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C, N, and S mineralization of crop residues as influenced by crop species and nutrient regime

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Abstract

The mineralization of C, N, and S from residues of three different crop species (wheat, lentil, and rape) grown under diverse nutritional regimes was measured over a 12-week incubation period under controlled conditions. The rate of decomposition, as measured by CO_2 evolution, varied considerably among treatments and appeared to be controlled almost entirely by N content of the residue ($R^2 = 0.98$). Similarly, N mineralization was strongly tied to N concentration. The critical N concentration, below which significant immobilization of N occurred, declined over time, ranging from 1.9% at day 14 to 1.1% at day 84. Mineralization of S was positively correlated with initial S concentration ($R^2 = 0.95$) and negatively related to N concentration, apparently because of a dilution effect. The results demonstrate that decomposition and N and S mineralization of crop residues, under conditions prevalent in the experiment, are primarily a function of their nutrient concentrations rather than biochemial composition related to crop species. As a result, it should be possible to enhance rate of residue decomposition, increase quantities of N and S mineralized, and avert detrimental immobilization losses in the following year by governing the nutritional regime under which the crop is grown.

Introduction

Crop residues are vital resources for the conservation of soil productivity. Not only are residues the primary substrate for the replenishment of soil organic matter, but they also serve as an important source of nutrients. The development of agronomic strategies for efficient utilization of crop residues demands an understanding of the factors affecting the decomposition and fate of this resource upon application to the soil.

One of the most important factors governing the turnover and fate of crop residues is their chemical composition. Large differences in decomposition rates and nutrient release patterns have been observed among different residue materials, particularly in the early stages of decomposition. These differences have been variously ascribed to differences in crop residue characteristics including concentrations of N, S, lignins, various carbohydrates, and water-soluble C and nutrients (Herman *et al.*, 1977; Parr and Papendick, 1978; Reinertsen *et al.*, 1984). Specific characterization of factors governing residue decomposition would facilitate production of more beneficial residue by manipulation of crop genotype or soil fertility.

The objective of the present study was to determine the relative importance of nutrient concentration and genetically controlled biochemical composition in determining rate of residue decomposition. This objective was addressed by measuring decomposition of residues from three diverse crop species, each grown under three nutritional regimes. In this way, the effect of nutrient concentration could be at least partially separated from that of composition inherent to a species. Decomposition was studied under conditions of intermittent leaching to remove accumulated nutrients and simulate nutrient uptake by crops.

Materials and methods

Oilseed rape (*Brassoca napus* L."Westar"), wheat (*Triticum aestivum* L. "Chester"), and lentil (*Lens culinaris* Medik "Laird") were grown to maturity in a 3:1 sand:soil mixture under controlled environment conditions. Each crop was grown under three general fertility regimes: low-N (N deficient), moderate-N (N close to adequate for maximum growth as estimated by visual observation), and high-N (N in excess of growth requirements). To achieve these treatments, N (as ^{15}N-labelled $Ca(NO_3)_2$, 20 % enrichment) was applied in solution form periodically throughout the growing season as required based on visual observation of growth rates and deficiency symptoms. Relative amounts of N applied at each time to the low-N, moderate-N, and high-N treatments were usually 1:2:4. Sulfur, as $Na_2(SO_4)$, was also applied periodically throughout the growing season in solution form. Sufficient K, P, and micronutrients were applied to ensure that these nutrients did not restrict growth. Crop residue constituted all shoot material, excluding grain and pods or chaff, plus any leaves which abscised during the course of the growing season. This material was dried (70°C), ground, and mixed to ensure uniformity of subsamples.

The dried crop residues were analyzed for total N content by digestion with sulfuric acid and hydrogen peroxide (Thomas *et al.*, 1967) and steam distillation of appropriate aliquots (Bremner, 1965) (Table 1). The distillate was dried and its $^{15}N/^{14}N$ ratio determined by mass spectrometer. Total S content of the residues was measured by digestion with perchloric, nitric, and hydrochloric acids and subsequent colorimetric analysis of the sulfate content. Proximate analysis of the crop residues was carried out in duplicate using the method of Harper and Lynch (1981).

The decomposition of crop residues was measured in a surface soil collected from a long-term unfertilized experimental plot in a fallow-wheat cropping system. Detailed analyses of this soil have been reported by Dormaar and Pittman (1980).

Three replicates of each crop residue treatment plus a control treatment receiving no crop residue (total of 10 treatments) were prepared. Soil (80 g) mixed with 80 g of washed silica sand to facilitate leaching was weighed into 150-ml polystyrene filter units. The various crop residues (1.6 g) were stirred into the soil, sufficient water was added to bring the moisture content to near field capacity, and the incubation vessel was sealed to prevent CO_2 escape. All soil treatments were then incubated for 84 days at 21°C.

During the course of the incubation, air was continuously passed over the soil surface and bubbled through absorption towers containing 1 *M* NaOH to remove and collect evolved CO_2. To avoid contamination from atmospheric N and C, and to prevent soil drying, the air stream was initially scrubbed with H_2SO_4 and KOH and bubbled through water. Any CO_2 originating from the atmosphere or the absorption solution was measured in parallel absorption towers. Periodically (after days 1, 3, 7, 10, 14, 21, 28, 42, 56, and 84) the NaOH in the absorption towers was removed for

Table 1. Composition of crop residues

Crop	N status	% N	N-15 (atom %)	% S	Proximate analysis[a] (%)				
					C/N[b]	WS	LI	HC	CL
Wheat	Low	0.389	-[c]	0.28	116	23	17	36	22
	Moderate	1.190	4.8761	0.23	38	28	20	29	22
	High	1.245	4.8790	0.15	36	31	21	24	23
Lentil	Low	1.212	2.5061	0.28	37	35	25	22	14
	Moderate	1.423	3.3645	0.31	32	32	27	18	21
	High	1.905	4.4435	0.28	24	41	27	16	15
Rape	Low	0.583	5.7435	0.97	77	24	28	22	26
	Moderate	0.684	4.6700	0.33	66	25	29	23	22
	High	1.184	5.0356	0.19	38	32	31	16	19

[a] WS = water-soluble fraction; LI = lignin fraction; HC = hemi-cellulose fraction; and CL = cellulose fraction.
[b] C concentration of 45 % assumed.
[c] Not determined.

analysis of CO_2, collected and replaced with fresh NaOH. The CO_2 collected in the NaOH absorption towers was measured by direct titration (Tiessen *et al.*, 1981).

Production of mineral N and S was determined using a method similar to that of Stanford and Smith (1972) by leaching the soils with 0.001 *M* $CaCl_2$ under vacuum (25 cm) at days 14, 28, 56, and 84. These extracts were analyzed for N concentration using steam distillation (Bremner, 1965). Portions of the distillate were dried and analyzed using a mass spectrometer to determine the abundance of ^{15}N. Sulfur concentration was determined by an automated method based on the colorimetric analysis of unprecipitated Ba.

The soil in several of the incubation vessels was contaminated with small amounts of NaOH as the result of momentary backflows in the air stream. These soils dispersed, yielding colored extracts, and were therefore excluded from statistical analyses.

Results

CO_2 evolution

The cumulative amount of CO_2 evolved during the decomposition of the applied residues was affected by crop species ($P = 0.0001$), nutrient status ($P = 0.0001$), and the interaction of these terms ($P = 0.001$) for all times of measurement.

In low-N fertility treatments, CO_2 production varied widely among crop species (Figure 1). Highest rates of CO_2 production in these treatments were observed in lentil residues, followed consecutively by rape and wheat. With increasing N status of the residues, the amount of C mineralized increased consistently in all crops, but the size of the response varied from crop to crop. In the lentil residues, amount of C evolved increased only marginally with increasing N status. By comparison, the amount of CO_2 evolved from wheat straw and rape straw increased substantially from the low-N to the high-N treatments. At the high-N status, therefore, the CO_2 evolution from all crop residues was essentially identical.

The amount of C mineralized was positively correlated with the N concentration of the crop residue and the size of the water-soluble fraction (Table 2). A significant negative correlation was observed for the relationship between C respired and C/N ration, S concentration, cellulose content, and hemicellulose content.

N mineralization

Cumulative N mineralization from the crop residue was affected both by crop species ($P = 0.0001$) and nutritional status ($P = 0.0001$) for all times of measurement. The interactive effect was only significant ($P = 0.0001$) for the first 14-day period.

In the lentil treatments, significant mineraliza-

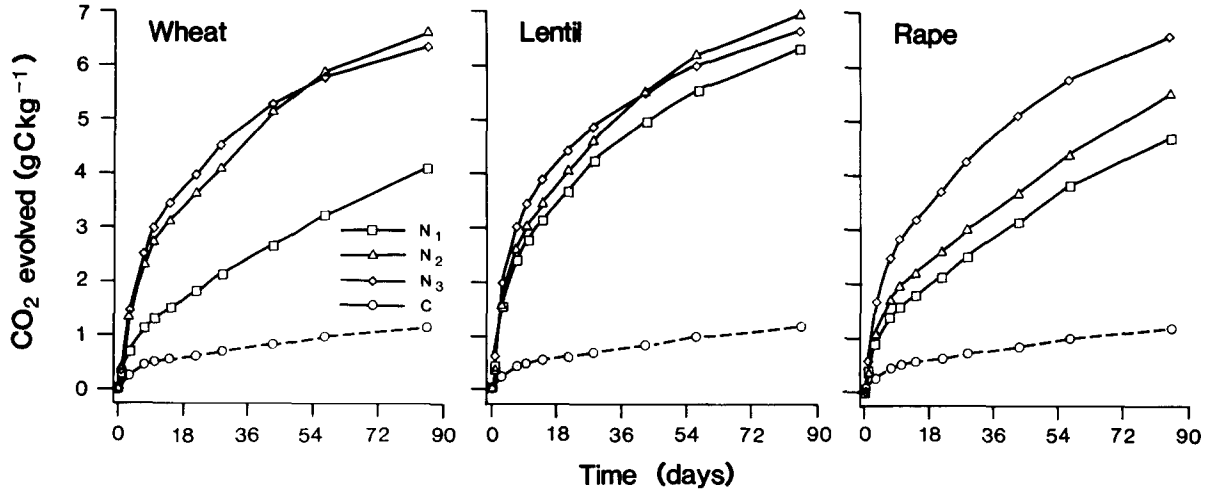

Fig. 1. Effect of crop and nutritional status on CO_2 evolution from crop residues (N_1 = low N; N_2 = moderate N; N_3 = high N; C = control [no residue]).

Table 2. Correlation between cumulative CO_2 production and various properties of crop residue for selected times

Dependent variable	Time (days)			
	7	14	28	58
r value				
N (%)	0.97	0.96	0.94	0.90
C/N	−0.95	−0.95	−0.95	−0.96
S (%)	−0.58	−0.58	−0.56	−0.54
Water-soluble	0.90	0.88	0.81	0.78
Lignin	NS	NS	NS	NS
Hemi-cellulose	−0.67	−0.63	−0.61	−0.61
Cellulose	−0.60	−0.57	−0.51	−0.49

tion of N was observed in all treatments and throughout the experiment (Figure 2) but the amount of mineralization was affected by nutritional status. Cumulative N mineralization increased as the N status of the residue increased, particularly at early stages of the incubation. Mineralization of N from the high-N residue was always higher than that in the control soil. In the moderate-N treatment, cumulative N mineralization exceeded that in the control only after 56 days. Cumulative N mineralization in the low-N lentil treatment remained below that observed in the control for most of the incubation.

Mineralization of N from wheat straw was more strongly affected by nutritional status of the crop than was observed for lentil (Figure 2). No appreciable N mineralization was measured in the soil of the low-N residue treatment for the duration of the experiment. The moderate-N residue treatment exhibited significant N mineralization after 28 days but amounts remained lower than that observed in the control for the entire experiment. Mineralization of N from the high-N residue exceeded the amount of N mineralized from the control after 28 days and approached that observed for the high-N lentil residue after 84 days. In all treatments, there was a complete suppression of N mineralization during the initial 14 days of incubation.

Nitrogen mineralization from rape residues was lower than that from either wheat or lentil residues. Mineralization of N in the low- and moderate-N treatments was negligible for the duration of the experiment. Significant mineralization of N was observed from the high-N residues but total amount mineralized never exceeded the amount observed in the control treatment. All rape residues, therefore, regardless of nutritional status, exhibited less N mineralization than the control treatment.

The direct contribution of the crop residues to the mineral N pool, as measured by ^{15}N analysis, was minimal (Table 3). After 4 weeks the net release of residue N into mineral form was usually less than 5 % of the amount applied, even in treatments where significant mineralization was observed.

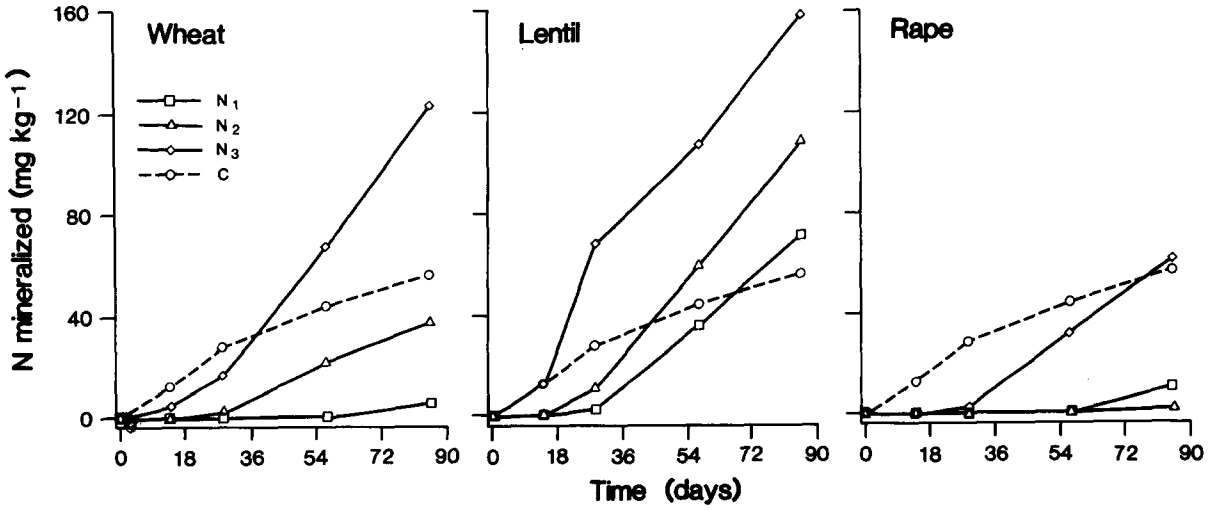

Fig. 2. Effect of crop and nutritional status on N mineralization from crop residues (N_1 = low N; N_2 = moderate N; N_3 = high N; C = control [no residue]).

Table 3. Effects of crop species and crop N on net mineralization of residue N content after 2 and 4 weeks of incubation as determined from ^{15}N analysis

Crop	N level	% residue-N mineralized		Residue N/total N (%)		
		0–2 wks	0–4 wks	0–2 wks	2–4 wks	6–8 wks
Wheat	1	n.d.	n.d.	n.d.	n.d.	n.d.
	2	0.04	0.46	43	55	62
	3	1.47	3.99	77	57	61
Lentil	1	0.05	0.71	44	69	61
	2	0.04	2.76	82	69	59
	3	2.58	13.70	76	76	64
Rape	1	0.04	n.d.	83	n.d.	20
	2	0.02	0.06	45	39	48
	3	0.05	0.53	84	50	59

Nitrogen derived from the crop residue usually accounted for over half of the extractable N present in the soil (Table 3). This parameter was affected both by crop species and by nutrient status ($P = 0.01$). Mean values for nitrogen derived from crop residue for the three measurement periods were 59, 67, and 54% for wheat, lentil, and rape residue, respectively. Values increased with increasing N status of the residues and average 55, 57, and 69% for low-, moderate-, and high-N treatments, respectively. The proportion of N derived from the residues tended to decline with time (65, 60, 56% for 0–2 wk, 2–4 wk, and 6–8 wk, respectively) but this effect was not statistically significant nor were any interactions significant.

Sulfur mineralization

Cumulative S mineralization was strongly influenced by crop species, nutritional status, and the interaction of these variables (Figure 3). In all crop species, the amount of S mineralized was inversely related to the N status of the plant residue. Of the various crop residues, highest amounts of cumulative S mineralization were observed in the rape straw treatments. Lowest mineralization of S was observed in the high-N lentil residue, where cumulative mineralization closely paralleled mineralization in the control treatment. Most of the mineral S appeared in the initial extraction.

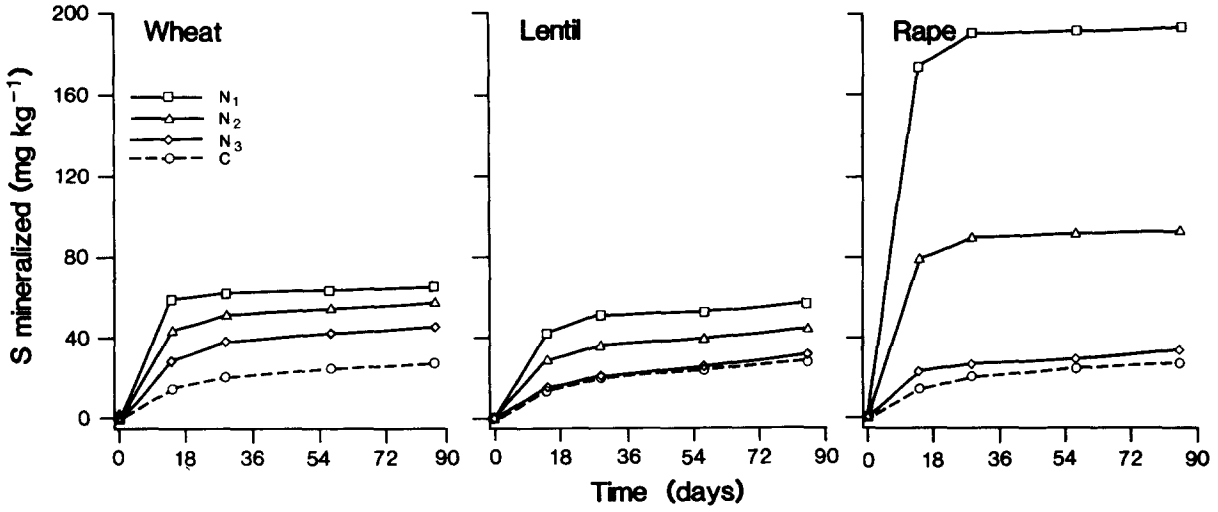

Fig. 3. Effect of crop and nutritional status on S mineralization from crop residues (N_1 = low N; N_2 = moderate N; N_3 = high N; C = control [no residue]).

Discussion

The rate of decomposition of the various crop residue materials, as measured by CO_2 evolution, was strongly affected by both crop species and nutritional regime under which the crop was grown. These differences appeared to be dictated almost entirely by the N status of the residues as indicated by a high correlation coefficient between initial N concentration and amount of CO_2 evolved (Table 2). While several other plant characteristics, including S concentration, water-soluble plant matter, cellulose, and hemi-cellulose, were also significantly correlated to CO_2 evolution, these relationships are clearly the result of collinearity with N concentration. For example, the size of the water-soluble fraction was highly correlated to the N concentration ($r = 0.94$). Step-wise regression, which ranks variables in terms of their contribution to the regression model, invariably indicated N and N^2 to be the most important dependent variables. In most cases, N accounted for greater than 90 % of the variability and addition of N^2 accounted for approximately an additional 5 % (Figure 4).

This dependence on adequate N concentration within the decomposing residue may have been intensified by the continual removal of soluble nutrients during the course of the decomposition. Similar conditions would be expected to occur in the presence of an actively absorbing root system. It is possible that the effect of N concentration would be less pronounced under conditions less favorable to rapid decomposition or where rates of application were lower, and hence demands for nutrients for decomposition were less.

Below a certain critical initial N concentration, the crop residue resulted in a significant net immobilization of N; that is, total N mineralization in the soil treated with crop residue was less than that in the control soil. The value of this critical initial N concentration for each time interval was estimated by fitting a quadratic curve to the relationship between N concentration and net N mineralization, and calculating the N concentration corresponding to zero net mineralization. This procedure provided a reasonably accurate and sensitive separation of mineralizing and immobilizing treatments (Figure 5). The value of the N concentration separating immobilizing from mineralizing treatments declined over time falling from 1.9 % at day 14 to 1.1 % at day 84. Because the critical value is time-dependent, any attempt to determine a single value is clearly in error. The critical values calculated for day 56 and day 84 are close to the range of values (1.0 and 1.3) cited by Bartholomew (1965) for one growing season.

The gradual decline in the value of the critical N concentration with progressively longer incubation times can be attributed to the gradual increase in the N concentration of the remaining residue resulting from simultaneous CO_2 evolution and N re-immobilization. Over the long term, all crop resi-

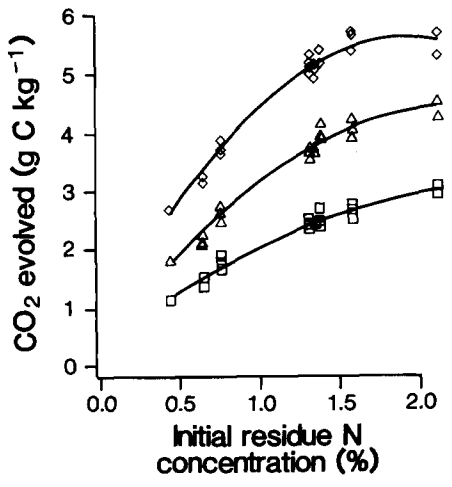

Fig. 4. Relationship between cumulative CO_2 evolution and initial residue N concentration at three time periods (R^2 for all *curves* equal to or greater than 0.98).

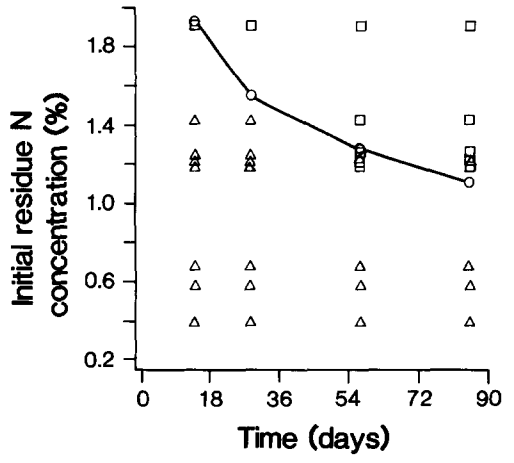

Fig. 5. Critical N concentrations of crop residues as a function of incubation time (□ = treatments exhibiting net N mineralization; △ = treatments exhibiting net immobilization; ○ = critical concentrations).

dues would be expected to show significant net mineralization. The time required for net mineralization to occur, however, increases as the initial concentration of N decreases. In the present experiment, those residues having an initial N concentration > 1.5% began mineralizing after 28 days, those with concentrations of 1.2 to 1.5% after 56 days, those with concentrations of 1.0 to 1.2% after 84 days, while those with concentrations less than 1.0% were not yet mineralizing N at the termination of the experiment.

Sulfur mineralization varied widely among crop species. Most of the variability in S mineralization among treatments can be accounted for by differences in initial S concentration. Regression analysis of the relationship between cumulative S mineralization by day 56 and initial S concentration, for example, reveals a highly significant linear relationship with an R^2 of 0.95. Thus rape, which generally has relatively high tissue S concentrations, showed much higher S mineralization than lentil or wheat. Mineralization of S was inversely related to N status of the residues. This observation can be attributed to the yield response of the crop to applied N and, hence, the dilution of S concentration in the crop residues. Under no conditions did S availability appear to limit C evolution since S mineralization in all treatments was equal to or exceeded that observed in the control. The very rapid flush of S early in the incubation suggests that much of the S mineralized existed in soluble inorganic or organic sulfate form.

The results demonstrate a dominant influence of nutrient concentration on residue decomposition, even in a comparison of very diverse crop species. Thus, agronomic practices which influence soil fertility in one crop will profoundly influence rate of residue decomposition and amounts of nutrients available for the subsequent crop. For example, straw from a well fertilized wheat crop could conceivably decompose at a similar rate and produce similar amounts of N as a legume residue. Similarly, establishment of high N fertility in a wheat crop to increase the N concentration in residues could avert large immobilization losses often associated with wheat straw decomposition. The agronomic and economic viability of such practices, however, remain to be addressed.

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