as being important characteristics governing the decomposition process (Berg and Staaf, 1980; Müller et al., 1988; Vigil and Kissel, 1991). Honeycutt et al. (1993) suggest that part of this apparent disagreement might be due to different lengths of the studies, to the absolute content and relative proportions of chemical constituents in the plant material, and to methodology and interpretation.

Frankenberger and Abdelmagid (1985) noted the usefulness of mineralization kinetic parameters as comparison tools between different substrates and as predictors for N fertilizer needs. They also emphasized the lack of kinetic studies on N mineralization from crop residues.

Information on interactions among plant parts during decomposition processes is currently very limited. Such interactions might be relevant for predicting N mineralization from cover crops. The objectives of this experiment were to: (i) quantify C and N mineralization dynamics for isolated stems, isolated leaves, and a mix of leaves and stems of wheat, rye, oat, and crimson clover; (ii) determine if decomposition of the mix can be predicted from decomposition of the isolated components; (iii) determine residue characteristics that could be used to predict C and N mineralization; and (iv) quantify surface crop residue N mineralization kinetics.

MATERIALS AND METHODS

Soil samples were collected from the upper 10 cm of a no-till field on a Cecil sandy loam. Air-dried (0.014 kg H_2O kg^{-1} dry soil) samples were passed through a 2-mm sieve and stored at room temperature until use. The soil had a pH (1 g soil/2 mL H_2O) of 6.2 and contained 6.01 g C kg^{-1} and 0.47 g N kg^{-1}. Before use, $\approx$7.5 kg of soil was wetted to 0.11 kg kg^{-1} with a N-free solution (Cabrera and Kissel, 1988) and the moist soil was incubated at 35°C for 15 d to obtain a relatively steady rate of N mineralization. After preincubation, the soil (7.5 kg) was packed into Buchner funnels (14-cm i.d.) and leached with 15 L of N-free nutrient solution to remove NO_3^-. The soil was allowed to drain under vacuum until its water content dropped to 0.11 kg kg^{-1} (−0.033 MPa); then it was mixed in a plastic bag, and two 5-g subsamples were

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extracted with 40 mL of 1 *M* KCl for 30 min. The NH_4^+ and NO_3^- concentrations of the soil extract were near zero.

The plant residues consisted of mature leaves and stems of crimson clover, rye, oat, and wheat. The residues were air dried, leaves were separated from stems, and both plant parts were stored at room temperature until use. Leaf sheaths were included in the leaf component. Permanganate lignin, cellulose, and hemicellulose were determined by the acid detergent fiber method (Goering and Van Soest, 1970), and total C and N were measured by dry combustion with a C and N analyzer (Carlo Erba Instruments, Milan, Italy).

Moist soil (90.5 g oven-dry equivalent) was packed to a depth of 3.5 cm in acrylic plastic cylinders (4.4-cm i.d., 10 cm long) to achieve 55% water-filled pore space and a typical field bulk density of 1.7 g cm^{-3} (Perkins, 1987). Water-filled pore space was calculated as (volumetric water content/porosity) $\times 100$ where porosity = (1 − bulk density/2.65).

The bottom end of each cylinder was closed by a perforated rubber stopper with a connector. A nylon screen cloth (screen size 5.3 by 5.3 μm) was located between the soil and the stopper to minimize soil loss during leaching. Two circles of fiberglass mesh (4.4-cm diam., mesh size 1 by 1 mm) were also placed between the nylon screen and the stopper to prevent the screen from adhering to the stopper and reducing the filtering area.

Three treatments were used for each crop residue: leaves, stems, and a mix of 50% leaves and 50% stems (L&S). All residues (1-cm pieces) were surface applied at a rate equivalent to 3000 kg dry matter ha^{-1} (Kamprath et al., 1958). To prevent the residues from floating when the soil was leached, fiberglass mesh (4.4-cm diam., mesh size 1 by 1 mm) was placed on top of the residue layer and held with an acrylic plastic ring that fit inside the cylinder. Each cylinder was placed inside a 0.95-L jar that was sealed with a screw-cap lid fitted with a rubber septum and placed in an incubator at 35°C. The treatments were arranged in a randomized complete-block design with three replications.

Air samples for CO_2 and N_2O analyses were taken daily during the first week and every other day during the following 9 d. Jars were flushed with ambient air after sampling. To trap NH_3 volatilized, each jar contained a vial with 15 mL 0.05 *M* H_2SO_4 that was replaced after 4, 8, and 16 d. After 16 d, the cylinders were retrieved from the jars and placed in a high-humidity (98% relative humidity) chamber (50 by 26 by 30 cm) at 35°C. The atmosphere of the chamber was continuously renewed by circulating humidified air at 1 L min^{-1}. Cylinders were removed from the chamber and sealed in jars 48 h before air sampling at 30, 60, 90, 128, and 160 d after residue application. Respiration rates between measurements were estimated by linear interpolation and rates were integrated with the Romberg method using Mathcad[3.1] (Mathsoft Inc., 1992).

Following air sampling at 8, 16, 30, 60, 90, 128, and 160 d, soil cores were leached with 160 mL of 0.01 *M* $CaCl_2$ solution in two 80-mL increments, followed by 30 mL of N-free solution (preliminary work had shown that leaching with 190 mL of solution was sufficient to remove all NO_3^-–N from the soil). The leachates were made up to 200 mL with 0.01 *M* $CaCl_2$, and subsamples were saved at −25°C for later analyses. After the leaching procedure, the cores were allowed to drain under vacuum until a weight within 0.1 g of that measured at the beginning of the experiment was achieved. The leaching procedure took ≈5 h.

After 160 d, the experimental units were taken apart. The remaining residue was separated from the soil core, oven dried at 65°C for 48 h, and weighed. The whole soil core was extracted with 500 mL of 1 *M* KCl for 30 min. A 40-mL subsample of the extract was centrifuged for 20 min at 608 $\times$ *g*, and a subsample of the supernatant volume was saved at −25°C for later analyses.

To estimate the content of soluble C in the residues, 0.5 g of each residue was vigorously shaken with 40 mL of double-deionized H_2O for 30 s, and the supernatant liquid was passed through a Whatman no. 42 filter paper prerinsed with 60 mL of double-deionized water. This whole procedure was repeated four times, and the filtrate was made up to 200 mL. Samples of double-deionized water passed through a prerinsed (60 mL) Whatman no. 42 filter paper were included as controls. Filtered extracts were stored at −25°C until they were analyzed for total C and N.

Leachates and soil extracts were analyzed for inorganic N ($NO_3^- + NO_2^-$)–N by the Griess–Ilosvay method (Keeney and Nelson, 1982), after reduction of NO_3^- to NO_2^- with a Cd column. Ammonium–N in leachates, soil extracts, and NH_3 traps was determined by the salicylate–hypochlorite method (Crooke and Simpson, 1971). Total N in leachates and soil extracts was determined by the alkaline persulfate oxidation method (Cabrera and Beare, 1993), and total organic C was measured with a combustion–nondispersive infrared method on a Shimadzu TOC-400 Analyzer (Shimadzu Corp., Kyoto, Japan).

The amounts of N mineralized from each residue were calculated by adding leached inorganic N and gaseous losses (NH_3 and N_2O) and subtracting values measured in control treatments. Carbon recovered from each residue was calculated as the sum of CO_2–C evolved (with control subtracted), C remaining on the soil surface at the end of the experiment, and total C in the leachates (with control subtracted). Nitrogen recovered was obtained by adding N mineralized, N remaining on the soil surface at the end of the experiment, and organic N in leachates (with control subtracted).

Data were analyzed using the procedure GLM in SAS (SAS Institute, 1985). A linear contrast of the form L&S minus one-half the leaves-only value minus one-half the stems-only value was used to determine if the decomposition of the mix of leaves and stems could be predicted from decomposition of isolated plant parts. Because percentages referred to different quantities (i.e., initial C or N applied), C and N estimates for L&S could not be obtained from the leaves-only and stems-only percentage data. Therefore, linear contrasts were applied to C and N mineralized or remaining expressed as mass per unit area (grams per square meter). Stepwise regression analysis was used to study the relationship between litter quality characteristics and C and N mineralized. Procedure NLIN in SAS (SAS Institute, 1985) was used to fit a model for describing cumulative net N mineralized with time.

RESULTS AND DISCUSSION

The chemical composition of the cover crop residues varied widely (Table 1). In all cases, leaves had a larger N concentration and a lower C/N ratio than stems. Also, the lignin concentration of stems was larger than that of leaves for all crops.

In general, CO_2 emission rates peaked 3 or 4 d after residue application and then decreased to reach relatively low values after 16 or 30 d. The high, initial rates of CO_2 emission are reflected in the sharp initial slopes of the cumulative curves (Fig. 1). Similarly, net N mineralization curves for residues that did not show net immobilization were characterized by an initial phase (0–16 d) of fast N release followed by a decrease in mineralization

Table 1. Selected properties of crop residues.

Residue	C/N	C		N	Lignin	Cellulose	Hemicellulose
		Total	Soluble				
		g kg^{-1}					
Clover leaves	10.1	445.4	111.8	44.1	56	180	89
Clover stems	31.9	433.8	59.9	13.6	142	414	109
Rye leaves	28.9	454.7	65.9	15.7	26	294	280
Rye stems	98.9	455.9	67.5	4.6	63	411	255
Wheat leaves	13.1	400.0	54.8	30.5	42	233	302
Wheat stems	86.5	449.8	134.0	5.2	83	277	146
Oat leaves	12.8	468.5	58.1	36.6	36	263	248
Oat stems	78.8	449.1	68.2	5.7	90	390	202

(Fig. 2). These observations led us to distinguish two periods for analysis purposes: from 0 to 16 d and from Day 17 until the end of the experiment.

In all cases, cumulative CO_2 evolved during the first 16 d was always larger for leaves than for stems (Table 2). The amount evolved from L&S was intermediate, except for wheat and clover where it was similar to the amount measured in leaves. The remaining C at the end of the experiment was larger in the stems than in the leaves of clover, rye, and oat. The amount of C remaining in wheat was similar for leaves, stems, and L&S, which agrees with the fact that the amount of CO_2 evolved during 160 d was similar for the three treatments.

We constructed contrasts to determine if the amount of CO_2 emitted from L&S could be predicted from the results of stems-only and leaves-only treatments (Table 3). A contrast not significantly different from zero indicates that the values for L&S can be predicted from stems and leaves. In the case of rye, wheat, and oat, the cumulative CO_2 evolved from L&S during the first 16 d was significantly larger than that predicted from isolated stems and leaves. However, the contrast for C evolved during the whole decomposition period and the contrast for remaining C at the end of the experiment were only significant for oat. These results suggest that in cereals, there was a strong interaction between leaves and stems in the initial stages of decomposition. After 160 d, however, this initial enhancement in CO_2 evolution was only significant for oat.

These findings agree with those of Collins et al. (1990) who reported that in a 30-d incubation, CO_2 evolution from a mixture of wheat plant parts increased up to 25% with respect to the amount predicted by summing CO_2 evolution from individual components. To compare our results with those obtained by Collins et al. (1990), we constructed contrasts for CO_2 evolved during the first 30 d. We found that the contrasts were significant for cereals, and that cumulative CO_2 evolved from L&S was 8, 6, and 5% above that predicted from isolated leaves and isolated stems of oat, wheat, and rye, respectively. The interaction effect would probably depend on the actual distribution of leaves and stems in the residues. We mixed 50% of each component because that was close to our field values (59, 42, 49, and 52% of the

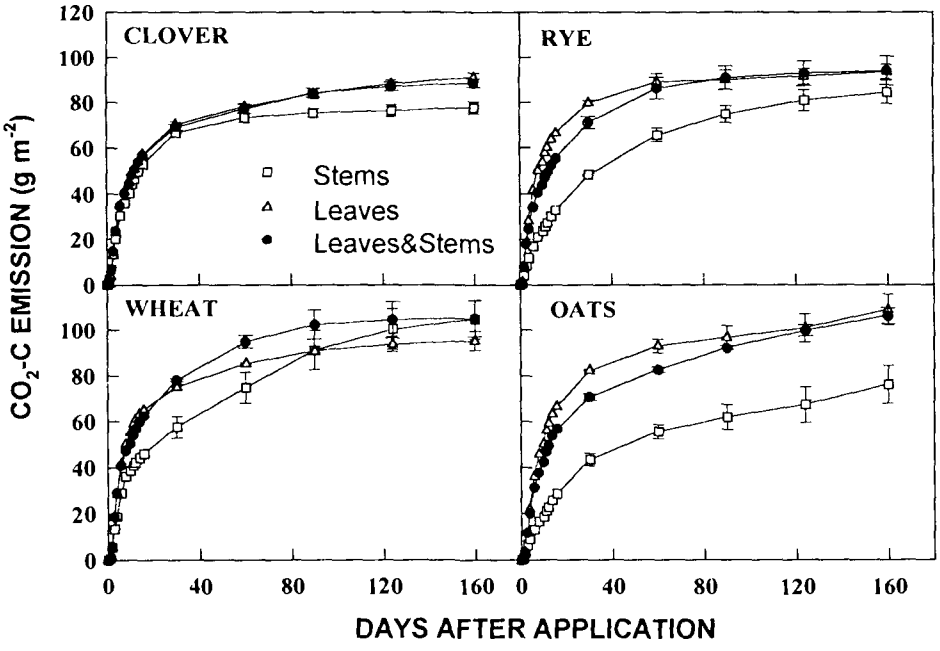

Fig. 1. Cumulative CO_2-C emission (± standard error) from isolated leaves, isolated stems, and stems and leaves of clover, rye, wheat, and oat applied on the soil surface and incubated at 35°C for 160 d. (Error bars are not included for the first 16 d to improve readability; where bars do not appear after 30 d, symbols were larger than errors).

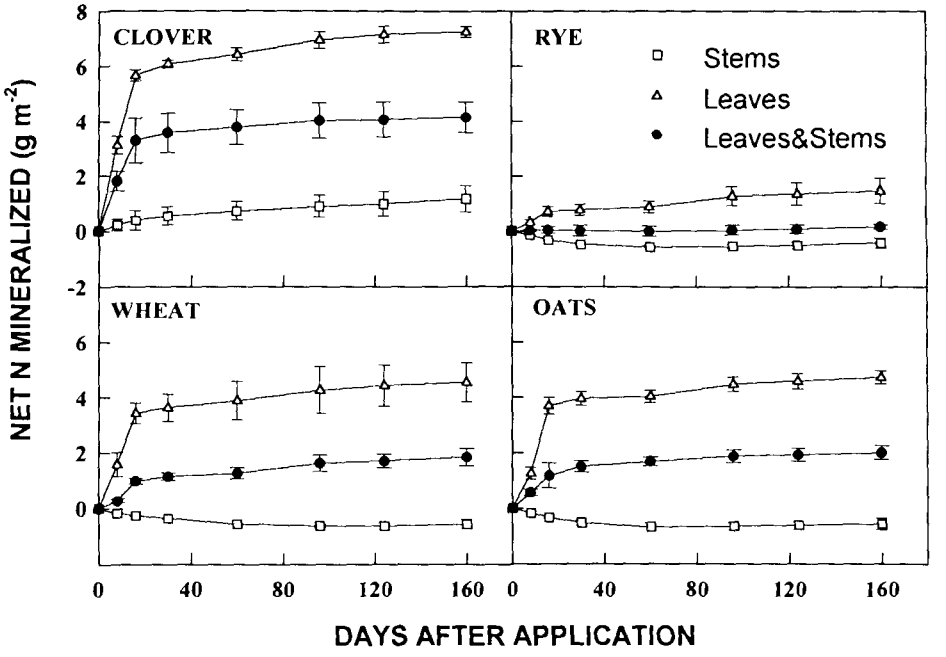

Fig. 2. Cumulative net N mineralized (± standard error) from isolated leaves, isolated stems, and stems and leaves of clover, rye, wheat, and oat applied on the soil surface and incubated at 35°C for 160 d. (Where bars do not appear, symbols were larger than errors).

dry weight were stems for clover, oat, rye, and wheat, respectively). However, it should be borne in mind that component proportions are likely to depend on many factors, such as desication time and cover crop type.

For all crops, the cumulative N released during the first 16 d was larger for leaves, followed by L&S, and finally stems (Table 4). Clover stems were the only stems that did not show net N immobilization at the end of this first period. During the second period (17–160 d), stems of cereals continued immobilizing N, whereas leaves and L&S showed net N mineralization. There was no significant difference in net N mineralized (17–160 d) among the three treatments of clover.

Net N mineralization was detected after 60 d for oat and rye stems and after 96 d for wheat stems. According to Stevenson (1985), net immobilization lasts until the C/N ratio of the decomposing material has been lowered to ≈20. In our case, the C/N ratio of the organic material remaining on the soil surface at the end of the experiment was >28 for the three cereal stems (Table 5), which indicates that net N mineralization can commence before the C/N of the residue ratio is lowered to 20.

It should be mentioned that in most cases, the amount of inorganic N in the leachates was above 0.8 mg N L^{-1} (except for the rye stems treatment at 16 d in which the inorganic N in leachates was 0.1 mg N L^{-1}), suggesting that the Cecil soil used, which has a low N mineralization rate (0.125 kg N ha^{-1} d^{-1}), was able to supply the N required for residue decomposition. These results support the observation of Smith and Sharpley (1990) of less drastic effects on soil N availability when high C/N ratio crop residues are left on the soil surface than when they are incorporated.

During the first 16 d, the cumulative N mineralized from the L&S cereal treatments was smaller than predicted from the isolated leaves and stems; it was significantly different for the wheat and oat at a 0.1 level and for rye at a 0.05 level (Table 3). These results support the strong interaction between leaves and stems (in the initial stages of decomposition) suggested by the CO_2 evolution data. The larger than predicted CO_2 emission from the L&S treatments was associated with a larger microbial activity that apparently led to an increase in N immobilization.

Table 2. Estimated cumulative CO_2-C evolved, C remaining, and C recovered from clover, rye, wheat, and oat residues applied on the soil surface and incubated at 35°C for 160 d.

Residue	Cumulative CO_2-C evolved 0–16 d	17–160 d	0–160 d	C remaining	C recovered†
	% of C applied				
Clover					
Stems	40.5 b‡	18.8 b	59.3 b	38.1 a	100.8 ± 0.9
Leaves	42.9 a	25.4 a	68.3 a	27.6 c	100.2 ± 1.4
L&S§	42.8 a	23.9 a	66.7 a	33.5 b	102.1 ± 1.3
Rye					
Stems	24.3 c	38.0 a	62.3 a	38.1 a	101.4 ± 3.5
Leaves	48.7 a	19.9 b	68.6 a	25.2 b	94.7 ± 1.7
L&S	40.9 b	28.4 b	69.3 a	29.9 b	100.1 ± 2.1
Wheat					
Stems	31.4 b	37.9 a	69.3 a	29.9 a	102.3 ± 1.7
Leaves	47.3 a	24.2 b	71.5 a	30.4 a	101.8 ± 0.3
L&S	43.8 a	29.9 b	73.7 a	28.5 a	103.8 ± 3.5
Oat					
Stems	21.4 c	35.4 a	56.8 b	42.3 a	100.7 ± 0.8
Leaves	47.4 a	30.2 b	77.6 a	24.9 b	105.1 ± 2.2
L&S	41.2 b	35.9 a	77.1 a	24.4 b	105.7 ± 1.6

† C recovered (mean ± standard error) = CO_2 evolved + C remaining + soluble C in leachates.

‡ Within a column and crop, means followed by the same letter are not significantly different according to Fisher's LSD at a 0.05 probability level.

§ L&S = 50% leaves + 50% stems.

Table 3. Contrasts† for cumulative CO_2-C evolved, N mineralized, and C and N remaining in residue from clover, rye, wheat, and oat applied on the soil surface and incubated at 35°C for 160 d.

Residue	Cumulative CO_2 evolved			C remaining	N mineralized			N remaining
	0–16 d	17–160 d	0–160 d		0–16 d	17–160 d	0–160 d	
	g m^{-2}							
Clover	1.43	2.32	3.75	0.95	0.133	−0.353	−0.213	0.268
Rye	6.03**	−0.78	5.26	−2.40	−0.176*	−0.205	−0.380	0.383*
Wheat	6.27**	−1.98	4.29	−2.08	−0.638**	0.385*	−0.253	0.201
Oat	8.98**	4.34	13.32*	−12.41**	−0.694**	0.420*	−0.274	0.218

* and ** Significant at 0.05 and 0.01 probability levels, respectively.
† Contrast = leaf and stem mix − ½ leaf-only − ½ stem-only.

The contrast for N remaining at the end of the experiment was not significant for wheat and oat but was positive and significant for rye (Table 3). This means that the amount of N remaining in L&S of rye was larger that the amount predicted from isolated leaves and stems, which further indicates an enhancement in N immobilization when leaves are mixed with stems. In fact, the contrast for N mineralized after 160 d was negative and significant for rye at a 0.1 level. The contrast for N remaining was not significant for wheat and oat, probably because during the second period, the N mineralized from L&S was larger than the amount predicted from isolated leaves and isolated stems.

The total amount of residue C recovered was ≈ 100% for all residues; however, recoveries of N were lower with the exception of clover (Tables 2 and 4). Total N recovered was as low as 71, 60, and 52% for rye, wheat, and oat stems, respectively. We think that the reason for that low N recovery might be that part of the soluble C in the residue (Table 1) was moved into the soil during the leaching process and that some of the inorganic N released from the residue and from the soil was reimmobilized by the soil microorganisms to meet their N requirements. This reimmobilization may occur in all treatments, but it may only be noticeable in the ones where the N concentration of the residue applied was low. As an example, in the case of wheat stems, the cumulative N immobilized at the end of the experiment was 0.89 mg, which represents 34.4% of the initial N applied. If we assume a biomass C/N ratio of 8 (Knapp et al., 1983), the amount of C immobilized with 0.89 mg N would have been 7.1 mg, which represents 3% of the initial C applied. Part of this C and N was probably immobilized in the residue, and therefore was recovered at the end of the experiment; however, another part was immobilized within the soil and was not accounted for in the final balance. Apparently, the percentage of C retained within the soil was too low to be detected in our final results.

Another possible explanation for the low N recovery might be a loss of N in gaseous form. However, denitrification losses were expected to be low according to the results of Aulakh et al. (1991). In fact, N_2O losses measured during the whole experiment were lower than 1% of the N applied (data not shown). Ammonia volatillization losses during the first 16 d were accounted for, with >92% of the total NH_3 loss measured during the first 8 d. Ammonia volatilization from crop residues applied on the soil surface has been reported to present a rapid initial phase and an indefinite period of very slow volatilization (Janzen and McGinn, 1991). Therefore, the NH_3 measured during the first 16 d must have represented most of the losses that occurred during the study.

A multiple linear regression stepwise procedure was

Table 4. Cumulative N mineralized, N remaining, and N recovered from clover, rye, wheat, and oat residues applied on the soil surface and incubated at 35°C for 160 d.

Residue	N mineralized			N remaining	N recovered†
	0–16 d	17–160 d	0–160 d		
	% of N applied				
			Clover		
Stems	10.1 b‡	18.9 a	29.0 b	69.86 a	107.4 ± 5.8
Leaves	49.3 a	12.2 a	61.4 a	32.39 b	99.5 ± 0.3
L&S§	41.6 a	9.7 a	51.3 a	44.32 b	103.1 ± 4.6
			Rye		
Stems	−23.7 c	−8.6 b	−32.3 c	99.36 a	70.8 ± 5.5
Leaves	16.6 a	16.0 a	32.6 a	57.43 b	95.6 ± 4.2
L&S	1.7 b	3.7 ab	5.4 b	79.50 c	86.5 ± 4.8
			Wheat		
Stems	−15.8 c	−17.8 b	−33.6 c	90.8 a	60.3 ± 8.8
Leaves	36.3 a	10.9 a	47.2 a	42.0 b	92.8 ± 7.4
L&S	16.8 b	13.9 a	30.7 b	52.8 b	87.6 ± 3.4
			Oat		
Stems	−19.7 c	−13.5 b	−33.2 c	82.3 a	51.9 ± 8.3
Leaves	37.2 a	9.6 a	46.8 a	32.9 c	82.4 ± 3.6
L&S	18.6 b	13.1 a	31.7 b	43.0 b	80.4 ± 3.8

† N recovered (mean ± standard error) = N mineralized + N remaining + organic N in leachates.
‡ Within a column and crop, means followed by the same letter are not significantly different according to Fisher's LSD at a 0.05 probability level.
§ L&S = 50% leaves + 50% stems.

Table 5. Amount and C/N ratio (mean ± standard error) of the organic material left on the soil surface after incubating clover, rye, wheat, and oat residues at 35°C for 160 d.

Residue	Dry matter	C/N
	g m^{-2}	
	Clover	
Stems	107.4 ± 2.8	17.4 ± 0.3
Leaves	87.9 ± 3.4	8.6 ± 0.1
L&S†	101.9 ± 1.3	11.5 ± 0.1
	Rye	
Stems	111.8 ± 3.4	37.9 ± 1.4
Leaves	71.4 ± 1.4	12.7 ± 0.1
L&S	86.0 ± 2.0	16.9 ± 0.5
	Wheat	
Stems	89.0 ± 4.6	28.7 ± 2.2
Leaves	87.4 ± 4.8	9.4 ± 0.1
L&S	85.4 ± 2.0	12.3 ± 0.1
	Oat	
Stems	111.6 ± 4.7	40.5 ± 1.2
Leaves	66.8 ± 5.2	9.0 ± 0.1
L&S	70.0 ± 1.2	12.4 ± 0.3

† L&S = 50% leaves + 50% stems.

Table 6. Predictive equations for the percentage of N mineralized, N_0†, and N remaining from clover, rye, wheat, and oat residues applied on the soil surface and incubated at 35°C for 160 d.

Independent variable‡	Equation	R^2	Equation	R^2
N mineralized 0 to 16 d	48.1 − 0.78C/N§	0.93	65.2 − 49.49 × 1/N	0.96
N mineralized 0 to 160 d	63.7 − 1.07C/N	0.95	49.4 − 36.40 × 1/N	0.94
N remaining after 160 d	32.3 + 0.66C/N	0.97	31.4 + 30.60 × 1/N	0.98
N_0	62.0 − 0.78C/N	0.95	63.5 − 50.98 × 1/N	0.96

† Nitrogen mineralization potential estimated from $N_{min} = N_0 (1 - e^{-kt})$.
‡ Independent variable expressed as percentage of N applied.
§ C/N = C to N ratio; C = C content (g kg^{-1}); N = N content (g kg^{-1}).

used in an attempt to identify the residue characteristics that best predicted CO_2 evolution and N mineralization. The variables considered were N content (actual value, square root of N content, and the reciprocal of the N content), C/N ratio, lignin content, lignin/N ratio, cellulose and hemicellulose content, percentage of soluble C, and acid detergent fiber.

The best model fit to the percentage of C evolved as CO_2 during the first 16 d (X) was

$$X = 49.04 - 0.122\text{C/N} - 0.780\,\text{LIGN/N} \quad R^2 = 0.82$$

where C, N, and LIGN are the C, N, and lignin concentrations (g kg^{-1}) of the residues (Table 1), respectively. We could not find good predictors for the CO_2 evolved during the second period of the experiment, for the total CO_2 evolved, and for the C remaining at the end of the incubation. These results agree with Berg (1986) in that the decomposition of organic material is only initially influenced by its nutrient level (especially N and P).

The stepwise regression showed that C/N ratio and the reciprocal of the N concentration of the residues were the best predictors for the percentage of N mineralized and for N remaining at the end of the experiment (Table 6). These results agree with those of Vigil and Kissel (1991); however, in our study, the reciprocal of the N concentration was a better predictor than the square root of N. Our findings also agree with other researchers who found N content and C/N ratio to be the best predictors for N mineralized (Iritani and Arnold, 1959; Frankenberger and Abdelmagid, 1985).

Cumulative N mineralized was adequately described by the first-order model:

$$N_{min} = N_0(1 - e^{-kt})$$

where N_{min} is the cumulative amount of N mineralized at a specific time (t), N_0 is the mineralization potential, and k is the first-order rate constant.

The N_0 values were quite close to the N mineralized in 160 d (Tables 4 and 7). In general, N_0 values were largest for leaves, followed by L&S, and then stems. There were also differences in k values, but because they are related to N_0, the comparison of k values between treatments having very different N_0 values is not very meaningful. The N_0 and k values are larger than the ones presented by Frankenberger and Abdelmagid (1985); however, the temperature used in our study was 35°C vs. the 23°C used in their study. As for N mineralized in 160 d, the reciprocal of the N concentration and C/N ratio were the best predictors of N_0 (Table 6). We could not find good predictors for the mineralization rate constants. We are aware that residue decomposition rates depend on microbial populations and their affinities for the various substrates available. However, it was not the objective of this study to elucidate the role of the different microorganisms involved.

Table 7. Kinetic parameters (N_0, k) and root mean square error (RMSE) for cumulative N mineralized from clover, rye, wheat, and oat residues applied on the soil surface and incubated at 35°C for 160 d.

Residue	N_0†	k†	RMSE
	% N applied	d^{-1}	%
	Clover		
Stems	27.4 b‡	0.0281 b	1.97
Leaves	59.0 a	0.0946 a	2.96
L&S§	49.8 a	0.0923 a	2.75
	Rye		
Stems	37.8 c	0.0643 a	3.87
Leaves	30.8 a	0.0351 b	3.08
L&S	4.9 b	0.0620 a	1.95
	Wheat		
Stems	37.6 c	0.0360 b	2.75
Leaves	44.6 a	0.0806 a	3.00
L&S	28.5 b	0.0370 b	2.75
	Oat		
Stems	36.9 b	0.0567 a	2.05
Leaves	44.7 a	0.0767 b	3.93
L&S	35.1 a	0.0507 a	3.28

† Estimated from the model $N_{min} = N_0 (1 - e^{-kt})$.
‡ Within a column and crop, means followed by the same letter are not significantly different according to Fisher's LSD at a 0.05 probability level.
§ L&S = 50% leaves + 50% stems.

To summarize, the dynamics of C and N mineralization of a mix of leaves and stems was different from the patterns predicted from isolated leaves and isolated stems. In particular, the N immobilized and the CO_2 released from cereals during the first 16 d of decomposition was larger than the amounts predicted from isolated leaves and stems. These results support the conclusion of Collins et al. (1990) regarding the existence of interactions between plant parts during decomposition. Information about interactions among residue constituents may be relevant for predicting N mineralization from cover crops, especially during the initial stages of decomposition when most of the potentially mineralizable N is released to the soil. A model involving C/N and lignin/N ratios gave the best fit to CO_2 evolved during the first 16 d of decomposition. The best predictors for N mineralized, N remaining at the end of the experiment, and N_0 of the crop residues were the C/N ratio and the reciprocal of N concentration of the residues. Further studies on N mineralization kinetics might be useful to compare the N supplying capacity of cover crops (N_0) under standardized conditions, and to understand the effect of soil characteristics and climatic conditions on mineralization rates.

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