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Modeling Rye and Hairy Vetch Residue Decomposition as a Function of Degree-Days and Decomposition-Days

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ABSTRACT

Temperature and precipitation affect crop residue decomposition rate. Degree-days (DGD) and decomposition-days (DCD) are used to account for the effect of temperature and precipitation, but little information is available about winter cover crop (WCC) residue decomposition as a function of DCD or DGD. This study was conducted to model the decomposition of rye (*Secale cereale* L.) and hairy vetch (*Vicia villosa* Roth) residues and the subsequent release of C and N under field conditions using DGD and DCD. Rye and hairy vetch WCCs were planted during the fall either in monoculture or biculture and killed before corn (*Zea mays* L.) planting. Grab samples of WCC residues were taken six times during the corn growing season. A single-pool exponential decay function was used to model biomass decomposition and C and N release. Most decay models showed coefficients of determination (r^2) larger than 0.7. Both DGD and DCD were equally effective as time scales. Winter cover crops differed in their initial biomass and C content and in their biomass decomposition and C and N release rates. At corn V6 stage, 33 and 75% of the initial N content had been released from rye and hairy vetch residues, respectively. At the end of the growing season, hairy vetch had almost completely decomposed while 5% of the initial biomass of rye remained undecomposed. Decomposition dynamics of hairy vetch residue indicate that it is a potential source of N while decomposition dynamics of rye indicate that it is more useful in soil conservation.

The management of crop residues is a key component of sustainable cropping systems. Residues protect the soil from water and wind erosion and provide the main source of C and nutrients for soil biological activity and ultimately available nutrients for the crops. Although cash crops are the most common source of residues, the addition of WCC into a cash-cropping rotation might further enhance the benefits of residues. Most frequently, WCCs are included in cropping systems as nutrient management tools. Legume WCCs are used as a source of N for the following cash crop (Smith et al., 1987) while grasses are mainly used to reduce NO_3 leaching (Meisinger et al., 1991). A biculture of a legume and a grass is used with the intention of providing both benefits simultaneously (Ranells and Wagger, 1996). Additional benefits from the use of WCCs include increased soil organic matter (Reeves, 1994), soil organic N (Kuo et al., 1997), and partial weed control (Warnes et al., 1991).

The detrimental or beneficial effects that managing residues have on soils and crops depend primarily on the quantity and quality of the starting residue (i.e., at kill date in the case of WCC) and its subsequent decomposition. For example, yield can be decreased by an excessive biomass cover that reduces crop stands due to poor soil–seed contact and germination. On the other hand, little residue may not be adequate for soil and water conservation goals. The appropriate amount of residue required varies depending on the role that residues play in the cropping system. To effectively manage WCC, it is critical to understand the factors that control residue decomposition and to be able to model it.

Nitrogen release from WCC residues is the first process in a series that transform residue organic N into soil mineral N. Carbon and N are the two elements controlling soil biological activity, and they strongly interact in both the short and long term. In the short term, available C can increase denitrification and immobilization of N (McKenney et al., 1993) while in the long term, residue C and N stabilize together (McGill and Cole, 1981) and changes in soil organic N are closely associated with changes in soil organic C (Kuo and Jellum, 2000). Consequently, it is relevant to study C and N releases at the same time.

The rate of decomposition and C and N release include the effects of the environment (i.e., air temperature, precipitation, and soil characteristics) and the biochemical composition of the residue (Quemada and Cabrera, 1995; Heal et al., 1997; Wagger et al., 1998). Any attempt to analyze and predict residue decomposition rates should consider these two factors and separate their exclusive effects. This paper investigates the effect of the environmental factors on residue decomposition and on C and N release.

Several methodologies have been developed to account for the effect of air temperature and precipitation on residue decomposition and C and N release. Honeycutt and Potaro (1990) used DGD to predict C and N residue mineralization while Stroo et al. (1989) proposed the calculation of DCD based on the minimum of a temperature factor and a moisture factor. The advantage of using these approaches is that they allow the comparison between field and lab experiments and among different locations and years. In addition, because cumulative DGD are commonly used to predict crop development, it is a practical methodology to match soil and crop processes and analyze the synchrony between residue N release and crop N uptake. A more detailed approach to model residue decomposition was taken by Andrén and Paustian (1987). These authors included the effect of soil temperature and soil water potential on buried residue using a variety of nonlinear models. Rodrigo et al. (1997) also described the effects of temperature and soil water potential on C and N transformation comparing nine simulation models.

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Abbreviations: DCD, decomposition-day(s); DGD, degree-day(s); ESS, error sum of squares; WCC, winter cover crop.

However, the simpler approach of using DCD for surface residue decomposition models is used in the submodels of the revised universal soil loss equation (RUSLE) and the revised wind erosion equation (RWEQ) (Schomberg et al., 1996; Schomberg and Steiner, 1997).

Most decomposition experiments reported in the literature have been performed under either controlled laboratory conditions (Honeycutt et al., 1993; Gilmour et al., 1998) or using the mesh bag technique under field conditions (Schomberg et al., 1994; Ranells and Wagger, 1996). These methodologies reduce the sources of error and require less intensive labor than field experiments using grab sampling (Steiner et al., 1999; Ma et al., 1999). However, the extrapolation from laboratory conditions to field environment may produce misleading conclusions. Mesh bags exclude soil fauna, modify residue microclimate, and put residues in contact with soil when in natural conditions, residues would be standing on or above the soil surface for a longer period. Steiner et al. (1999) suggest that there is a need for research conducted under more realistic field conditions to produce reliable management recommendations.

The objectives of this study were to (i) estimate the equation parameters of biomass, C, and N decomposition of WCC residues expressed as a function of cumulative DGD and DCD; (ii) analyze the effects of WCCs and location on decomposition; and (iii) compare the DCD and DGD methodologies.

MATERIALS AND METHODS

This field experiment was conducted during 1999 and 2000 at Brownstown and Urbana, IL. The soil is a Cisne silt loam (fine, smectitic, mesic Vertic Albaqualf) at Brownstown and a Drummer silty clay loam (fine-silty, mixed, superactive, mesic Typic Endoaquoll) at Urbana. At Brownstown, soil total C was 7.5 and 8.13 g kg^{-1}, soil total N was 0.52 and 0.61 g kg^{-1}, and pH was 6.4 and 6.2 for 1999 and 2000, respectively. At Urbana, total C was 14.7 and 12.4 g kg^{-1}, total N was 1.02 and 0.83 g kg^{-1}, and pH was 6.0 and 6.3 for 1999 an 2000, respectively.

The experiment was conducted using no-till practices in land that had been in a corn–soybean [*Glycine max* (L.) Merr.] rotation for at least 5 yr. In the second year, the experiment was conducted in a field adjacent to the field used the previous year. The experimental design was a split-plot arrangement of treatments in a randomized complete block design with four replications. Main-plot treatments were WCC (rye, hairy vetch, and rye–hairy vetch in biculture) and fallow. Main plots were 9 m wide by 20 m long. Split-plot treatments were four levels of N fertilizer: 0, 90, 180, and 270 kg N ha^{-1} applied as ammonium nitrate at corn V6 stage. Split plots were 4.5 m wide by 10 m long and accommodated six rows of corn planted 76 cm wide.

Winter cover crops were drilled on soybean stubble on 3 Oct. 1998 and 2 Oct. 1999 at Brownstown and on 1 Oct. 1998 and 5 Oct. 1999 at Urbana. Seeding rates were 134 and 34 kg ha^{-1} for rye and hairy vetch, respectively. In the biculture, the seeding rate was 67 and 23 kg ha^{-1} for rye and hairy vetch, respectively. Hairy vetch was inoculated each year with *Rhizobium leguminosarum* var. *viciae* (Urbana Labs, St. Joseph, MO). Winter cover crops were killed with a mixture of 1.1 kg a.i. ha^{-1} glyphosate [*N*-(phosphonomethyl)glycine] and 0.4 kg a.i. ha^{-1} of 2,4-D (2,4-dichlorophenoxyacetic acid) on 28 Apr. 1999 and 29 Apr. 2000 at Brownstown and 2 May 1999 and 4 May 2000 at Urbana.

Grab samples were collected from the control plots (0 kg N ha^{-1}) at six times during corn growing season to monitor residue decomposition. The first sampling time was done right before killing the WCC, and subsequent samples were taken approximately every 3 wk during the growing season until 1 wk before corn harvest. Grab samples were taken using a frame and consisted of three subsamples (0.12 m^2 each) on the first three sampling dates and two on the last three sampling dates. The area comprised of the three central corn rows was selected for sampling. Standing residues were cut at ground level with electric shears, and the plant material was gathered by hand. Rye and hairy vetch residue components of the biculture were separated in the laboratory. Residue samples were dried for 3 d at 65°C, weighed, and ground to pass through a 1-mm mesh. Residue samples were analyzed for total C and N with an automated Dumas instrument (LECO CHN-2000, LECO Corp., St. Joseph, MI). The residue weight was calculated on an ash-free weight basis by determining the ash content on a 1-g subsample (550°C).

Degree-days were calculated as the average of daily maximum and minimum temperature, assuming 0°C as the base temperature for residue decomposition (Honeycutt and Potaro, 1990). Degree-days were accumulated daily during the sampling season.

The model first developed by Stroo et al. (1989) and later used by Steiner et al. (1999) and Ma et al. (1999) was used for the calculation of DCD. This model considers two factors: moisture and temperature. Each factor is included in the DCD using a coefficient that ranges from 0 to 1. A value of 1 indicates optimum conditions for decomposition, and 0 indicates no decomposition. It is assumed that the most limiting factor controls decomposition. The DCD for a given day is equal to the minimum of the moisture coefficient or the temperature coefficient.

The moisture coefficient is set to 1 if the precipitation for that day is ≥4 mm. It is assumed that 4 mm of rain is enough to fully wet a dense layer of residues (Steiner et al., 1999). If precipitation is <4 mm, then the moisture coefficient is set to be equal to the precipitation divided by 4 plus half of the moisture coefficient of the previous day. In the absence of precipitation, the moisture coefficient decreases by a factor of 0.5 each day after the last precipitation.

The temperature coefficient (TC) is calculated based on Steiner et al. (1999) as follows:

$$\mathrm{TC} = \frac{2 \times (\mathrm{Tmean})^2 \times (T_{\mathrm{opt}})^2 - (\mathrm{Tmean})^4}{(T_{\mathrm{opt}})^4} \quad [1]$$

where Tmean is the average between daily maximum and minimum air temperature and 32°C is considered the optimum air temperature for residue decomposition ($T_{\mathrm{opt}} = 32$). In addition, a base temperature of 0°C is assumed for decomposition; thus, Tmean has a minimum value of 0. The daily DCD was recorded during the sampling season. Maximum and minimum daily temperature and daily precipitation data for DCD and DGD calculation were obtained from meteorological stations located within 2 km of each location.

Biomass decomposition and C and N release were analyzed by fitting a first-order exponential single-pool decay model:

$$Y_t = Y_o \exp^{-kt} \quad [2]$$

where Y_t is biomass, C, or N content (kg ha^{-1}) at time t (expressed in DCD or DGD time scales); Y_o is initial condition (i.e., biomass, C, or N content at $t = 0$); and k is the relative decomposition rate.

Table 1. Monthly mean temperature and cumulative precipitation at Brownstown and Urbana, IL, for 1999, 2000, and 30-yr averages (Avg. 30).

	Brownstown			Urbana				Brownstown			Urbana		
	1999	2000	Avg. 30	1999	2000	Avg. 30		1999	2000	Avg. 30	1999	2000	Avg. 30
	Mean temperature, °C							Precipitation, mm					
May	18.2	19.3	18.2	18.1	17.9	17.0		110	120	111	89	157	149
June	22.5	22.0	22.8	22.1	21.1	22.1		89	169	95	156	115	113
July	26.2	23.4	24.8	25.7	22.7	23.7		99	92	73	97	62	109
August	22.3	24.1	23.9	21.7	22.9	22.8		56	146	60	127	80	104
September	19.3	19.2	19.5	18.7	18.3	18.7		37	98	67	49	64	75
Mean	21.7	21.6	21.8	21.3	20.6	20.8	Total	391	625	406	518	478	550

Model parameters were estimated for each cover crop at each location and year using the NLIN procedure of SAS (SAS Inst., 2000). Residuals were analyzed visually for abnormal patterns and tested for autocorrelation using the Durbin–Watson test. The normality of residuals was assessed with the UNIVARIATE procedure of SAS (SAS Inst., 2000). Model parameters were considered significant if the 95% confidence interval did not encompass zero.

Model parameters obtained for biomass decomposition and C and N release were statistically analyzed with the MIXED procedure of SAS (SAS Inst., 2000). The parameters obtained with time expressed as DCD and DGD were analyzed separately. Location and WCC were considered fixed factors, and year was considered a random factor.

To determine if nonlinear regressions models using DGD and DCD as time differed in error sum of squares (ESS), an *F*-test ratio between the ESS of DCD and DGD models was performed as proposed by Thuries et al. (2001). The ratio was calculated between ESS for each WCC, location, year, and variable (biomass, C, or N) combination using an $\alpha = 0.05$ to reject the null hypothesis that ESS were equal.

RESULTS AND DISCUSSION

Weather and Accumulation of Degree-Days and Decomposition-Days

Growing season mean temperature and cumulative precipitation in 1999 and 2000 and 30-yr averages at Brownstown and Urbana are presented in Table 1. Temperature at both locations and years did not depart from the 30-yr averages. However, precipitation was higher than normal at Brownstown 2000, particularly during the months of June and August. In addition, Urbana 2000 was drier than normal during July and August. Cumulative DGD reflect differences in temperature between locations and years. The accumulation of DGD at harvest was 213°C larger at Brownstown than at Urbana (Fig. 1), which is in agreement with the longer growing season at Brownstown. At each location, more DGD accumulated in 1999 than 2000, particularly during the period after 75 d from killing date of WCC.

The final cumulative DCD reflects the difference in precipitation between site-years (Table 1 and Fig. 1). The largest DCD (47 DCD) accumulation was for Brownstown 2000, which received 625 mm while the lowest (35 DCD) accumulation was for Brownstown 1999, which received 391 mm of precipitation. At Urbana, differences in DCD between years were smaller than at Brownstown, with the 40-mm difference in total precipitation between 1999 and 2000.

The accumulation of DGD was relatively constant and smoother than the accumulation of DCD regardless of site-year (Fig. 1). Cumulative DCD showed periods of rapid accumulation and periods of no accumulation, which coincided with dry periods when moisture was the limiting factor for residue decomposition. Ma et al. (1999) compared different decomposition models and concluded that under rainfed conditions, the moisture coefficient was the limiting factor for DCD accumulation. It is expected that during summer, moisture controls the accumulation of DCD. Decomposition-days reflected larger differences between years than DGD, which is in agreement with the greater differences in precipitation than in temperature between years. In summary, the contrasting dynamics of DCD and DGD accumulation methods affect the relative position in time (expressed as DCD or DGD) of a given calendar date. Because the rate of accumulation of DGD only depends on air temperature, the accumulated DGD be-

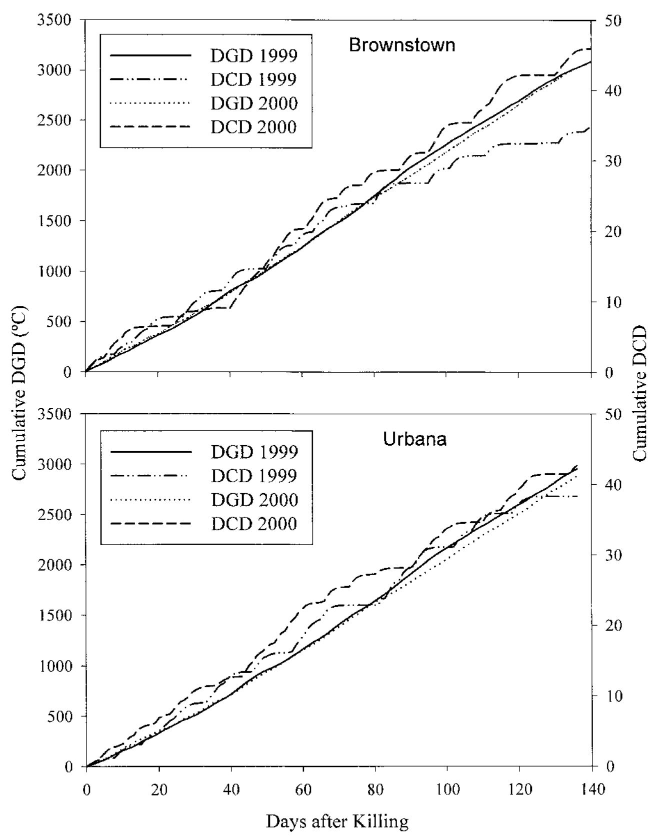

Fig. 1. Cumulative decomposition-days (DCD) and degree-days (DGD) at Brownstown and Urbana in 1999 and 2000.

Table 2. Biomass, C concentration, and N concentration of winter cover crops (WCCs) at killing time for Brownstown and Urbana in 1999 and 2000.

Location	WCC†	Biomass	C	N
		kg ha^{-1}	g kg^{-1}	
			1999	
Brownstown	R	4734	407.5	12.7
	RB	3973	409.2	14.2
	HV	1980	405.7	16.1
	HVB	495	408.1	19.0
Urbana	R	4016	402.9	14.9
	RB	3894	401.8	16.3
	HV	944	400.8	41.1
	HVB	332	403.3	43.2
			2000	
Brownstown	R	2924	427.3	12.0
	RB	2574	425.5	12.1
	HV	1306	425.5	35.8
	HVB	368	427.1	43.2
Urbana	R	3155	420.3	14.3
	RB	2506	419.4	16.6
	HV	1234	424.5	35.1
	HVB	437	429.6	41.4

† R, rye; RB, rye in biculture; HV, hairy vetch; HVB, hairy vetch in biculture.

tween any two dates is, for all practical purposes, a straight line (Fig. 1). On the contrary, DCD accumulation is a function of precipitation. For example, in a dry period, it is possible that DCD accumulation will not change in many days, but in a wet period (after precipitation), DCD increases rapidly within the same number of days (Fig. 1).

Decomposition Models

Winter cover crop biomass, C, and N concentrations at the time of killing are presented in Table 2. At both locations and years, rye biomass production was similar to values commonly reported in the literature (Clark et al., 1994; Ranells and Wagger, 1996). However, rye N concentration was higher compared with Wagger (1989) and Ranells and Wagger (1996). In contrast, hairy vetch produced less biomass and had lower N content than that reported in areas with higher average temperatures during the winter months (Reeves, 19944). Lower temperatures reduce biomass production of hairy vetch in the upper Midwest (Bollero and Bullock, 1994).

Parameter estimates from nonlinear regression equations describing biomass decomposition and C and N release and their coefficient of determination (r^2) and root mean square error (RMSE) for each year, location, and WCC combination are presented in Tables 3 and 4 for DCD and DGD.

All biomass, C, and N exponential decay models were significant at $p < 0.0001$, and the coefficient of determination (r^2) averaged 0.71, ranging from 0.21 for hairy vetch N release at Brownstown in 1999 for DCD (Table 3) to 0.98 for N release of hairy vetch in biculture at Urbana in 1999 for DCD and DGD (Tables 3 and 4). Only 5 out of 48 nonlinear regressions for either DCD or DGD had an r^2 lower than 0.5, and all of them were from Brownstown 1999. Three of these five nonlinear regressions were biomass, C, and N from the rye plots, and the other two were N release from rye in biculture and from hairy vetch plots (Tables 3 and 4). The lack of fit for rye was due to a large variability in biomass, particularly at the third sampling time. It is important to remark that data were obtained under field conditions, which included the spatial variability of initial biomass and added variability generated by machinery passes, which caused some rows of rye and rye in biculture to fall and some to remain standing for a longer period of time. An encouraging aspect of this study is the fact that r^2's larger than 0.7 were obtained for most of the regressions using grab sampling methodology.

Table 3. Parameters of exponential decay models and goodness-of-fit statistics for C, N, and biomass decomposition as a function of decomposition-days (DCD).***

		C				N				Biomass			
Location	WCC†	Y_o‡	k§	r^2	RMSE¶	Y_o	k	r^2	RMSE	Y_o	k	r^2	RMSE
		kg ha^{-1}	DCD^{-1}			kg ha^{-1}	DCD^{-1}			kg ha^{-1}	DCD^{-1}		
							1999						
Brownstown	R	2093	0.0250	0.37	609.2	60.7	0.0208	0.38	15.0	5055	0.026	0.39	1420.8
	RB	1511	0.0226	0.54	267.2	50.2	0.0194	0.35	11.7	3674	0.024	0.56	649.0
	HV	807	0.0185	0.54	111.9	40.1	0.0183	0.21	14.7	1987	0.018	0.53	276.5
	HVB	198	0.1173	0.59	58.1	8.8	0.0941	0.56	2.7	490	0.121	0.58	147.8
Urbana	R	1581	0.0380	0.71	275.9	56.0	0.0288	0.58	11.3	3921	0.034	0.69	697.1
	RB	1631	0.0424	0.83	214.8	63.5	0.0341	0.80	8.2	4053	0.040	0.83	534.8
	HV	382	0.0808	0.73	77.8	39.5	0.0979	0.75	7.8	962	0.064	0.70	203.8
	HVB	156	0.1564	0.91	17.9	14.3	0.1713	0.98	0.7	331	0.127	0.96	22.1
							2000						
Brownstown	R	1111	0.0330	0.65	228.1	30.9	0.0266	0.91	6.8	2589	0.032	0.63	540.2
	RB	1000	0.0364	0.75	171.2	27.9	0.0264	0.63	5.7	2342	0.036	0.93	408.0
	HV	557	0.1855	0.83	84.4	47.0	0.2178	0.87	6.3	1308	0.189	0.90	193.7
	HVB	207	0.2789	0.76	42.7	21.6	0.3668	0.75	4.7	368	0.244	0.85	49.6
Urbana	R	1282	0.0406	0.89	132.2	43.7	0.0336	0.90	4.0	3027	0.036	0.88	324.2
	RB	1064	0.0390	0.88	119.7	42.1	0.0354	0.91	3.8	2530	0.036	0.87	285.7
	HV	517	0.0292	0.56	124.9	43.3	0.0362	0.68	8.9	1270	0.029	0.59	288.8
	HVB	184	0.0950	0.79	28.2	17.6	0.1386	0.87	2.1	427	0.088	0.78	67.6

*** All regressions are significant at $p < 0.001$.
† WCC, winter cover crop: R, rye; RB, rye in biculture; HV, hairy vetch; HVB, hairy vetch in biculture.
‡ Y_o, initial C, N, or biomass content.
§ k, relative decomposition rate.
¶ RMSE, root mean square error.

Table 4. Parameters of exponential decay models and goodness-of-fit statistics for C, N, and biomass decomposition as a function of degree-days (DGD).***

		C				N				Biomass			
Location	**WCC†**	Y_o‡	k§	r^2	RMSE¶	Y_o	k	r^2	RMSE	Y_o	k	r^2	RMSE
		kg ha^{-1}	10^{-3} DGD^{-1}			kg ha^{-1}	10^{-3} DGD^{-1}			kg ha^{-1}	10^{-3} DGD^{-1}		
							1999						
Brownstown	R	2056	0.32	0.40	590.7	59.2	0.26	0.40	14.6	4955	0.38	0.43	1378.6
	RB	1436	0.26	0.50	280.1	47.5	0.21	0.30	12.1	3483	0.27	0.51	684.9
	HV	790	0.24	0.54	112.0	40.8	0.25	0.30	13.8	1945	0.23	0.53	276.5
	HVB	197	2.03	0.58	58.7	8.7	1.53	0.55	2.7	489	2.10	0.57	149.3
Urbana	R	1532	0.53	0.70	280.4	54.1	0.38	0.56	11.5	3803	0.47	0.68	704.0
	RB	1596	0.61	0.84	209.0	61.7	0.47	0.79	8.4	3964	0.56	0.83	521.1
	HV	379	1.30	0.73	77.6	39.3	1.63	0.75	7.9	949	0.99	0.70	202.6
	HVB	156	2.73	0.91	18.1	14.3	3.01	0.98	0.7	330	2.19	0.95	23.4
							2000						
Brownstown	R	1157	0.55	0.70	211.4	32.1	0.45	0.92	6.4	2696	0.54	0.68	501.7
	RB	1032	0.59	0.78	158.8	28.8	0.44	0.67	5.4	2420	0.59	0.94	379.2
	HV	555	2.49	0.84	82.9	47.0	2.98	0.88	6.3	1304	2.55	0.90	190.5
	HVB	207	3.89	0.76	42.7	21.6	5.19	0.75	4.7	367	3.37	0.85	49.4
Urbana	R	1243	0.66	0.88	143.0	42.3	0.53	0.88	4.4	2927	0.57	0.86	349.7
	RB	1038	0.64	0.88	117.4	41.0	0.57	0.91	3.8	2465	0.58	0.88	280.0
	HV	503	0.46	0.57	123.7	42.1	0.58	0.69	8.8	1241	0.46	0.61	282.4
	HVB	183	1.86	0.77	29.1	17.6	2.78	0.86	2.2	426	1.73	0.76	69.6

*** All regressions are significant at $p < 0.001$.
† WCC, winter cover crop: R, rye; RB, rye in biculture; HV, hairy vetch; HVB, hairy vetch in biculture.
‡ Y_o, initial C, N, or biomass content.
§ k, relative decomposition rate.
¶ RMSE, root mean square error.

According to the F test, there was no significant difference in ESS between DCD and DGD (not shown). Both methods performed similarly as estimators of weather effects on WCC residue decomposition. This result is surprising, considering that the calculation of DCD includes the effect of moisture on decomposition combined with an optimum value of temperature while DGD does not consider moisture and assumes a linear increase of decomposition rate with temperature. It is likely that the effect of precipitation was not large enough to obtain significant differences between DCD and DGD and that the ranges of temperatures explored in this study were not large enough to generate differences between the DCD and DGD models on the decomposition and release rates.

When four site-years are considered, relative biomass decomposition rates (k) of rye and rye in biculture ranged from 0.27×10^{-3} to 0.59×10^{-3} DGD^{-1}. The biomass decomposition rate for hairy vetch and hairy vetch in biculture ranged from 0.23×10^{-3} to 3.7×10^{-3} DGD^{-1}. These values for C release rates were similar to the ones reported by other authors. For example, Ma et al. (1999) reported a range of k for wheat (*Triticum aestivum* L.) crop residue between 0.3×10^{-3} and 0.45×10^{-3} DGD^{-1} for three locations in eastern Colorado. Kaboneka et al. (1997) incubated soybean, corn, and wheat residues at 24°C for 30 d. They found k values that ranged between 0.013 and 0.03 d^{-1} for a slow-decomposing C fraction, which are equal to 0.54×10^{-3} and 1.25×10^{-3} DGD^{-1}.

Honeycutt (1999) reported N mineralization rates of buried hairy vetch residues of 12.3×10^{-3} and 7.9×10^{-3} DGD^{-1}. Varco et al. (1993) compared hairy vetch decomposition under no-till and conventional till and found that surface residues decomposed four times faster when mixed in the top 20 cm of soil than on the surface. Similarly, Douglas and Rickman (1992) used a factor to correct for residue placement and used 0.8 for buried and 0.2 for surface residue. If corrected by the fourfold difference between buried and surface-placed residues, the mineralization rates reported by Honeycutt (1999) are 3.1×10^{-3} and 1.9×10^{-3} DGD^{-1}. In agreement, the decomposition rates (k) for hairy vetch in Brownstown 2000 and for hairy vetch in biculture at Urbana 1999 and 200 were within that range.

Relative decomposition rates (k) for biomass of rye, rye in biculture, hairy vetch, and hairy vetch in biculture ranged from 0.018 to 0.244 DCD^{-1} (Tables 3 and 4). In an experiment involving residue decomposition of oat (*Avena sativa* L.), barley (*Hordeum vulgare* L.), spring wheat, and winter wheat, Steiner et al. (1999) reported k values ranging from 0.015 to 0.042 DCD^{-1}. Relative decomposition rate values of rye and rye in biculture obtained in this study were within the same range. There are no reports in the literature of relative decomposition rates for legume WCC with time expressed as DCD. However, as expected, relative decomposition rates for hairy vetch and hairy vetch in biculture were higher than those for cereal WCC. It is broadly accepted that legume residues decompose faster than cereal residues.

Initial biomass and initial C and N content (Y_o) of WCC reflect the differences in dry matter accumulation between rye and hairy vetch as well as the larger N concentration of hairy vetch. With the four site-years, the range of initial biomass was from 2400 to 5000 kg ha^{-1} for rye and from 330 to 1940 kg ha^{-1} for hairy vetch.

The estimates of k and Yo for biomass, C, and N decomposition models were used to analyze the effect of location and WCC on these parameters. For DCD and DGD, WCC had a significant effect on biomass, C, and N relative decomposition rates (Table 5). The significant effect of cover crops on relative decomposition rate was also reported by Wagger (1989) and Ranells and Wagger (1996). These authors used a single-

Table 5. Variance for random effects and significance level (p) for fixed effects on relative decomposition rate (k) of models using degree-days (DGD) and decomposition-days (DCD).

	DCD			DGD		
	C	N	Biomass	C	N	Biomass
Random effects				Variance estimates		
Year	0	0	0	0	0	0
Year × location	0.0015	0.0026	0.0012	2.9×10^{-7}	5.2×10^{-7}	2.1×10^{-7}
Year × WCC†	0	0	0	0	0	0
Residual	0.0022	0.0048	0.0018	3.4×10^{-7}	8.5×10^{-7}	2.7×10^{-7}
Fixed effects				$p > F$		
Location	0.64	0.70	0.54	0.78	0.86	0.62
WCC	0.02	0.04	0.028	0.006	0.018	0.006
Location × WCC	0.54	0.76	0.45	0.65	0.91	0.50

† WCC, winter cover crop.

pool decomposition model, and they found that hairy vetch had a larger relative decomposition rate than rye.

Location and location × WCC did not show a significant effect on WCC biomass decomposition or C and N release rates (k). Other authors also found the lack of significant effect of location on relative decomposition rate of residues placed on soil surface. For instance, Ma et al. (1999) did not find a significant effect of location or slope position (summit, sideslope, and toeslope) that included a range of soil textures from sandy loam to clay loam. Similarly, Stroo et al. (1989) working with soils of similar texture but different soil organic matter content (13–36 g kg^{-1}) concluded that there was no significant effect of soil on wheat residue decomposition rate.

The variance components of the random effects in the model (i.e., years and location and WCC interactions with years) were smaller than the residual. Clearly, these results indicate that year and its interactions with location and WCC were not a significant source of variability for relative decomposition rate, in turn suggesting that DGD and DCD were able to account for year-to-year variability.

Winter cover crop had a significant effect on initial (Yo) biomass and C content, for both DCD and DGD (Table 6). There was no WCC effect on initial (Yo) N content. In addition, the WCC × location interaction was not significant for initial biomass, C, and N content. For initial N content, the variance component of the random effect of year × WCC was more than four times larger than the residual. This suggests that there is an important variability on N concentration between years due to the large effect of soil residual N and weather on crop growth and N uptake. In addition, for initial C and biomass, the random effects presented similar or lower variances than the residual.

Since there was a significant effect of WCC on relative decomposition rate (k), the mean parameters were used over all locations and years for each WCC to plot the C and N decomposition as a function of DCD and DGD. Rye and rye in biculture had the same C and N contents at killing, whereas hairy vetch accumulated more C and N than hairy vetch in biculture. The C and N release rate of rye and rye in biculture was similar between them and lower than that of hairy vetch and hairy vetch in biculture.

At corn V6 stage (17 DCD or 1000 DGD), rye and rye in biculture had released approximately 33% of its initial N content while hairy vetch had released nearly 75% of its initial N and hairy vetch in biculture released 100% of its initial N (Fig. 2 and 3). Similar results were obtained for C at corn V6 stage (Fig. 2 and 3). At the end of the growing season (60 DCD or 3500 DGD), C and N from rye in both monoculture and biculture were not completely released (Fig. 2 and 3).

Residue N release is the first step in N mineralization. This study shows that hairy vetch in either monoculture or biculture is a potential source of N for corn. However, in addition to a timely release of N, N content at killing is also a critical factor for a WCC to be considered a reliable source of N for corn production. If both the recycling of N in the soil microbial biomass and possible losses (i.e., leaching, denitrification, and volatilization) are considered, the average N content of hairy vetch at killing time (40 kg N ha^{-1}) is not enough to significantly reduce the N fertilizer rate applied to the following

Table 6. Variance for random effects and significance level (p) for fixed effects on initial C, N, and biomass (Y_o) of models using degree-days (DGD) and decomposition-days (DCD).

	DCD			DGD		
	C	N	Biomass	C	N	Biomass
Random effects				Variance estimates		
Year	278	0	2185	252	0	1975
Year × WCC	408	1.14	2829	318	0.95	2241
Year × location	93	0	657	35	0	287
Residual	294	0.25	1548	293	0.21	1600
Fixed effects				$p > F$		
Location	0.62	0.18	0.70	0.51	0.22	0.59
WCC	0.03	0.12	0.03	0.02	0.10	0.02
Location × WCC	0.60	0.27	0.56	0.57	0.22	0.54

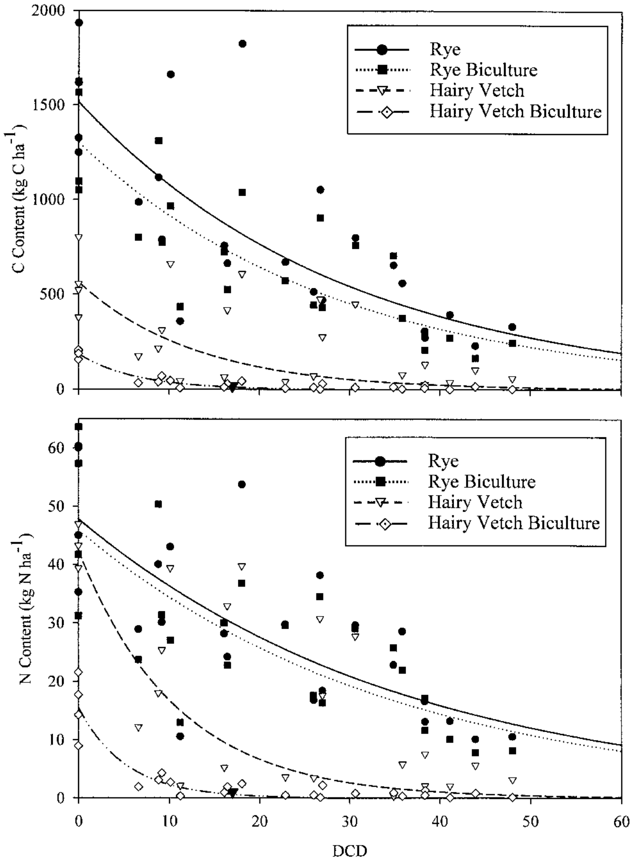

Fig. 2. Carbon and N release for rye, rye in biculture, hairy vetch, and hairy vetch in biculture as a function of decomposition-days (DCD). ▼ indicates corn V6 stage.

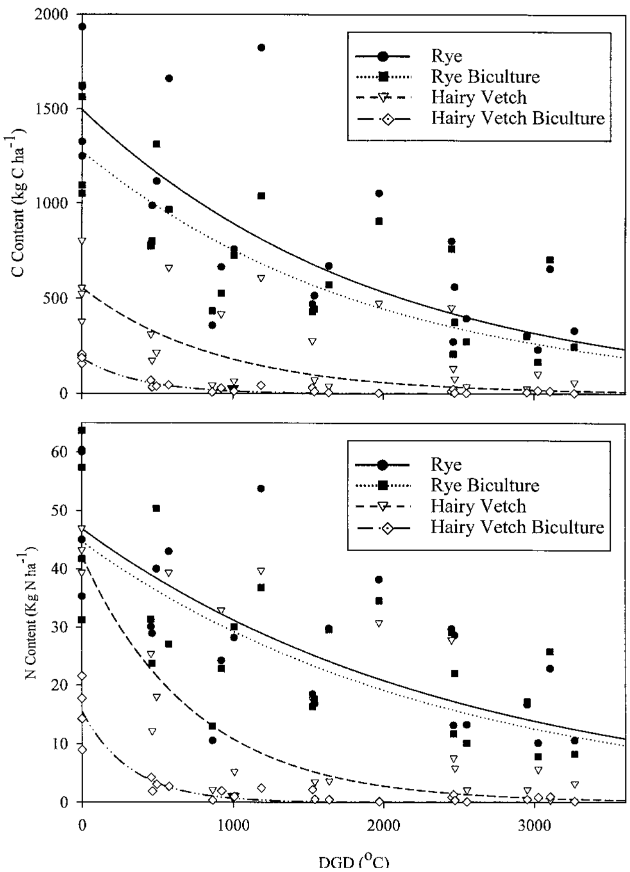

Fig. 3. Carbon and N release for rye, rye in biculture, hairy vetch, and hairy vetch in biculture as a function of degree-days (DGD). ▼ indicates corn V6 stage.

summer crop. Rye and rye in biculture decomposed too slowly to be considered reliable sources of N. In addition, their higher C/N ratios might even cause N immobilization, reducing soil N availability for crop uptake. Thus, a possible management alternative that needs to be evaluated is adjusting rye killing time to improve the synchronicity between rye decomposition and corn uptake.

Rye and the rye component of the biculture offer a potential value as soil and water conservation tools due to their relatively low decomposition rate. Figures 2 and 3 show that at corn stage V6, rye and rye in biculture contained approximately 80 kg C ha^{-1}, which provided good soil cover. In contrast, hairy vetch and hairy vetch in biculture had very low biomass and C content remaining at corn stageV6 and thus a reduced effectiveness as soil covers. In addition, rye and rye in biculture increase soil organic matter and total soil N in the long term, as reported by Kuo and Jellum (2000).

In conclusion, rye in monoculture or biculture presented lower N concentration but larger biomass than hairy vetch, resulting in similar N content at killing time. Hairy vetch, when grown in biculture, did not affect rye composition and did not increase rye decomposition or C and N release rates. We were able to model residue biomass decomposition and C and N release of WCC with data obtained from field experiments by grab sampling and time expressed as DCD and DGD. There was no difference in using either DCD or DGD to account for the effect of temperature and moisture on biomass decomposition and C and N release. The decomposition dynamic of hairy vetch makes it a potential source of N for corn. However, its low N content at killing might reduce its capacity to provide enough N to replace N fertilizer. In contrast, rye presented a slow decomposition, which does not contribute N to corn and might even immobilize soil N. However, rye is an excellent tool for conservation tillage systems. More research of the optimum killing times of hairy vetch and rye under midwestern conditions is needed to improve WCC management and profitability. We believe that, although labor intensive, grab sampling in field experiments provides good estimates of decomposition rates. The next step necessary to understand and model decomposition is to analyze the effect of residue quality on *k* and to be able to predict it.

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