NITROGEN CYCLING

Role of cover crops in nitrogen cycling

John W. Doran and M. Scott Smith

Historically, agricultural systems evolve as we manage nature to meet our food and fiber needs and adjust for the environmental consequences of altering natural ecological balances. Defining sustainable management systems for agriculture is complicated by the need to consider their utility to humans, efficiency of resource use, and favorable balance with the environment *(10)*. Major technological revolutions in the United States this century have dramatically influenced production and sustainability in agriculture.

Agricultural mechanization at the turn of the century enabled massive cultivation of fertile virgin prairie soils in America's breadbasket. However, without return of nitrogen (N) and other nutrients, soil organic matter levels in Great Plains soils declined dramatically, and agricultural sustainability was threatened by drought and unprecedented soil erosion in the 1930s. In many areas net mineralization of soil humus fell below that needed for sustained crop production *(2)*. Reduced tillage, crop residue conservation, and green manuring practices were introduced to reduce erosion and microbial oxidation of organic matter and to rebuild soil fertility. Research by F. L. Duley, J.C. Russel, T. M. McCalla, and other early soil conservationists demonstrated the utility of legume green manure crops and conservation tillage management practices for producing wheat and corn grain crops while protecting and rebuilding the structure and fertility of soil *(23)*.

After World War II, inexpensive and abundant fertilizer-N decreased the role of N-fixing legume cover crops in cropping systems. Increased cultivation and monoculture production of cash grain crops, the development of higher-yielding cultivars, and greater reliance on synthetic chemical and energy inputs increased crop yields two- to three-fold in the 40 years following World War II. However, these yield increases were associated with declines in native soil fertility, reduced profitability from greater capital inputs, and increased soil erosion and environmental contamination in much of the United States. At present, agriculture is considered the largest areal contributor to nonpoint-source water pollution in the United States *(17)*. Thus, producers must once again adopt agricultural management approaches that balance adequate production levels with acceptable environmental quality.

Alternative management systems

Producers are seeking alternative crop management systems that will reduce off-farm inputs to offset rising production costs, decrease environmental and health hazards of agricultural chemicals, and maintain soil productivity levels. Such systems commonly use animal wastes and legume and green-manure crops in rotation with cash grain crops to reduce use of synthetic chemicals. These alternative systems, however, may initially result in lower cash grain yields due to conservation of carbon (C) and nitrogen (N) in the soil/plant system, increased competition from weeds, and user adjustment to new management techniques. In southeastern Pennsylvania, Culik *(3)* reported that corn yields from organic management systems (using animal manure and legumes as N sources) during the second year of conversion from conventional management were 40% lower than conventional systems where herbicides and fertilizer were used. Decreased production resulted primarily from insufficient available soil-N and competition from excessive weeds. As the data in table 1 illustrate, increased dry matter and yields in corn with

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conventional management were nearly balanced by increases in weeds and microbial biomass in the low-input, organic management system. The higher overall N yields of conventional management reflected the additional application of 110 pounds/acre of fertilizer, given a fertilizer N recovery of about 25%. Thus, lower aboveground crop yields with organic management during the transition period were not the result of lower productivity, but rather a different partitioning into plant and soil pools that serve as potential nutrient reserves for future crops. The ecological productivity (aboveground and belowground resources) of the organic and conventional systems is similar.

In the above research study, corn grain yield in the reduced input cash grain system in the fifth year after conversion averaged 152 bushels/acre, which was equal to or greater than corn grain yield in the conventional management system. By this time, the plant/soil ecosystem with organic management had reached a new equilibrium, resulting in less weed pressure and greater turnover of microbial biomass and recycling of available N to grain crops during the growing season *(5)*. However, another important management change was the overseeding of a hairy vetch (*Vicia villosa* Roth) winter cover crop into the preceding wheat crop. Mineralization of the hairy vetch cover crop (aboveground matter contained 162 pounds N/acre) in the fifth year increased soil nitrate-N (NO_3-N) levels by 92 pounds/acre within 1 month after incorporation by plowing (Table 2). Soil microbial biomass N and potentially mineralizable N reserves decreased by 34 and 75 pounds/acre, respectively, during this same time period. This illustrate the importance of microorganisms in mediating release of N from cover crop residues and the importance of management in synchronizing soil N availability with time of maximum N need by the grain crop. The hairy vetch cover crop was effective in reducing the potential for overwinter leaching losses of NO_3-N; it was so effective, in fact, that the levels in the top foot of soil shortly before planting averaged only 8 pounds/acre, well below the late spring value of 32 pounds/acre considered minimal for producing an adequate crop of corn in the Northeast *(13)*. However, we cannot discount the potential for leaching later in the season, subsequent to mineralization of cover crop N, (June 12, table 2).

Table 2. Management and cover crop effects on N cycling parameters in the top foot of soil and related changes during the corn growing season in the 5 years after conversion from conventional management (5).

Management and Date	Soil N Pools Microbial N	 Potentially Mineralizable N	 Nitrate N
	pounds N/acre		
Alternative			
(corn/clover/winterwheat/soybean rotation + Vetch)			
April 10	108	1,125	8
May 15*	101	1,125	35
June 12	67	1,050	127
July 14	109	1,090	88
Conventional			
(corn/soybean rotation with herbicides and fertilizer)			
April 10	82	880	38
May 15	50	850	50
June 12†	57	880	74
July 14	92	910	95

*Hairy vetch cover crop (162 lbs N/A) plowed into soil on May 8.

†100 pounds N/acre of ammoniun nitrate fertilizer sidedressed on June 17.

Cover crops: A sink and source for nitrogen

Cover crops play a multitude of roles in modern crop management systems:

1. They provide cover and protect the soil from wind and water erosion.
2. They serve as sinks for plant nutrients that might otherwise be lost by volatilization or leaching.
3. They provide weed control through competition and allelopathy.
4. They assist in control of disease and insects by increasing crop diversity.
5. They act as a source of supplemental N (legumes) and slow-release nutrients.

The many functions of cover crops challenges our ability to optimize their use within a given management system. The capacity of cover crops to serve as a repository for plant-available N, thereby reducing potential for environmental contamination, also complicates the timely supply of adequate N for grain crop nutrition.

The capacity of winter cover crops to serve as an effective source of nutrients for grain crops depends, to a large extent, on climate, growth stage and quality of the cover crop, soil and cropping characteristics, and tillage management practices. As shown in table 3, considerably greater quantities of N are accumulated in legume winter cover crops in the humid temperate environments of the East and Southeast than in cover crops in the subhumid western Corn Belt and eastern Great Plains. Legume winter cover crops commonly accumulate from 60 to 150 pounds N/acre in the East and Southeast as compared with 30 to 40 pounds/acre in the drier, cooler climates of Iowa and Nebraska; a N content that is more typical to that of rye, wheat, or oat cover crops.

Table 1. Soil productivity shifts between alternative management using legumes in rotation and conventional management using fertilizers and herbicides 2 years after conversion from conventional management (7).

Biomass Component	Dry Matter Yields Legume/Cash Grain Rotation	 Conventional Cash Grain	Nitrogen Yields Legume/Cash Grain Rotation	 Conventional Cash Grain
	pounds/acre		pounds N/acre	
Corn (grain, stover, roots)	11,530 (87bu/a)	20,130 (152 bu/a)	113	216
Weeds (tops + roots)	5,610	188	46	2
Microbial Biomass (in top foot of soil)	2,339	1,770	140	106
Totals	19,480	22,090	299	324

Table 3. Nitrogen content, C to N ratio, and fertilizer N equivalency of winter cover crops for grain crop production at several U.S. locations.

Location and Soil	*Tillage and Summer Crop*	*Cover Crop*	*N Content (pounds/acre)*	*C/N Ratio*	*N Fertilizer Equivalency (pounds/acre)*	*Reference*
Delaware	No-till corn	Hairy vetch + oats	154	16	100	(*16*)
Sandy loam		Oats	45	31	<27	
Kentucky	No-till corn	Hairy vetch	92	13	67	(*1*)
Silt loam		Bigflower vetch	60	13	58	
		Rye	12	57	0	
	No-till sorghum	Hairy vetch	92	13	112	
		Bigflower vetch	60	13	120	
		Rye	12	57	0	
Georgia	No-till corn	Hairy vetch	114	11	110	(*15*)
2-clay loams		Crimson clover	96	13	88	
		Wheat	29	22	-	
Georgia	No-till sorghum	Hairy vetch	137	11	80	(*9*)
Sandy loam		Common vetch	120	13	53	
		Crimson clover	152	17	69	
		Subterranean clover	102	14	51	
		Rye	34	42	0	
Pennsylvania	Conventional corn	Hairy vetch	152	9	100	(*5*)
Silt loam						
Iowa	Ridge-till corn	Hairy vetch +	36	8	*	(*6*)
Silt loam		Rye	28	12	*	
Nebraska	Conventional corn	Hairy vetch	33	8	55	(*18*)
Silty clay loam	No-till corn	Hairy vetch	33	8	*	

*Yields lower with cover crop due to competition with grain crop for N or water.

Table 4. Effect of cover crop use over 3 years on physical properties of surface soil (top 2 inches) for no-till soils at two locations in Georgia (*15*).

	Total Organic C (%)		*Water Stable Aggregates (%)*		*Infiltration Rate (inches/hour)*	
Cover Crop	*Limestone Valley Gravelly Clay Loam*	*Coastal Plain Sandy Clay Loam*	*Limestone Valley Gravelly Clay Loam*	*Coastal Plain Sandy Clay Loam*	*Limestone Valley Gravelly Clay Loam*	*Coastal Plain Sandy Clay Loam*
Hairy vetch	1.02b*	1.18a	58.2a	36.7a	1.53a	2.30a
Crimson clover	1.06a	1.28a	55.0a	37.9a	-	1.67b
Wheat	0.89c	1.18a	65.1a	32.6ab	0.92b	1.49c
Fallow	0.85c	1.01b	56.3a	28.9b		

*Means in the same column followed by the same letter do not differ significantly at P = 0.05.

The N-fertilizer equivalency of winter cover crops has been used as an estimate of the N-supplying capacity for summer grain crops. The N-fertilizer equivalency of legume cover crops commonly ranges from 50 to 120 pounds N/acre and is generally related to higher N contents than nonlegumes and greater mineralization potential as indicated by C/N ratios of less than 20:1 (Table 3). The N-fertilizer equivalency of nonlegume cereals, such as oats (*Avena sativa* L.), wheat (*Triticum aestivum* L.), and rye (*Secale cereale* L.), is low or negligible (perhaps negative) due to a lower N content and a higher C/N ratio, which often results in immobilization of N during the cropping season.

In cooler, drier climates, the N fertilizer equivalency of legume cover crops, such as hairy vetch, may be limited by lower total production of N and slower mineralization and release of plant available N. Power et al. *(18)* found that in the subhumid environment of eastern Nebraska little of the N in chemically killed surface hairy vetch residues became available to no-till corn (*Zea mays* L.). Where vetch was disked into soil, however, corn grain yields were equivalent to or greater than where 55 pounds of fertilizer N was applied. Much of the N from vetch residues was apparently mineralized in mid-season to late season during the corn grain-fill period.

In contrast, in the warmer and more humid East, Varco et al. *(21)* found little difference between conventional and no-till corn in apparent recovery of vetch N that averaged 51% and 57%, respectively, over 2 years. The average recovery of isotopically labeled vetch residue, however, did vary with tillage and averaged 32% with conventional tillage and 20% with no-till. The discrepancy between N uptake-based and isotopic methods for estimating vetch N recovery in corn results from mineralization/immobilization/turnover and from added belowground, cumulative, and non-N benefits, which are accounted for when N recovery is calculated by comparing corn N uptake with a vetch cover crop to that where only corn residue is retained. The greater effect of no-till on isotopic recovery than recovery-by-difference suggests greater exchange between soil N and vetch N pools and greater (or longer) storage of vetch N in soil N pools.

The fact that the N-fertilizer equivalency of winter cover crops can exceed their aboveground N contents results in part from their effect on conserving water, building soil organic matter levels, and conferring desirable physical characteristics to soil that benefit nutrient cycling and plant growth (Table 4). Blevins et al. *(1)* found that vetch cover crops enhance yields of no-till corn and sorghum (*Sorghum bicolor* [L.] Moench) beyond that of N alone, and that enhancement varies with grain crop type. Utomo et al. *(20)* observed higher soil organic matter levels and no-till corn yields with a hairy vetch cover crop but concluded that reduced fertilizer-N requirements might be negated by the higher yield potential with cover crops. This clearly demonstrates the need to understand the additional role of cover crops, apart from supplying nutrients, in defining the soil physical environment for plant growth.

The recovery of cover crop N in the grain crops that follow them is markedly lower than that of inorganic fertilizer N, and is often influenced by climate, quantity of N added in residues, soil fertility status, and previous cropping history. Smith et al. *(19)* reported ^{15}N recoveries in grain crops of 7% to 30% from labeled legume and nonlegume cover crops as compared to an average of 25% to 40% from inorganic fertilizer N. Ladd et al. *(11, 12)* have contributed greatly to understanding the transformations of legume N and subsequent availability to wheat in the semiarid climate of South Australia. As figure 1 illustrates, crop recovery of fertilizer N applied at planting was almost twice that from medic (*Medicago littoralis*) residue N applied 6 months before planting, although the efficiency of recovery of both sources of N was directly related to the amount of N applied. More of the medic residue N (62%) was recovered in soil organic matter than fertilizer N (29%) after the first cropping season.

In earlier research, Ladd et al. *(12)* reported that differences in soil fertility status for two soils similar in texture and pH influenced medic N recovery in wheat crops. Medic residue-N recovery in wheat for a high-N soil (0.17%) averaged 28%, whereas that for a low-N soil (0.09%) was 20%. They attributed this to differences in the quality and turnover of the active organic matter pools in soil through which the medic residue N cycled. In a pot experiment, Yaacob and Blair *(24)* measured the transfer of ^{15}N from soybeans or siratro (*Macroptilium atropurpureum*) residues to Rhodes grass (*Chloris gayana*). Recovery was low from both legumes, 13% to 17%, except where cropped to siratro several times. Residue N recoveries in Rhodes grass after three or six crops of siratro increased to 42% and 56%, respectively. Reasons for this enhanced N recovery are unclear but may indicate a lower potential for immobilization and higher turnover of residue N as related to increased soil N contents and enhanced soil physical properties with multiple cropping, as they later observed *(25)*.

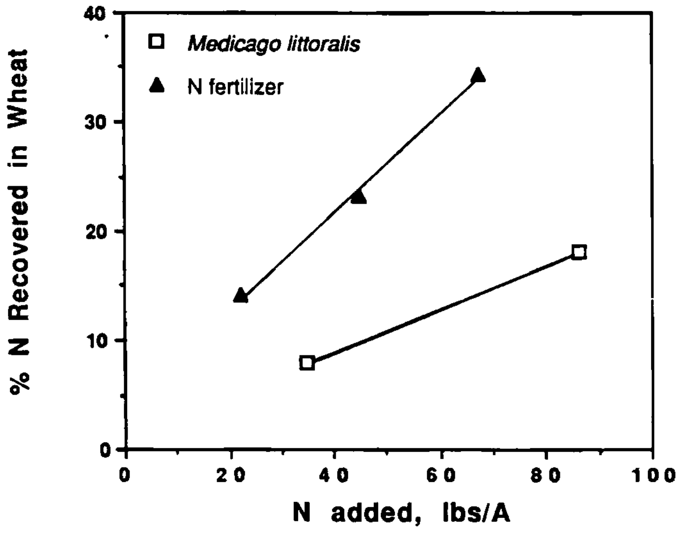

Figure 1. Nitrogen recovery in wheat from fetilizer-N or medic residue in South Austrailia (11).

Table 5. Residual N benefits to conventional (CT) and no-tillage (NT) corn as influenced by previous fertilizer and cover crop management (*14*).

*Previous Fertilizer and Cover Crop**	*Corn Grain Yield*			*N Uptake at 18 Weeks*		
	CT	*NT*	*Average*	*CT*	*NT*	*Average*
	— bushels/acre —			*— pounds N/acre —*		
No fertilizer N						
No cover	51	50	50	51	47	49
Cereal rye	46	48	47	48	58	53
Hairy vetch	72	71	71	81	76	78
Average			56			60
96 pounds N/year						
No cover	56	67	61	71	63	67
Cereal rye	57	76	67	62	87	74
Hairy vetch	82	80	81	110	76	93
Average			70			78

*Previously, 7 or 8 years of no-till corn with and without fertilizer N and cover crops.

It is apparent that summer grain crops can receive significant first season benefits from winter cover crops *(8, 9)*. Long-term use of winter cover crops may build soil fertility levels and provide residual sources of plant-available N. Under the humid climate of central Kentucky, McCracken et al. *(14)* found that, regardless of tillage and fertilizer management, a history of using hairy vetch as a winter cover crop increased the grain yield and N uptake of unfertilized corn an average of 20 bushels/acre and 28 pounds N/acre, respectively, as compared with management of no cover crop (Table 5). A rye cover crop had little or inconsistent effects on corn yield or N uptake as compared with no cover; an exception was the greater yield and N uptake for rye cover for N-fertilized soils in no-till as compared with conventional tillage. It was interesting that there was so little effect of tillage management on residual effects of cover crops.

Cover crops in sustainable systems

Cash grain yield in management systems using legumes for supplemental N, cover crops to reduce erosion and overwinter NO_3 leaching, and tillage to stimulate N mineralization and control weeds depends on the farmer's ability to synchronize available soil N supplies with time of maximum crop need. Early season N release from winter cover crops depends mainly on microbial mineralization/immobilization of C and N which is influenced by the C/N ratio of the residue, its degree of incorporation in soil, and soil temperature and

Table 6. Nitrogen resources at planting time for ridge-till with cover crops and conventional tillage without cover for a corn/soybean rotation in Iowa (6).

Management and N Resource	*Nitrogen Resources For*		*C/N Ratio*
	Soybean, 1988	*Corn, 1989*	
	pounds N/acre		
Ridge tillage + Vetch and Rye			
Crop Residues			
Corn	46	5	42
Soybean	0	18	49
Hairy vetch	36	17	8
Rye	-	29	12
Soil N (top foot)			
Nitrate	42	20	-
Fertilizer	0	60	-
Microbial	270	304	7
Conventional Disk			
Soil N (top foot)			
Nitrate	52	43	-
Fertilizer	0	60	-
Microbial	255	321	7
Both Treatments			
Organic matter	8,400	8,400	12

moisture regimes *(22)*. Depending on these soil conditions, it may take 1 to 3 weeks after cover crop incorporation before N release exceeds N immobilization. The farmer managing biological resources to reduce purchased inputs must decide if additional fertilizer N is needed and, if so, how much. Careful management of available soil N will also reduce the potential loss of N through leaching or denitrification during the time of the year when the soil is not cropped.

Vetch and rye cover crops are often used with ridge tillage management without herbicides to provide cover that affords weed control through competition and, in the case of rye, allelopathy. The cover crops also protect the soil from erosion and reduce the potential for overwinter leaching losses of available N. In the spring, the farmer who does not use herbicides or soil tillage until planting is challenged to provide adequate soil N for his or her grain crop.

Effects of ridge-tillage management with hairy vetch and rye winter cover crops on microbial biomass, available soil N, and crop growth for a corn/soybean rotation were evaluated in 1988 and 1989 on the Thompson farm in Boone, Iowa *(6)*. Investigators used a conventional management practice of fall and spring disking without cover crops for comparison. Because of dry weather, N yields for vetch and rye cover crops were only 17 to 36 pounds N/acre and 29 pounds N/acre, respectively (Table 6).

However, use of winter cover crops with ridge tillage management resulted in reduced soil NO_3 levels and a lower potential for off-season NO_3 leaching losses as compared with disk tillage with no cover. Assuming that 50% of the vetch and rye cover crops would be available to grain crops during the first 5 to 6 weeks after planting, the total available N resources (cover crop/2 + soil NO_3 + fertilizer N) was similar for ridge tillage and conventional tillage and averaged 56 pounds/acre for soybeans in 1988 and 103 pounds/acre for corn in 1989.

Availability of soil N and crop response to ridge-tillage management with cover crops is greatly influenced by management-related changes in the soil physical environment. One year's results for corn from the Thompson farm are presented in table 7; but findings for soybeans the previous year were similar.

Results were influenced somewhat by a dry, early cropping season in 1989. Cooler, wetter, and presumably less aerobic soil conditions with ridge-tillage management during early spring apparently resulted in less available N. Early in the growing season, soil microbial biomass N with ridge tillage averaged 30 to 50 pounds/acre more than that of the conventional treatment. Soil NO_3-N levels in the top foot with ridge tillage averaged 20 pounds/acre less than those with conventional disking and for much of the growing season were below the 70-pound/acre level recommended for non-N-limited growth of corn in this area.

Soil NO_3 levels for ridge-tillage management were lowest in the between-row areas where crop residues were greatest and soil density and water content were highest. Gaseous loss of soil NO_3-N through microbial denitrification was also greatest in between-row wheel-track areas with ridge-tillage management and reached maxima of 0.5 to 1 pounds N/day.

Lower early season soil NO_3-N levels with ridge-tillage plus winter cover crops apparently limited growth and final grain production of corn as compared with conventional tillage without a cover crop. Slower growth and development of corn (12%-35% less) in ridge tillage plus a cover crop compared with conventional tillage without cover also resulted from cooler early season soil temperatures, a less aerobic environ-

Table 7. Effect of tillage management and hairy vetch and rye cover crops on the soil environment, N availability, and 1989 corn yields in central Iowa (4).

Soil Property or Crop Yield	*Double Disk, No Cover*	*Ridge-Till + Cover Crops*	*Difference Between Ridge-Till vs Disk*
Pre-Planting			
Soil Temperature (°F) at 2"	72	60 to 64	10-12° cooler
Water-filled Porosity (%)	48	50 to 78*	Less aerobic
Soil Nitrate-N (pounds/acre-foot)	44	24	20 pounds/acre less
Microbial-N (pounds/acre-foot)	321	299	Less microbial N
7 weeks after planting			
Soil Nitrate-N (pounds/acre-foot)	69	47	N limiting
Microbial-N (pounds/acre-foot)	268	318	More microbial N
Crop dry matter (pounds/acre)	625	410	35% lower
Harvest			
Final grain yield (bushels/acre)	157	142	10% lower

*Highest in wetter, more compact between-row wheel track with ridge tillage.

ment, and perhaps competitive water use by the cover crops in this dry year. Environmental soil conditions and residue accumulations with ridge-tillage in the between-row areas during early May apparently resulted in the loss of 18 to 25 pounds of NO_3-N/acre, presumably via microbial immobilization and denitrification.

The supply of available N during the growing season for ridge-tillage management with cover crops might be increased by supplemental fertilizer N at planting or by earlier tillage to aerate and warm the soil, and to enhance mineralization of crop residues and soil organic matter.

Conclusions

Understanding the effects of alternative management systems employing winter cover crops on soil-microbial activity and associated N cycling in soil is critical to developing economical and environmental management systems that are sustainable in the near and distant future.

Optimized use of biological resources through diversified crop rotations, N-fixing cover and catch crops, and specialized tillage to reduce inputs and environmental degradation while maintaining crop productivity will require high levels of management and information. Present constraints in both areas—management techniques and information—limit application of cover crop systems. Management options for regulating cover crop function are particularly limited and presently consist largely of various tillage management practices. Additional possibilities include timing and method of cover crop kill; genetic improvement of cover crops, especially in suitability for use in drier climates; design of compatible grain production practices; and perhaps manipulation of the soil environment to control cover crop decomposition.

Consideration of the above-mentioned strategies for cover crop management leads us to the conclusion that we know little about cover crop management systems. Quantitative knowledge and predictive ability are lacking with regard to N transfers from crop residues to growing crops; long-term cover crop effects on the quality and availability of soil organic N; and effects of cover crops on weed ecology, soil structure and tilth, NO_3 leaching, soil-water interactions, and many other areas that directly and indirectly influence nutrient cycling. Cover crops present both a unique opportunity to better manage our N resources and a complex management challenge for agronomists, ecologists, and farmers.

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Soil nitrogen movement under winter cover crops and residues

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Water quality issues have become increasingly important as water demand has increased *(2)*. Agricultural management has affected water quality in some locations of the United States under soils that have been intensively managed and have surface soil textures and subsoils that permit high water permeability and low nutrient retention. Conservation tillage increases water infiltration and has shown a potential for both increased *(1)* and decreased water quality problems associated with this tillage modification *(3)*. Investigators have cited cover crops as a means of removing nitrate-nitrogen (NO_3-N) from the soil during high rainfall months and when general row crops are not normally grown *(4, 5)*. We designed this experiment to look at various tillage management techniques and the use of both a legume and a grass cover crop for reducing NO_3-N concentrations in the soil profile.

Methods and materials

We initiated this experiment in October 1988 when hairy vetch (45 pounds/acre) and rye (90 pounds/acre) cover crop plots were seeded and the fall chisel treatment was established. The soil was Dillard soil series (fine-loamy, mixed, mesic Aquic Hapludults). We first sampled all cover crop-treated plots for rye and vetch biomass on March 28, 1989 and then deep soil cored to 120 inches. We plowed all spring-plowed plots after coring and disked both plowed and fall-chisel-treated soils on May 17, 1989.

We sampled cover crop biomass on all remaining no-till plots on May 17 and planted all plots with a no-till corn planter at a rate of 29,700 seeds/acre (DeKalb 689 seed corn). We applied Gramoxone Super 1.5L (2.5 pints/acre), Dual 8E (2.5 pints/acre), and Atrazine 4L (1 quart/acre) to all plots on May 22. Fertilized plots received 180 pounds N/acre (as ammonium sulfate) on May 25; we did not fertilize the remaining plots with N.

We removed soil samples (3-inch diameter) from the treatment soils with Gidding soil-core equipment. We placed each sample in a plastic zip-lock bag and stored it in a cooler until we could refrigerate it at the laboratory. We kept all soil samples at 38°F and extracted them (1 N KCl) within 3 days. We analyzed liquid extracts for ammonium (NH_4-N) and NO_3-N using a Technicon Auto Analyzer.

Results

Crop Data. We first sampled cover crops on March 28, 1989. Shoot biomass averaged 5,170 pounds/acre for rye and 2,770 pounds/acre for hairy vetch. Forty-nine days later (May 16), rye biomass was 10,600 pounds/acre and hairy vetch was 5,700 pounds/acre. Nitrogen concentration in both cover crop species decreased as biomass increased (not shown). The carbon (C)/N ratio increased over time for both cover crops, with a resulting C/N ratio of 10:1 for hairy vetch biomass and

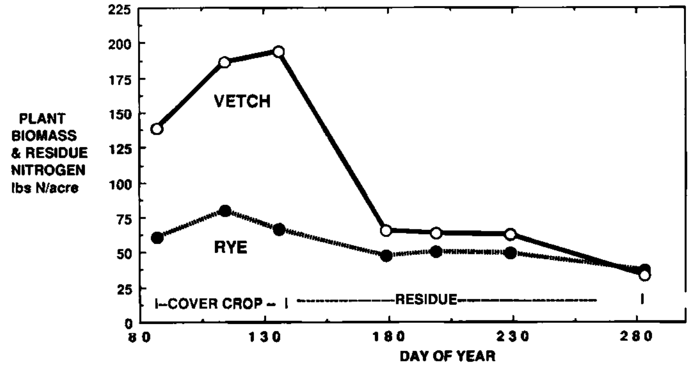

Figure 1. Plant and residue N from rye ande vetch cover crops

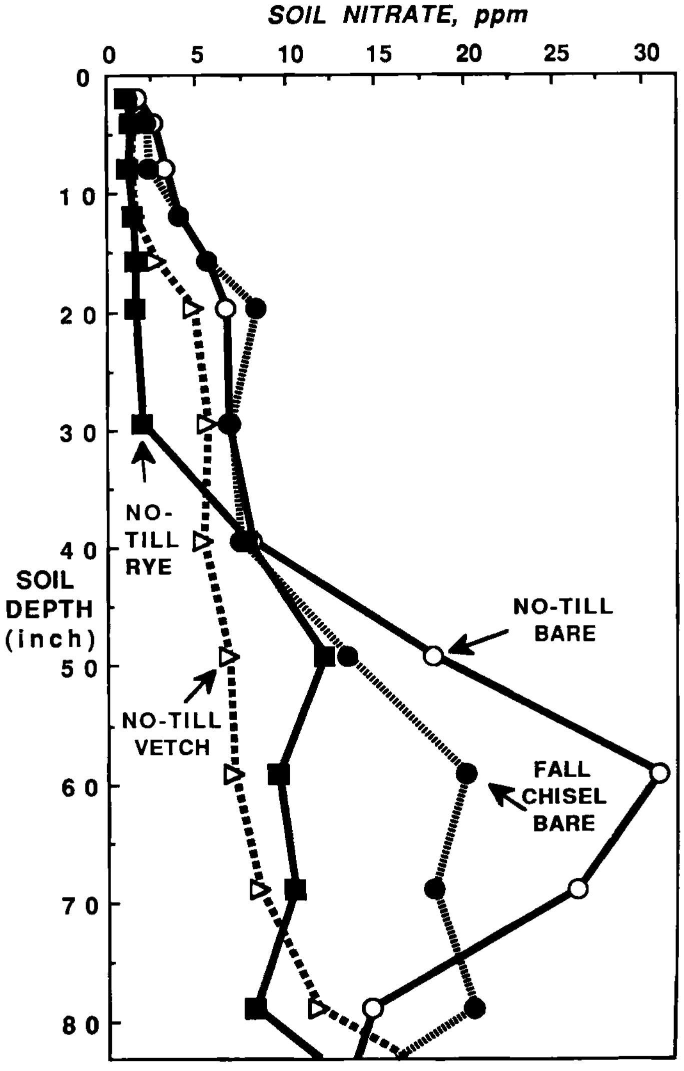

Figure 2. March 28 soil NO_3-N under tillage and cover treatments.

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68:1 for rye biomass (May 16). This large difference in these two species was reflected in the decomposition rate that occurred during the summer. Total N accumulation in the cover crops shows the symbiotic-N fixation of the hairy vetch with over 192 pounds/acre accrued in the shoot biomass (Figure 1). Rye, however, removed 67 pounds N/acre and partially reflects the amount available from the soil.

Nitrogen release following cover crop decomposition progressed rapidly for the hairy vetch, going from a maximum N content of 192 pounds N/acre to 66 pounds N/acre after 43 days (a loss of about 126 pounds N/acre). Nitrogen loss from the rye residue totaled 22 pounds N/acre for the same time period (Figure 1). Heavy rainfall (>13 inches) during this June period may have accelerated the decomposition and N loss from the residue.

Soils data. The abundant growth and N content of rye and vetch on March 28, 1989 reflected the NO_3-N concentrations in the surface layer of those soils with covers (Figure 2). We measured low soil NO_3-N concentrations under the rye and vetch cover crops down to 16 inches—less than 2 parts per million (ppm) NO_3-N. Soil NO_3-N under rye cover continued to be low (<2 ppm) down to 30 inches (probably the lower depth of rooting), then increased to around 10 ppm NO_3-N down to 80 inches. Soils under vetch began to increase in NO_3-N concentration at 16 inches to around 5 ppm NO_3-N and increased gradually to a depth of 80 inches. Both bare-surface treatments (bare-soil, no-till and bare-soil, fall chisel) generally had higher NO_3-N concentrations than the cover crop soil treatments throughout the soil profile, increasing to as high as 30 ppm NO_3-N in the no-till, bare-soil treatment and to 20 ppm in the fall-chisel, bare-soil treatment. This increased NO_3-N concentration at a depth of 40 to 80 inches in the bare-soil treatments reflect the efficiency of cover crops in removing NO_3-N during the winter and spring season.

Soil NO_3-N measured under treatments cored on June 28 (Figures 3 and 4) show substantial differences in NO_3-N movement due to fertilizer, tillage, and cover crop residue. Where no additional fertilizer N was applied at corn planting (Figure 3), we measured low NO_3-N concentrations in the soil profile down to a depth of 50 inches. In this top 50 inches, soils

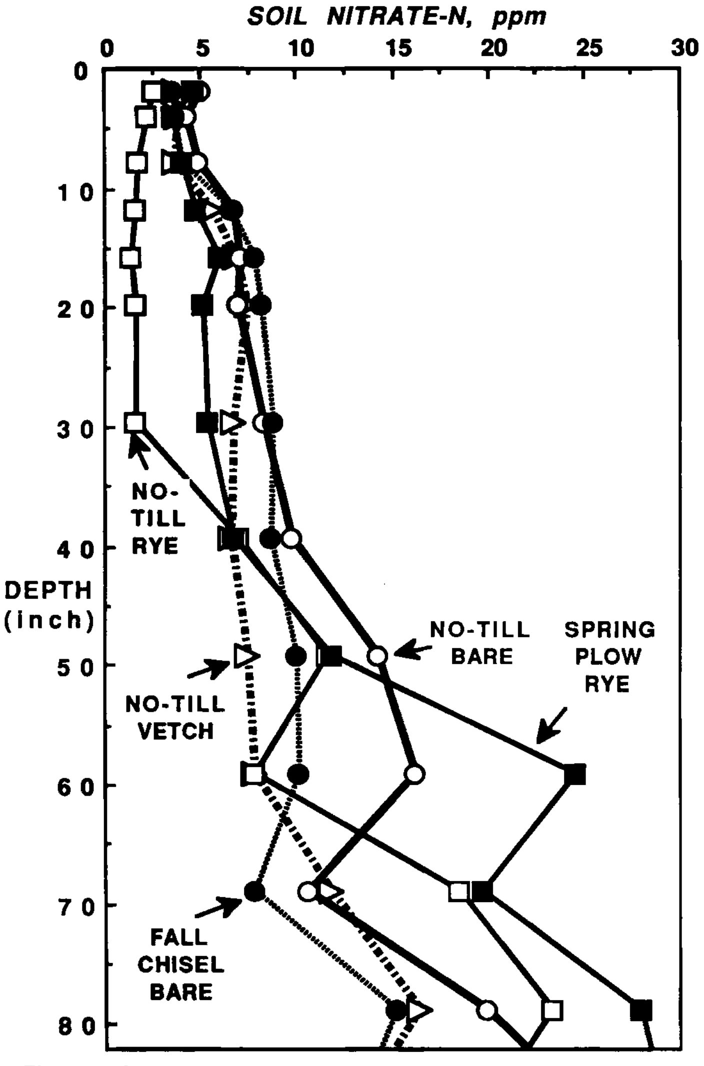

Figure 3. June 28 soil NO_3-N under tillage and cover treatments, no fertilizer N added.

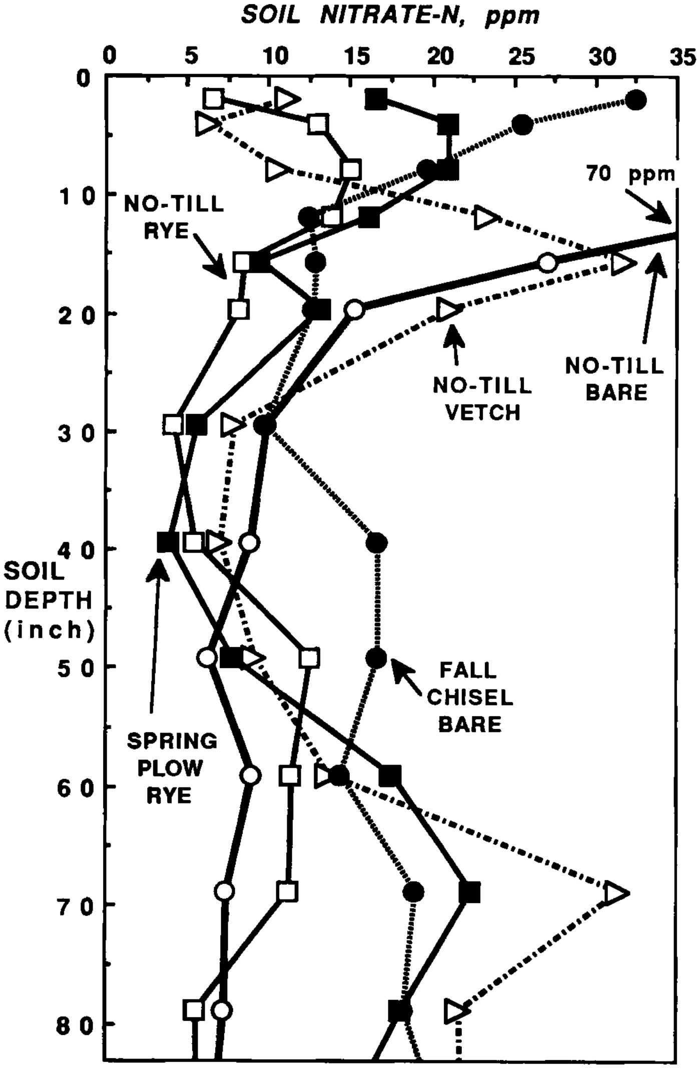

Figure 4. June 28 soil NO_3-N under tillage and cover treatments, 178 pounds N/acre added.

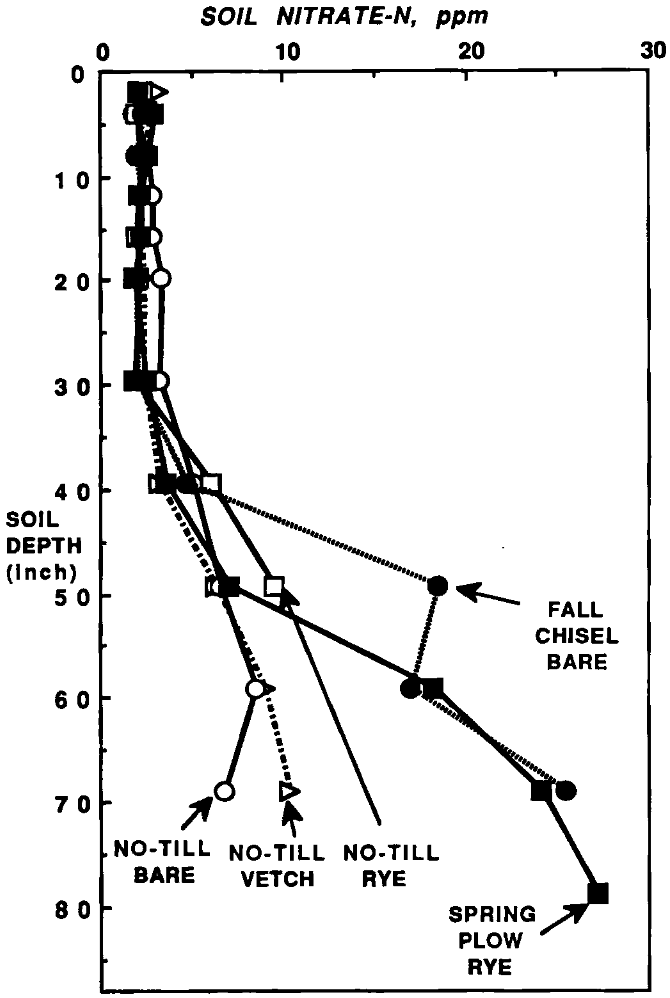

Figure 5. October 10 soil NO_3-N under tillage and cover treatments, no fertilizer added.

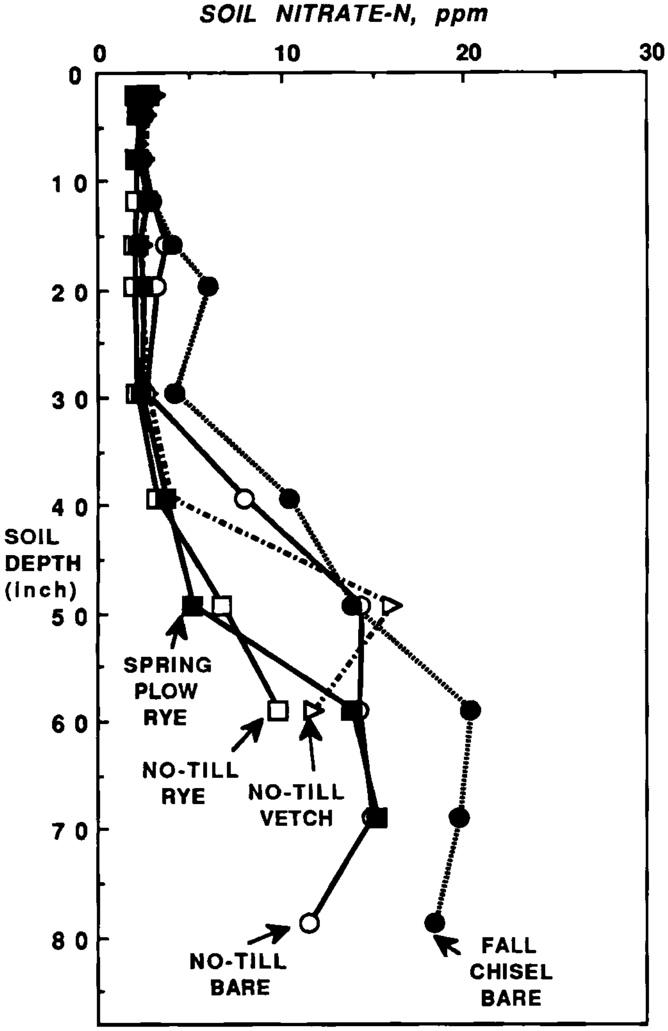

Figure 6. October 10 soil NO_3-N under tillage and cover treatments, 180 pounds N/acre added.

managed with no-till and rye residue contained the lowest NO_3-N (<2 ppm NO_3-N) down to 30 inches. The other four tillage and cover crop treatments (no-till vetch residue; no-till, bare surface; spring-plowed rye; and fall-chisel, bare-surface) produced similar NO_3-N patterns in the soil profile to 50 inches. Spring-plowed rye and no-till, bare-soil treatments produced higher concentrations of NO_3-N at the soil 50-inch depth than the other three treatments. There was a general trend of all treatments increasing in NO_3-N concentration as depth increased, with all treatments above 10 ppm NO_3-N concentration at 80 inches.

The addition of 180 pounds N/acre to each tillage and cover crop residue treatment produced expected increases in NO_3-N in soils extracted on June 28. We found increased NO_3-N concentrations (compared with zero fertilizer-N treatments) mainly in the top 20 inches (Figure 4). We found the highest NO_3-N concentrations at the 0- to 2-inch depth for both no-till, bare-soil (70 ppm NO_3-N) and fall-chisel bare-soil (33 ppm NO_3-N) treatments. Spring-plowed rye (no surface residue during the summer) was next highest with 15 to 20 ppm NO_3-N in the surface 4 inches. Both no-till rye and no-till vetch treatments had soil NO_3-N concentrations around 10 ppm NO_3-N in the surface 4 inches. Also evident were lower soil NO_3-N concentrations in the soil profile in the two treatments with rye residue or cover crop (the no-till rye residue and the spring-plowed rye incorporated residue) where we applied 180 pounds N/acre. The lack of soil NO_3-N from 16 to 80 inches in the soil profile in treatments with rye growing in the spring indicates that fertilizer N had not yet moved down to that soil depth. This indicates that a growing cover crop of rye can accumulate NO_3-N from the soil and can be used in soils containing NO_3-N that might otherwise be lost. We should be concerned about a continued lack of NO_3-N in the surface-soil profile when rye is being used as a cover crop. Lower corn yields will usually reflect this condition unless adequate N is added.

Nitrate concentrations measured in soil cores taken from zero fertilizer-N treatments on October 10 were consistently low to a depth of 40 inches (Figure 5). Crop removal or leaching decreased NO_3-N levels below 3 ppm. All treatments showed increases in NO_3-N concentrations below 30 inches. Soils (October 10) analyzed for NO_3-N in the 180-pound/acre N treatments showed both the fall-chisel, bare-soil and no-till, bare-soil treatments with higher concentrations of NO_3-N in the top 40 inches of soil than the other three treatments. All treatments increased to more than 10 ppm NO_3-N at soil depths below 40 inches (Figure 6).

Conclusions

We designed this experiment to follow N movement during the growing season following a cover crop and to quantify where N was located during the year. The practice of growing a cover crop produces a pool of organic N that might otherwise be lost below the rooting-depth horizon and allows the N to be recycled at a later date. Soils in the unfertilized treatments tended to have lower N concentrations in the upper 40 inches of soil on June 28 but contained high (>10 ppm) NO_3-N concentrations similar to the 180-pound/acre N tillage and cover crop treatments below the 40-inch depth. We can explain the need for additional N for corn production where rye cover crops are used by the lower NO_3-N concentrations in the soil profile throughout the entire corn growing season and at harvest on October 10.

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Influence of cover crops on denitrification and nitrogen mineralization

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Available organic carbon (C) is one of the most important factors affecting biological denitrification *(1)*. Similar rates of denitrification occurred when equivalent amounts of soluble C were added with either alfalfa or wheat straw *(2)*. Both the quantity and nature of the available C compounds from the particular plant species affect the quantity of nitrogen (N) denitrified. Because biomass C contents were increased with cover crops such as reed canarygrass and alfalfa when compared with corn and soybean, it follows that the soluble C content in the soil would also be increased *(3)*. Therefore, denitrification losses of added N should be enhanced as a result of the C supply from the cover crop.

Cover crops show potential for reducing leaching of nitrate (NO_3) through the soil profile by incorporating N during the fall into the forage and microbial biomass and releasing N in the spring through mineralization. Cover crops supply the denitrifiers with available C via root exudation and mineralization of decaying plant tissue. Carbon exudates will also stimulate microbial respiration and thereby deplete oxygen in soil. Therefore, denitrification may be enhanced with cover crops as a direct result of available C supply and as an indirect result of inducing anoxic conditions. Our objective was to determine if forage type (grass and legume) and their decomposition stage affect N mineralization and denitrification in soil.

Materials and methods

We chose a Brookston soil (mesic, Typic Agriaquall) for this study. The soil contained 36% clay, of which 44% was composed of clay mica and 5% vermiculite clay minerals and 2.1% C. We weighed soil samples into 1-quart mason jars. We ground the aboveground portion of grass and legume forages with a microwiley fitted with a 20-mesh screen. We mixed the ground residue with the soil (1% weight/weight) as was a dextrose solution (0.12% weight/weight). We also included a control (no C addition) treatment. Each of the eight treatments were replicated three times.

The legumes we selected were alfalfa, hairy vetch, and red clover; the grasses were annual ryegrass, orchardgrass, and reed canarygrass. We added distilled water to all flasks to adjust soil moisture to 28% gravimetric moisture content. We sealed the mason jars with lids fitted with a Suba-Seal (William Freeman and Co., Barnsley, England S75 6DH*)* to allow sampling of the headspace atmosphere. We incubated the soils for 3, 7, 10, 14, and 21 days at 68°F. At the end of each incubation period, we removed gas samples (0.25 ml) and

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analyzed them for carbon dioxide (CO_2)and oxygen (O_2)using a gas chromatograph fitted with a thermal conductivity detector with Porapak N and molecular sieve columns, respectively. We opened the mason jars and weighed the 0.5-ounce samples (oven-dry basis, 221° F) into 8-fluid ounce Erlenmeyer flasks; we added potassium nitrate (KNO_3) solution (100 ppm N) to each flask. We obtained denitrification estimates as described by Drury et al. *(4)*.

Results

Oxygen was consumed rapidly with legume- and annual-ryegrass-amended soil (Table 1). Alfalfa, hairy vetch, and red clover treatments resulted in 5.4%, 1%, and 3.4 % O_2, respectively, after 3 days. The O_2 concentration continued to decrease to less than 1% by 10 days for these leguminous treatments. Oxygen consumption was considerably slower with the orchardgrass, reed canarygrass, and dextrose-amended soils than with the annual ryegrass and legume treatments. The control treatment consumed small quantities of O_2. The legumes and annual ryegrass resulted in the highest CO_2 production, followed by orchardgrass, reed canarygrass, and the dextrose treatment (Table 1). The control treatment produced comparatively small amounts of CO_2.

Extractable ammonium (NH_4) levels in soil increased to a maximum of 153 ppm N at 21 days with the hairy vetch treatment (Table 1). Red clover and alfalfa treatments also increased extractable NH_4, however, in these cases the NH_4 levels were only about one-third of that produced with the hairy vetch treatment. When the soils were incubated anaerobically, CO_2 production was greatest at 3 days and then decreased over time (Table 2). Initially, the hairy vetch treatment resulted in the greatest amount of CO_2 produced, 358 ppm C, followed by red clover and annual ryegrass at 254 and 184 ppm C, respectively. Orchardgrass, reed canarygrass, and dextrose had similar amounts of CO_2 produced at all incubation periods. The control treatment had low CO_2 production levels ranging from 12 to 29 ppm C over the 21-day incubation period.

Hairy vetch and red clover treatments produced the most nitrous oxide (N_2O) (100 and 90 ppm N, respectively) after the 3-day incubation, whereas the control treatment resulted in the lowest N_2O production at 3.5 ppm N (Table 2). Generally, the level of N_2O produced decreased over time. The content of NO_3 in the control treatment was greater than all other treatments at all periods (Table 2). Between 10 to 21 days there was an apparent increase in NO_3. However, we observed a considerable variation in NO_3 with all other treatments over the 21-day incubation. At 3 days, virtually no NO_3 remained in soils amended with hairy vetch, which is consistent with the high-level of N_2O produced at this time (Table 2).

Table 1. Oxygen consumption, carbon dioxide, and ammonium production from soils amended with either alfalfa, hairy vetch, red clover, annual ryegrass, orchard grass, reed canarygrass, dextrose, or no amendments (control).

Treatment	*Time Days*	*Oxygen (%)*	*Carbon Dioxide (ppt C)*	*Ammonium (ppm N)*
Alfalfa	3	5.4(0.18)*	1.03(0.02)	21.9(1.63)
	7	1.1(0.01)	1.31(0.01)	20.6(3.21)
	10	0.8(0.08)	1.42(<0.01)	34.5(2.24)
	14	0.6(0.11)	1.58(<0.01)	34.8(1.07)
	21	1.0(0.01)	1.60(<0.01)	43.4(0.27)
Hairy Vetch	3	1.0(0.01)	1.39(0.01)	69.5(2.88)
	7	1.0(0.01)	1.42(0.01)	82.9(2.00)
	10	0.9(0.01)	1.47(0.01)	107.1(0.95)
	14	0.5(0.10)	1.65(0.01)	115.4(7.50)
	21	1.0(0.01)	1.66(0.01)	153.0(2.34)
Red Clover	3	3.4(0.08)	1.17(0.01)	16.8(0.67)
	7	1.1(0.01)	1.35(<0.01)	26.9(0.37)
	10	0.9(0.02)	1.42(<0.01)	32.0(0.85)
	14	0.4(0.07)	1.57(<0.01)	36.9(1.61)
	21	1.0(0.01)	1.61(0.01)	52.6(0.13)
Annual Ryegrass	3	7.8(0.06)	0.88(<0.01)	7.9(0.15)
	7	2.3(0.11)	1.25(0.01)	6.1(0.43)
	10	0.9(0.01)	1.39(0.01)	11.5(0.63)
	14	0.8(0.10)	1.52(0.01)	12.7(0.28)
	21	1.0(<0.01)	1.58(0.01)	21.2(1.93)
Orchardgrass	3	12.8(0.67)	0.52(0.04)	7.4(0.15)
	7	7.4(0.07)	0.91(0.01)	6.5(0.43)
	10	6.8(1.42)	0.98(0.07)	7.2(0.31)
	14	1.2(0.14)	1.37(0.03)	3.8(0.05)
	21	1.0(0.01)	1.48(0.01)	9.9(0.60)
Reed Canarygrass	3	15.0(0.03)	0.35(<0.01)	6.0(0.19)
	7	12.4(0.04)	0.59(<0.01)	5.3(0.13)
	10	10.0(0.40)	0.75(0.01)	7.8(0.20)
	14	5.3(0.85)	0.95(0.03)	3.3(0.47)
	21	3.7(0.33)	1.28(0.03)	2.5(0.09)
Dextrose	3	14.5(0.22)	0.43(0.01)	3.3(0.29)
	7	10.7(0.22)	0.74(0.01)	5.8(0.46)
	10	10.1(0.04)	0.82(<0.01)	4.0(0.01)
	14	4.4(0.42)	0.94(0.01)	2.6(0.09)
	21	6.9(0.13)	1.08(0.01)	2.4(0.09)
Control	3	19.7(0.05)	0.01(<0.01)	0.9(0.16)
	7	20.4(0.05)	0.08(<0.01)	5.6(1.09)
	10	19.0(0.12)	0.09(<0.01)	3.4(0.31)
	14	18.5(0.14)	0.11(0.01)	1.9(0.10)
	21	17.0(015)	0.16(0.01)	1.9(0.11)

*Numbers in parentheses are standard errors (N = 3).

Discussion

We found that the legumes released the greatest amount of decomposable C compounds when they were incubated aerobically. Most of these C compounds, particularly those from legumes, were mineralized to CO_2 within 3 days. It was interesting to note that annual ryegrass was similar to the legumes in the amount of C converted to CO_2. The initial amount of CO_2 produced with the orchardgrass and reed canarygrass was lower than that with the legumes and annual ryegrass; however, the rate of CO_2 production from 3 to 21-days was greater. The total amount of CO_2 produced with the legumes and grasses converged by 21 days. The plant residues were the primary source of evolved CO_2, as demonstrated by the low CO_2 production from the control treatment. The high level of microbial activity in soils amended with the legumes and annual ryegrass was responsible for the rapid depletion of O_2. The treatments that had greater quantities of decomposable materials were also the ones showing the greatest O_2 consumption rates. Conversely, the control treatment had low CO_2 production and did not appreciably reduce the amount of O_2 in the mason jars. The hairy vetch treatment released considerable quantities of NH_4 during the aerobic incubation. Presumably, the NH_4 was converted from the N-containing compounds in the plant material during mineralization processes. We need to conduct further studies using ^{15}N to confirm this hypothesis.

Availability of C for anaerobic processes, such as denitrification, appeared to decrease during the longer, aerobic incubation times. With a decrease in the amount of readily decomposable C over time, it was not surprising that the amount of NO_3 denitrified also decreased from the 3- to 21-day period. Therefore, when leguminous plant materials are mixed into soil, they will readily decompose and release C substrates that are available to denitrifiers. When the soil was amended with NO_3 and flushed with helium to remove O_2, the amount of NO_3 denitrified was related to the amount and/or type of C compounds in the soil. We found that forage species differed in the amount and/or quality of soluble C that denitrifiers consumed. Decomposition of the forage species markedly affected the amount and/or nature of the soluble C compounds released, and hence, the denitrification capacity of the soil.

Therefore, we should regulate soil and crop management practices to ensure that N fertilizer is not added to the soil just after a forage species is cut or incorporated into the soil. In this study we demonstrated that the rapid decomposition of legumes and annual ryegrass increased the N mineralization rate. In addition, soluble C released during the decomposition stimulated denitrification.

Table 2. Nitrous oxide, carbon dioxide production, and nitrate in soils amended with either alfalfa, hairy vetch, red clover, annual ryegrass, orchard grass, reed canarygrass, dextrose, or no amendments (control).

Treatment	*Time Days*	*Nitrous Oxide (ppm N)*	*Carbon Dioxide (ppt C)*	*Nitrate (ppm N)*
Alfalfa	3	67.2(0.6)*	123.9(2.3)	48.8(3.4)
	7	54.0(10.6)	175.4(1.4)	49.1(14.5)
	10	45.6(3.6)	118.9(11.0)	30.3(2.9)
	14	70.0(10.4)	103.8(7.1)	20.6(7.9)
	21	31.7(7.1)	78.8(14.6)	56.3(8.7)
Hairy Vetch	3	99.7(1.8)	357.8(24.6)	0.1(0.1)
	7	56.8(8.0)	200.7(65.1)	29.0(8.1)
	10	18.9(1.2)	123.8(33.5)	57.0(3.6)
	14	32.1(2.9)	70.7(4.9)	54.5(7.3)
	21	11.8(1.1)	32.4(2.6)	81.1(1.4)
Red Clover	3	90.0(13.2)	253.8(4.6)	48.4(30.4)
	7	69.8(2.1)	146.4(5.9)	18.7(2.1)
	10	48.9(7.3)	138.1(2.8)	31.3(6.4)
	14	28.0(8.2)	147.6(44.2)	60.8(9.0)
	21	27.2(5.5)	60.0(8.4)	51.8(13.7)
Annual ryegrass	3	51.3(11.1)	184.1(14.5)	30.0(9.2)
	7	56.2(17.7)	145.7(10.1)	52.4(22.5)
	10	32.2(2.0)	81.1(0.5)	50.6(1.1)
	14	63.8(7.0)	97.0(4.1)	17.8(8.4)
	21	28.7(6.9)	101.6(9.2)	63.5(6.2)
Orchardgrass	3	46.6(2.3)	106.8(7.7)	46.2(5.0)
	7	38.7(3.3)	94.7(3.3)	47.1(5.0)
	10	25.3(2.3)	73.4(0.6)	61.6(3.6)
	14	43.2(2.3)	84.3(1.4)	54.3(2.3)
	21	26.3(2.0)	71.0(6.6)	65.4(3.3)
Reed Canarygrass	3	27.5(3.0)	81.1(1.8)	70.0(2.9)
	7	26.2(2.9)	90.6(6.9)	76.1(2.0)
	10	10.5(3.9)	71.5(9.9)	73.4(13.9)
	14	43.2(4.0)	73.0(2.0)	50.5(4.6)
	21	26.8(3.1)	59.6(5.2)	66.7(3.6)
Dextrose	3	25.9(1.7)	87.5(5.4)	57.6(10.6)
	7	26.5(1.2)	84.2(12.6)	57.5(1.5)
	10	14.8(3.9)	80.6(16.1)	68.3(7.6)
	14	32.0(1.9)	61.6(3.1)	65.4(2.2)
	21	22.2(1.3)	55.2(4.0)	76.6(0.6)
Control	3	3.5(2.6)	28.6(9.3)	130.8(4.6)
	7			
	10	6.1(1.0)	17.7(1.7)	116.9(5.3)
	14	5.9(2.5)	25.3(6.0)	132.8(3.0)
	21	2.1(0.8)	12.0(3.2)	149.4(2.2)

*Numbers in parentheses are standard errors (N = 3).

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Effects of winter cover crops on corn yield in Paraná, Brazil

Ademir Calegari

The state of Paraná located in the southern part of Brazil is one of the most important agricultural regions in the country. Representing only 2.4% of the country's total area (78,378 square miles), Paraná contributes about 20% to the total national production and 24% toward total agricultural exports.

In Parana, about 15 million acres are cultivated with summer crops, such as soybeans, corn, blackbeans, cotton, upland rice, wheat, etc. Approximately half of this area remains in fallow during the winter season. This situation, as well as heavy rainfall, aggravates soil loss. Soil erosion is one of the most serious problems related to agricultural production. Protecting the soil surface with winter cover crops is an effective way of reducing soil erosion and improving the productivity of summer crops *(1)*.

Our objective in this study was to evaluate the effects of winter cover crops on corn yield with and without nitrogen (N) under conventional and no-till systems.

Materials and methods

I conducted field experiments at the Agronomic Institute of Paraná (IAPAR) Experimental Station at Pato Branco, Paraná, Brazil (52° 41' W, 26° 07' S, and 2,296-foot altitude). Climatologically the area belongs to the zone of subhumid tropical climate or Koeppen's Cio. The soil of the experimental site is an Oxisol (very acid, clay texture; 75% clay, 13% silt, and 12% sand) and dominated by kaolinitic minerals with total cation-exchange capacity of 10-12 milliequivalents (meq) per 100 grams of soil. Relevant chemical properties of the soil are given in table 1. The soil site was not fertilized and limed before the beginning of the trial.

Treatments combined winter cover crops, two levels of N, and two tillage systems. The winter cover crops used were wheat, lupins, hairy vetch, common vetch, rye, blackoats, oilseed radish, sweet peas, spergula, serradella, ryegrass, and fallow. Cover crops were grown during the winter of 1986; they were controlled at the flowering stage by applying weedkiller (ryegrass, spergula, and fallow) or cutting them with a knife roller (lupins, hairy vetch, common vetch, rye, black oats, oilseed radish, sweet peas, and serradella). Only the wheat grain was harvested, leaving the mat of dead materials on top of the soil as a mulch. The no-till system was disk-plowed (8- to 10-inch depth) for conventional tillage.

Corn (cultivar AG 64A) was planted at the beginning of the three summer seasons of 1986, 1987, and 1988 at a spacing of 39 inches by 8 inches and at a population of 20,200 plants/acre. Fertilizers were applied annually to the corn crop only. Phosphate (single superphosphate 9.68% P) at rates of 7.9, 31.4, and 31.4 pounds P/acre and potassium (potassium chloride 55.6% K) at rates of 11.1, 29.6, and 33.3 pounds P/acre were applied in 1986, 1987, and 1988, respectively. Applied fertilizers were broadcast before planting corn. Two rates of N fertilizer were evaluated for corn only: 0 and 80 pounds N/acre. Nitrogen (urea) was applied in two split dosages: one-half broadcast applied at planting and one-half N banded at 6 weeks after planting corn. Conventional tillage (disk plow and two disking) and a no-tillage treatment were used. At flowering, plant samples (aerial and roots) were taken of each cover crop to determine green matter and dry matter (dried them at 158° F.) Subsamples were ground for chemical analysis. Plant tissues were digested with nitroperchloric acids and analyzed for phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), zinc (Zn), and manganese (Mn). Nitrogen was determined using a microkjeldahl block digestion apparatus. Treatments were organized according to split-plot design with three replications. Winter cover crops were the main plots and tillage systems and N-rates were subplots.

Results and Discussion

Table 2 shows shoot dry matter production and the amounts of nutrients recycled by cover crops for the no-till system. These results represent means of three years (1986, 1987, and 1988). The results for conventional tillage are not presented in table 2 because there was no significant difference between the two tillage systems. The treatments that produced the highest shoot dry matter were as follows: black oats >spergula = rye> blue lupin = serradela (2.23, 2.19, 2.19, 1.92, and 1.92 tons/acre, respectively). Root dry matter production (data not presented) was as follows: black oats > rye > hairy vetch (0.62, 0.58, and 0.49 tons/acre, respectively). These three cover crops should have the greatest capacity for growing roots in acidic soil.

On average, the materials that produced highest shoot green mass (data not presented) were as follows: spergula > serradella > lupins > black oats (13, 11, 10, and 8 tons/acre, respectively). These plant species had the greatest capacity to cover the soil surface, thus decreasing the soil erosion losses. As expected, the leguminous cover crops (lupins, serradella, sweet peas, hairy vetch, and common vetch) and spergula had the highest amount of N and the lowest C/N ratio in the residues. In general, the spergula should have the highest amount of nutrients in the residue, except for Ca.

Table 3 shows the treatment effects on corn grain yields in 1989. The corn yields without N in both tillage systems after leguminous, spergula, and oilseed radish winter cover crops were higher than for fallow winter treatment. The lupins treatment showed the greatest effect on corn yields without N. Corn yields increased with N application (80 pounds/acre) after all winter cover crop treatments. This effect was higher for the no-till treatment than conventional tillage. Corn yield after lupins without N was slightly higher than fallow winter with N application. This result was due to higher N content in the lupins residues (Table 2).

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Table 1. Chemical properties of the soil site at the beginning of the trial.

Soil Depth (cm)	pH 0.01M $CaCl_2$	Exchangeable Cations Al	Ca	Mg	K	Total Acidity (H+Al)	Organic C (%)	P (ppm)
		cmol(p^+)/kg						
0-10	4.7	0.12	3.67	2.10	0.43	5.74	2.54	3.8
10-20	4.7	0.16	3.35	1.95	0.31	5.88	2.43	2.2
20-40	4.7	0.27	2.80	1.65	0.23	6.19	2.22	1.7

Table 2. Dry matter production and amount of nutrients recycled by cover crops.

Cover Crops Treatments	Dry Matter (tons/acre)	Nutrients N	P	K	Ca	Mg	Organic C	C/N Ratio	Nutrient Cu	Zn	Mn
		pounds/acre							pounds/acre		
Serradella	1.9	91.6	5.7	124.9	52.9	18.0	2,057	22.4	0.042	0.022	0.518
Hairy vetch	1.3	70.1	4.4	69.9	13.7	4.6	1,458	18.6	0.027	0.010	0.196
Common vetch	1.3	72.7	3.9	76.4	24.5	8.7	1,353	18.6	0.025	0.010	0.223
Fallow	0.3	30.0	2.3	30.5	8.6	6.0	593	19.7	0.021	0.036	0.011
Wheat	1.3	28.6	3.2	29.4	3.2	3.5	1,564	54.6	0.016	0.036	0.170
Ryegrass	1.9	48.2	3.8	110.9	12.7	7.9	2,137	44.2	0.026	0.080	0.589
Sweet peas	1.3	85.7	4.3	68.5	13.4	8.6	1,479	17.2	0.037	0.080	0.232
Rye	2.2	41.5	2.7	63.8	14.8	7.4	2,640	63.5	0.026	0.062	0.250
Oilseed radish	1.1	45.3	2.1	72.8	29.7	13.2	1,155	25.4	0.013	0.071	0.143
Black oats	2.2	69.6	6.7	126.2	10.7	9.8	2,570	36.9	0.027	0.062	0.723
Blue lupin	1.9	109.7	6.1	95.9	51.0	20.7	2,129	19.4	0.046	0.152	2.445
Spergula	2.2	91.0	8.3	140.0	16.1	27.9	2,359	25.9	0.074	0.312	1.454

Table 3. The effects of winter cover crops, nitrogen rates, and tillage systems on corn grain yields, 1989.

	Corn Grain Yield by Tillage System and N Rate			
	No-Till		Conventional Till	
Winter Cover Crops	0 Pounds/Acre	80 Pounds/Acre	0 Pounds/Acre	80 Pounds/Acre
	pounds/acre			
Serradella	3.9	4.9	3.8	3.6
Hairy vetch	4.2	4.9	3.3	4.0
Common vetch	3.9	5.4	4.3	5.1
Winter fallow	3.7	4.6	3.1	4.7
Wheat	3.0	4.7	3.1	4.2
Ryegrass	3.7	4.7	3.9	5.1
Sweet peas	3.9	5.0	3.8	4.4
Rye	2.2	4.6	3.3	4.4
Oilseed radish	4.0	5.0	3.9	5.0
Black oats	3.1	4.6	3.1	5.2
Blue lupin	4.9	5.8	4.2	4.9
Spergula	4.2	5.4	3.9	4.5
Tkeytest (0.05); V.C. = 10.52%; msd = 1.74				

The average corn yield in 1987 (first cropping) was higher for conventional tillage than no-till (data not presented). However, in 1988 and 1989 (second and third cropping), corn yields increased gradually for the no-till system. During the experimental period, I did not observe any serious problems with insects and diseases for winter and summer crops.

Conclusions

Corn yields without N were higher after legumes and lower after grass winter cover crops than winter fallow for conventional and no-till systems.

With no N application, lupins caused an increase of more than 892 pounds/acre of corn yield in relation to winter fallow.

Nitrogen application (80 pounds/acre) increased corn yields in all winter cover crop treatments.

Corn yields without N after lupins were equivalent to yields obtained in winter fallow with 80 pounds/acre for the no-till system.

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Benefits of a winter legume cover crop to corn: Rotation versus fixed-nitrogen effects

H. A. Torbert and D. W. Reeves

The beneficial effects of using winter legumes as cover crops for corn (*Zea mays* L.) production is well documented. Most of the benefits are attributed to increased levels of soil nitrogen (N) following the winter cover crop due to N_2 fixation by legumes *(3, 4, 7)*. However, other benefits due to rotation from continuous corn could also contribute to the increased yields normally seen following a legume. Benefits, such as improved soil physical properties, elimination of phytotoxic substances *(1)*, addition of growth-promoting substances *(8)*, and reduction of disease incidence *(2)* have been identified as possible rotation effects from a legume cover crop. In addition, long-term benefits from winter cover crops include reduced erosion and decreased nutrient leaching during winter *(3)*.

Management of fertilizer N, however, can be complicated by the use of winter cover crops. Studies have shown that plant N from legumes is available during more optimum periods because nonlegume residue may tie up available N longer than legume residue *(5)*. In addition, the rotation effects from cover crops could result in healthier plants with larger root systems that could better use available soil N *(6)*. Because of environmental concerns over the fate of N fertilizer, it is important to understand how both soil-N and fertilizer-N use is affected by winter cover crops.

Methodology

We initiated research in 1990 at the Alabama Agricultural Experiment Station's E.V. Smith Research Center in east-central Alabama. We planted corn in a split-plot design of four winter cover crops and four N rates. The cover crops were 'Tibbee' crimson clover (*Trifolium incarnatum* L.); an ineffective-nodulating crimson clover, CH-1 (10); rye (*Secale cereale* L.); and winter fallow. We applied a split application of 40 pounds/acre of fertilizer N as ammonium nitrate (NH_4NO_3) to the winter cover crops to ensure adequate growth of both the CH-1 clover and the rye. Application of ^{15}N enriched NH_4NO_3 (40 pounds N/acre) containing 2.0 atom percent ^{15}N was applied to 3 square-foot microplots in each of the cover crops. We collected plant and soil samples from the microplot area of each cover crop.

We applied broadcast applications of 0, 50, 100, and 150 pounds N/acre to the corn. Inside each plot, we applied ^{15}N depleted NH_4NO_3 at the appropriate N rate to a 10- by 10-foot microplot. At harvest, we collected plant and soil samples from 10 feet of row inside the microplots and analyzed them for total N content and isotope ratio. We calculated total fixed-N for clover cover crops and, from these data, determined fertilizer N and soil N in corn grain. Separation of fixed N and rotation effect was performed by procedures of Russelle et al. *(9)*.

Results and discussion

We included the ineffective-nodulating crimson clover (CH-1) for separation of fixed N and rotation effects when compared with the Tibbee crimson clover. However, contamination of the CH-1 seed through cross pollination of N-fixing crimson clover occurred, resulting in effective-nodulating crimson clover. Calculation of total fixed N by the clover confirmed that CH-1 plants fixed significant amounts of N_2 with an estimated 59 pounds/acre of fixed N for the CH-1 and 95 pounds/acre for the Tibbee crimson clovers. Therefore, we performed separation of fixed N and rotation effects using the procedures described by Russelle et al. *(9)*.

As expected, grain yield increased with increasing N application for all four winter cover crops (Figure 1). Corn following crimson clover resulted in higher yields, although not always statistically different, than other cover crop treatments at all N rates. Yields following clover were similar following winter fallow at the 100- and 150-pound N/acre rate, and following rye at the 150-pound/acre N rate. This indicates that a large portion of the beneficial effect of clover was due to

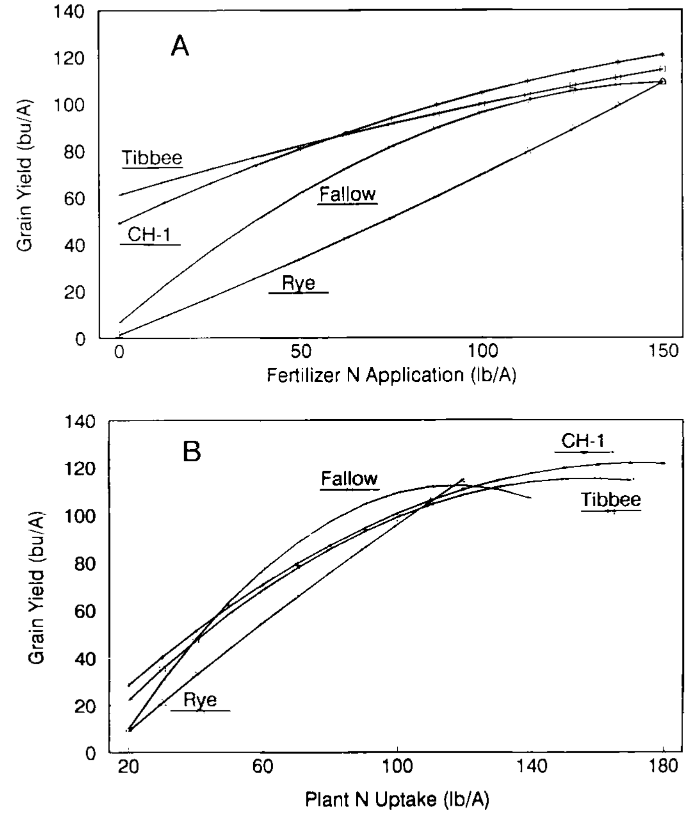

Figure 1. Regression analysis of fertilizer-N appplication (A) and N uptake (B) in corn versus grain yield for fallow, Tibbee crimson clover, rye, and CH-1 winter cover crops.

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fixed-N effect, because yields were similar when adequate N was applied.

We also performed regression analysis of grain yield versus grain N uptake (Figure 1). According to the procedures of Russelle et al. *(9)*, the difference in expected yield with fallow and yield following clover at the same N uptake can be attributed to rotation effects. However, corn yields versus N uptake were similar for all four winter cover treatments, indicating that rotation effects did not play a significant role in the yield response of corn in this year. Further, these data indicate that the negative response of corn following rye, compared with fallow was due to immobilization and consequent reduction in available soil N.

We performed regression analysis of both fertilizer N uptake and soil N uptake in the plant versus applied fertilizer-N (Figure 2). Results indicated that both fertilizer and soil N uptake increased as fertilizer N application increased. Soil N uptake in the plant was much higher following clovers, both Tibbee and CH-1, than following winter fallow and rye, indicating that significantly higher levels of soil N were available, presumably due to N_2 fixation by the clover. While uptake of fertilizer N was similar for all four cover crops (Figure 2), fertilizer N content was highest following CH-1, indicating that rotation effects may increase N uptake, increasing N use and potentially reducing N pollution.

To summarize, a crimson clover cover crop resulted in a significant beneficial effect to corn compared with winter fallow or rye. During this first year of the study, we attributed the beneficial effect almost entirely to increased levels of soil N following clover. However, preliminary data indicate that rotation effects may increase N use following clover, indicating a possible lower N pollution potential.

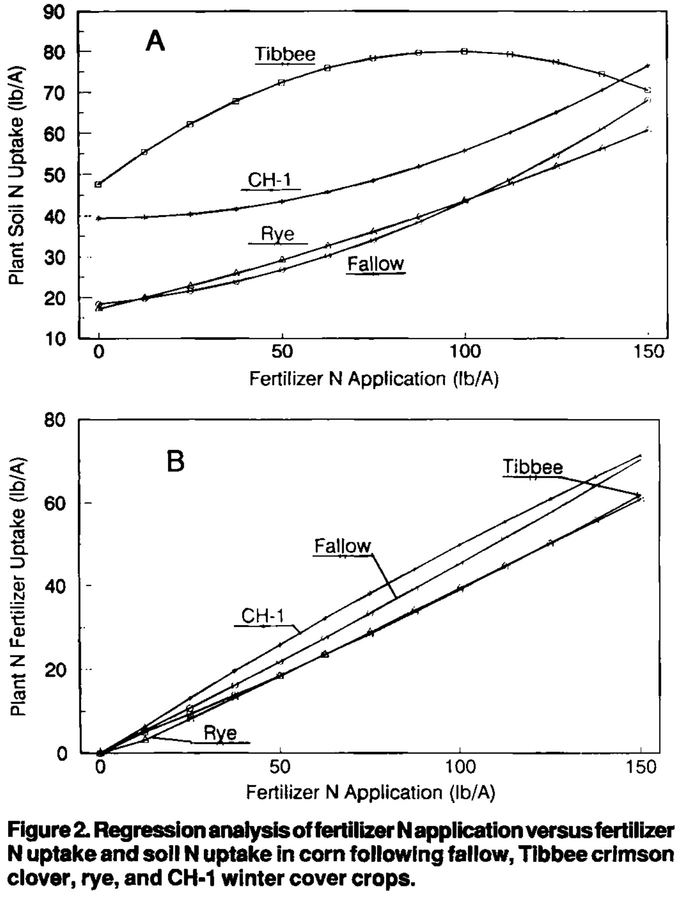

Figure 2. Regression analysis of fertilizer N application versus fertilizer N uptake and soil N uptake in corn following fallow, Tibbee crimson clover, rye, and CH-1 winter cover crops.

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Rye nitrogen cycling for corn and potato production

G. K. Evanylo

Small grain winter cover crops are efficient scavengers of residual soil nitrogen (N) because they possess deep-growing, fibrous root systems that are able to procure soil N during periods when some other crops are not growing optimally. Such crops may reduce nitrate (NO_3) enrichment of groundwater from fertilizers and animal manures by retaining N within the soil-crop system. Unfortunately, immobilization of residual and fertilizer N by nonlegume cover crops, due to the high C/N ratio of their biomass, often prevents recycled N from becoming available to the following crop, which increases the fertilizer N requirement *(1, 4)*.

Increasing use of agricultural soils in the mid-Atlantic Coastal Plain for disposal of animal waste poses the potential for groundwater contamination by NO_3. Annual rye (*Secale cereale* L.), commonly planted as a winter cover in this region for cropping systems that include high N-requiring crops, such as white potatoes (*Solanum tuberosum* L.) and corn (*Zea mays* L.), may be employed as an N trap crop. Rye may be less apt to immobilize N in a potato rotation than in a corn rotation, because the cover is generally killed about a month earlier for potato production, at which time the C/N ratio of the rye biomass is lower. Likewise, availability of rye-scavenged N to corn may be increased by earlier-than-normal killing of the cover crop *(5)*.

Because few studies investigate the capability of rye to accumulate and recycle N in the mid-Atlantic Coastal Plain, our purpose in this study was to determine to what extent residual, fall-applied N could be recycled by annual rye for use with subsequent potato and corn crops.

Materials and methods

We conducted field studies from September 1987 to July 1989 at the Eastern Shore Agricultural Experiment Station in Painter, Virginia, on a Bojac loamy sand (fine-loamy, mixed, thermic Typic Hapludults). Potato study treatments consisted of four residual N rates (0, 100, 200, and 300 pounds/acre) applied in September 1987 and 1988 and six N rates (0, 30, 60, 90, 120, and 150 pounds/acre) side-dressed at seedling emergence in 1988 and 1989. Corn study treatments consisted of three residual N rates (0, 100, and 200 pounds/acre) applied in September 1987 and 1988 and five side-dressed N rates applied when the corn was 12 to 18 inches tall in 1988 (0, 100, 200, 300, and 400 pounds/acre) and 1989 (0, 50, 100, 150, and 200 pounds/acre). We situated all treatments on the same plots in both years of the study. We factorially combined the treatments in a randomized complete block design employing four replications. Plots were six rows wide and 25 feet in length. Row spacings for potatoes and corn were 36 inches and 30 inches, respectively.

Following the disking of the previous potato crop residue and the mechanical harvest of corn each September, we broadcast residual N treatments as ammonium nitrate onto the soil. We disked the potato study soil again in late October and conventionally planted rye (cultivar Abruzzi) into the potato soil and drilled no-till into the corn soil at a rate of 75 pounds/acre. We planted potato (cultivar Superior) seed pieces on March 23, 1988 and April 13, 1989, following incorporation of the rye on March 16, 1988 and March 29, 1989 by moldboard plowing and disking immediately prior to planting. We planted corn (cultivar Pioneer 3320) on April 12, 1988 and April 19, 1989, following killing of the rye with paraquat on March 31, 1988 and April 14, 1989. We applied side-dressing N treatments by streaming urea ammonium nitrate solution next to each row with a backpack sprayer at the appropriate growth stage. Cultivation practices routinely employed at this time for weed control in potatoes served to incorporate the N fertilizer.

Seven to ten days prior to rye incorporation in the potato plots and paraquat application in the corn plots, we sampled soil to a depth of 24 inches in the potato soil and 36 inches in the corn soil to determine inorganic N (NH_4+NO_3). Concurrently, we sampled rye for total dry matter production, total carbon (C), and total Kjeldahl N. At harvest, we mechanically dug potato tubers from the two middle rows of each plot, and weighed those with a diameter greater than 1.88 inches for fresh yield estimates. We estimated corn yields following the hand-harvesting of the two middle record rows from each plot and adjusted the moisture content to 15.5%. We statistically analyzed data by analysis of variance with linear and quadratic partitioning (GLM) and quadratic and plateau yield modeling (NLIN) employing the Statistical Analysis System (SAS).

Results and discussion

Rye growth and N uptake was increased by residual N treatments in the corn and potato studies in both years (Table 1). In the potato study, dry matter produced by the highest N rate was 2.2 and 3.4 times as great as the control in 1988 and 1989, respectively; corresponding N uptake increased 4.1 and 5.2 times. In the corn study, dry matter production and N uptake by rye with 200 pounds fall-applied N/acre were 7.2 and 13.6 times as great, respectively, as that in the control in 1988, but only 2.2 and 2.4 times as great in 1989. Rye C/N ratios were reduced with increasing residual N, ranging between 8.9:1 and 19.0:1 for potatoes and 10.1:1 and 32.1:1 for corn.

Rye dry matter production, but not N uptake, was higher in 1989 than in 1988, because excessive soil moisture in 1989 did not permit us to implement cover crop management practices as early as in 1988; hence, the rye had a longer growing period in 1989. Because the capability of rye to trap N is a function of the physiological activity of the root system and the availability of soil N, the lower N content of the rye (relative to dry matter) in 1989 was probably due to increased

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N leaching losses and decreased root activity.

We observed no effect of residual N on soil inorganic N to a depth of 24 inches in 1988, despite the wide range in fall-applied N. Soil N levels were apparently equalized by the joint effects of rye leaching and uptake. In 1989, soil N was increased only by the highest residual N rate. Except for that produced by the highest residual N rate in the second year of the study, it is doubtful whether the resultant amounts of mineral N in the sampled soil profile each spring could account for differences in potato-crop available N. Soil mineral N at greater depths than measured in this study probably did not contribute to the N requirement of the potato crop because inorganic N below a depth of 12 inches in sandy soils at the end of the winter period has been shown to be largely unavailable to a potato crop *(3)*, whose root system typically exploits the soil to a shallow depth of 24 inches or less *(2)*.

Soil N in the corn study was increased by fall-applied N only at the highest rate in 1988. Rye trapped much of the N supplied by the 100 pounds/acre rate, thereby preventing significant soil accumulation. In 1989, cover crop accumulation and leaching appeared to reduce soil N to insignificant levels.

The response of tuber yields to side-dressed N was dependent upon residual N rates (Table 2). With no fall N, 158 and 68 pounds N/acre were required to produce 90% of maximum yield in 1988 and 1989, respectively. As residual N increased, side-dressed N rates required to achieve 90% of maximum yield decreased further. At or above 200 pounds residual N/acre, yields did not respond to side-dressed N. Because soil inorganic N levels were significantly high only with 300 residual N/acre in 1989 (Table 1), the major source of crop-available N influencing tuber biomass response to side-dressed N was probably the rye cover crop.

In both years, side-dressed N required to achieve 90% of maximum corn grain yield was reduced by increasing amounts of fall-applied N (Table 2). In 1988, when yields were limited by moisture and less side-dressed N was required than in 1989, grain yields plateaued at 85 bushels/acre with no fall-applied N. At higher levels of residual N, required side-dressed N rates were decreased and the yield plateau was raised, indicating that the beneficial effects of residual N were greater than solely as an N source. The greater amounts of biomass produced with 100 and 200 pounds residual N/acre than by the control resulted in a longer-lasting mulch that probably improved soil-plant water relations and increased yield potential.

Table 2. Effect of fall-applied N on rate required for potatoes and corn.

	Fall-applied N (pounds/acre)							
	1988				*1989*			
Effect	*0*	*100*	*200*	*300*	*0*	*100*	*200*	*300*
Probability of corn yield response to fertilizer N*	S01	S01	NS	NA	S01	S01	S01	NA
Corn yield plateau (bushels/acre)	85	134	139	NA	146	144	145	NA
Required N rate for 90% maximum yield (pounds/acre)	52	40	0	NA	154	147	79	NA
Probability of tuber yield response to fertilizer N*	S01	S05	NS	NS	S05	S05	NS	NS
Tuber yield plateau (hundred weight/acre)	219	207	205	215	146	162	158	163
Required N rate for 90% maximum yield (pounds/acre)	158	25	0	0	68	73	0	0

*S01 and S05 indicate significance at 0.01 and 0.05 levels of probability, respectively; NS, not significant at 0.10 level of probability; NA, not applicable.

In 1989, maximum corn yields were similar to those achieved in 1988, but higher rates of side-dressed N were required to attain those levels. Because rye N contents were about the same in 1988 and 1989, the higher side-dressed N requirement in 1989 was probably due to rye immobilization of N.

By employing a nonlegume winter cover crop, it is possible to trap residual N from unused fertilizer or animal waste and

Table 1. Response of soil and rye to fall-applied nitrogen.

	1988				*1989*			
Crop and N Rate	*Inorganic Soil N*	*Rye Dry Matter*	*Rye N Uptake*	*Rye C/N*	*Inorganic Soil N*	*Rye Dry Matter*	*Rye N Uptake*	*Rye C/N*
		pounds/acre				*pounds/acre*		
Potato Study								
0 pounds/acre N	84	1,620	42	16.9	44	1,234	28	19.0
100 pounds/acre N	78	2,797	102	12.0	40	3,499	93	16.4
200 pounds/acre N	82	3,300	145	10.0	67	3,920	129	13.2
300 pounds/acre N	58	3,591	174	8.9	154	4,207	146	12.5
F test*								
Linear	NS	S01	S01	S01	S01	S01	S01	S01
Quadratic	NS	S01	NS	S01	S05	S01	S01	NS
Corn Study								
0 pounds/acre N	31	444	10	19.5	30	3,501	51	30.7
100 pounds/acre N	49	2,609	84	13.4	33	6,722	95	32.1
200 pounds/acre N	149	3,185	136	10.1	46	7,581	124	27.0
F test*								
Linear	S01	S01	S01	S01	NS	S01	S01	NS
Quadratic	S05	S05	NS	S05	NS	NS	NS	NS

*S01 and S05 indicate significance at 0.01 and 0.05 levels of probability; NS, not significant at 0.10 level of probability.

recycle the nutrient for crop use during the following season. At the time that we normally incorporate rye into the soil for potato production, its biomass typically possesses a C/N ratio that should favor mineralization rather than immobilization of N. In order for rye to prevent immobilization of N in corn production, the cover crop should be killed earlier than usual. A disadvantage to early kill in no-till corn production is loss of a protective soil mulch due to poorer cover crop establishment; however, with proper management, residual N trapped by a nonlegume cover crop may supply a considerable portion of a potato or corn crop's N needs in sandy Coastal Plain soils.

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Decomposition and nitrogen recycling of cover crops and crop residues

Z. C. Somda, P. B. Ford, and W. L. Hargrove

Tillage methods that allow crop residues to remain on the soil surface are becoming more widespread. Maintaining crop residues on the soil surface can enhance soil physical and chemical properties as well as reducing erosion losses *(4)*. Improvements in soil productivity associated with crop residue management are related to crop residue decomposition and nutrient mineralization rates.

Decomposition of and nitrogen (N) release from crop residues are greatly influenced by a number of biotic and abiotic factors *(7)*. Initial residue quality plays a preeminent role in determining the rate of residue decomposition and N mineralization. Reports of significant correlations between initial N concentration, lignin content, initial carbon (C)/N ratios, and N mineralization rate have been published extensively *(5)*.

Residues with similar C/N content can have different decomposition rates because different C compounds exhibit different decomposition rates. Because comparative data for a wide range of residue properties are sparse, we initiated this study to determine rate of decomposition and N release from a wide variety of crop residues under controlled-environment conditions.

Materials and methods

We conducted the study under growth chamber conditions using aluminum trays (3 x 3 x 0.69 feet) containing an Appling sandy loam (clayey, kaolinitic, thermic Typic Kanhapladult) with initial pH of 6.58, bulk density of 1.43 g cm^{-3}, and 1.29% C and 0.14% N content. We maintained the soil near 75% moisture capacity and an ambient temperature at 95° F. The experimental design was a strip-split plot with four replications (blocks) with the residue type in strips, and the split plots being residue removal date.

We harvested aboveground portions of the different crops at or near maturity, then air-dried and characterized them (Table 1). We placed crop residues of 0.4 ounces in separate 0.04-inch mesh nylon bags (6" x 6") and buried them in the soil at a depth of 3 inches. We removed one bag of each residue type per tray at 1, 2, 4, 8, and 16 weeks after incubation in order to determine the dry weight and the C and N content in the remaining residues.

We determined ash-free dry weights, the content of C and N in the harvested residue to correct for soil contamination by using the ash content determined prior to and after grinding, and the initial soil content of C and N.

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We determined daily decay rates using a two pool exponential model, as follows:

Remaining residue weight/initial residue weight= $P_1e^{-k1t} + P_2e^{-k2t}$

where P_1 and K_1 represent the relative size and the decay rate constant for the readily decomposable pool and P_2 and K_2 represent the relative size and the decay rate constant for the recalcitrant pool, respectively. We determined pool sizes and decay rates by the nonlinear regression procedure *(8)*.

Results and discussion

Residue decomposition. We can best describe decomposition over time for most residues investigated using a two-pool model, with the first daily decay constant (K_1) indicating more rapid initial decay and the second decay constant (K2) reflecting a slower rate of decay over a longer time period (Table 2). High decay rates in the first pool are indicative of the rapid decomposition of simple carbohydrates and other low C/N ratio compounds. Residues with low initial C/N ratios for example, legume crop residues, generally decomposed to a much greater extent compared with residues having high initial C/N ratios for example, nonlegume crop residues) (Figure 1). We correlated net decomposition (percent residue lost) (r = -0.43, significant at the 0.0001 probability level) with initial C/N ratio. We defined the percentage of residue that decomposed as the two pools (P_1 and P_2). Decay rates of the first pool were well related to initial C/N ratio and N content, whereas we correlated the decay rates of the second pool (r = -0.65) with initial lignin content. However, decay rates for the second pool were not as significantly affected by residue types due to the relatively small range of initial lignin/N ratios of the residues used in this study (Table 1).

The use of a two-pool model recognizes that the decomposition rate of residue changes over time and provides information on the decomposition rate of each pool. Additionally, the two-pool models appear to provide a better fit in the early stages of decomposition compared with one-pool models used extensively in determining the kinetics of crop residue decomposition *(1, 2, 6)*. Although single-pool models can accurately predict net decomposition over short periods of time, they tend to neglect changes in the decomposition of material with time *(3)*.

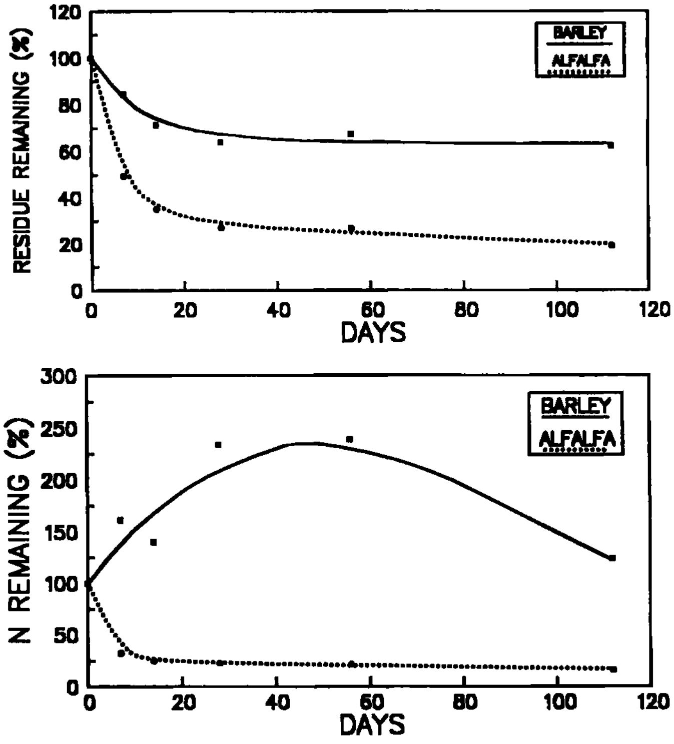

Figure 1. Percentage of initial dry weight and N remaining during decomposition of alfalfa and barley residues under controlled environmental conditions.

Nitrogen mineralization/immobilization. Table 3 presents equations describing N content changes over time. Whereas changes in N content of legume crop residues conformed to the two-pool exponential model used to describe decomposition, those of nonlegume crop residues were best described by polynomial equations. Most leguminous residues released the majority of their N within the first 14 days (Figure 1). This rapid N release may be related to the rapid decomposition of an initial pool of N due to high microbial activity in response to the large amount of available N. We correlated net N release (percent N remaining) with initial C/N ratio (r = -0.72)

Table 1. Initial crop residue characteristics.

Residue	*Scientific Name*	*C (%)*	*N (%)*	*C/N*	*Lignin (%)*	*Lignin/N*
Legume crops						
Alfalfa	*Medicago sativa* L.	41.50	3.56	11.7	6.57	1.84
Crimson Clover	*Trifolium incarnatum* L.	42.97	2.14	20.1	13.91	6.50
Hairy vetch	*Vicia villosa* L. Roth	40.77	5.36	7.6	9.50	1.77
Peanuts	*Arachis hypogaea* L.	40.89	1.50	27.3	12.98	8.66
Non-legume crops						
Barley	*Hordeum vulgare* L.	44.91	0.30	140.3	10.02	31.31
Canola	*Brassica najus* L.	41.99	0.95	44.2	9.80	10.32
Millet	*Pennisetum glaucum* L.	40.58	1.34	30.3	5.15	3.84
Oats	*Avena sativa* L.	42.85	0.23	186.3	10.23	44.48
Rye	*Secale cereale* L.	44.32	0.51	86.9	10.00	19.61
Sorghum	*Sorghum bicolor* L.	40.91	1.49	27.4	6.57	4.41
Triticale	*X. tricicosecale*	42.92	0.38	113.0	11.04	29.05
Wheat	*Triticum aestivum* L.	43.82	0.45	97.4	10.65	23.67

Table 2. Selected legume and non-legume crop residues decay rate equations under controlled environment conditions.*

Residue	*Equation*	R^2
Legume crops		
Alfalfa	$Y = 100(.686e^{-.1836t} + .314e^{-.00409t})$	0.90
Crimson clover	$Y = 100(.419e^{-.1786t} + .581e^{-.00432t})$	0.95
Hairy vetch	$Y = 100(.638e^{-.1413t} + .362e^{-.00432t})$	0.96
Peanuts	$Y = 100(.559e^{-.1628t} + .441e^{-.00327t})$	0.74
Non-legume crops		
Barley	$Y = 100(.359e^{-.0981t} + .641e^{-.00015t})$	0.93
Canola	$Y = 100(.464e^{-.0942t} + .536e^{-.00301t})$	0.98
Millet	$Y = 100(.559e^{-.1502t} + .490e^{-.00646t})$	0.94
Oats	$Y = 100(.738e^{-.0161t} + .262e^{-.00524t})$	0.94
Rye	$Y = 100(.311e^{-.1342t} + .689e^{-.00061t})$	0.98
Sorghum	$Y = 100(.421e^{-.1507t} + .579e^{-.00400t})$	0.86
Triticale	$Y = 100(.354e^{-.0973t} + .646e^{-.00005t})$	0.91
Wheat	$Y = 100(e^{-.0158t})$	0.93

*All models were significant at the 0.05 probability level.

Table 3. Nitrogen mineralization/immobilization equations for selected legume and non-legume crop residues under controlled environment conditions.

Residue	*Equation*	R^2†
Legume crops		
Alfalfa	$Y = 100(.739e^{-.33079t} + .261e^{-.00397t})$	0.76***
Crimson clover	$Y = 100(.556e^{-.31900t} + .443e^{-.00041t})$	0.85***
Hairy vetch	$Y = 100(.243e^{-.31800t} + .757e^{-.00294t})$	0.98***
Peanuts	$Y = 100(.511e^{-.48053t} + .486e^{-.00028t})$	0.98***
Non-legume crops		
Barley	$Y = 106.6 + 5.05t - 0.0439t^2$	0.50***
Canola	$Y = 85.4 - 0.26t$	0.15*
Millet	$Y = 48.6 + 0.87t - 0.0077t^2$	0.30**
Oats	$Y = 92.0 + 2.55t - 0.0230t^2$	0.68***
Rye	$Y = 104.7 + 3.95t - 0.0230t^2$	0.32**
Sorghum	$Y = 85.1 - 0.12t - 0.0001t^2$	0.17ns
Triticale	$Y = 105.4 + 3.95t - 0.0300t^2$	0.49**
Wheat	$Y = 97.5 - 0.15t + 0.0002t^2$	0.07ns

†Ns, *, **, *** denote model was not significant or significant at the 0.10, 0.05, and 0.0001 probability level, respectively.

and initial N content (r = 0.81). The second mineralization constant represents a second recalcitrant pool of N, which is probably composed primarily of lignoproteins.

Decomposition of nonlegume crop residues resulted in significant amounts of net N immobilization (Figure 1). The polynomial equations used to describe immobilization do not provide the descriptive information that can be obtained from the two-pool exponential model; however, we can make some inferences from the pattern of immobilization observed. Immobilization in all residues occurred during the first 56 days, followed by a slow N-release period.

Conclusion

We can describe decomposition of a wide variety of crop residues under controlled growth chamber conditions using a two-pool exponential model that allows for the differentiation of residue material into a readily decomposable pool and a recalcitrant pool. Decay rates between residue types differ most significantly during decomposition of the first pool and converge during decomposition of the second pool. Final net residue appears to be determined primarily by initial decay rate and size of the readily decomposable pool.

Net N mineralization in legume crop residues exhibited decay patterns similar to weight loss and were also described by a two-pool exponential model. Net immobilization patterns were not as uniform as mineralization patterns and could be described by quadratic equations for most residues.

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Effect of cover crops on cycling of nitrogen and phosphorus in a winter wheat-corn sequence

R. A. Samson, C. M. Foulds, and D. G. Patriquin

In much of northeastern North America, a 2- to 3-month growing season remains after harvest of winter wheat. In Ontario, this period is commonly used to cultivate or apply herbicides for weed control or to grow red clover for plowdown.

Estimates of the nitrogen (N)-supplying value of red clover plowdown for corn vary from 40 to 110 pounds N/acre fertilizer equivalent. Hairy vetch has also been shown to be an effective supplier of N to corn in Ontario. Less information is available on the role of cover crops in phosphorus (P) cycling, especially in temperate systems. However, studies in tropical and subtropical systems reveal significant effects of cover crops on soil and plant P *(3)*. In 1988, we tested several cover crops and different times of seeding red clover into winter wheat in the spring on sandy loam and silt loam sites. In 1989, we evaluated the most promising species for their effects on yield and on the N and P status of the following corn crop.

Methodology

Cover crop and control plots, 30 feet by 130 feet, were set out in existing winter wheat fields on two farms in southwestern Ontario in a randomized complete block design with three replicates. Prior to spring plow-down, we broadcast urea-N on subplots (30 feet by 43 feet) at rates of 0, 35, and 70 pounds/acre; control plots also received treatments of 105, 140 and 175 pounds N/acre. We sampled corn for N and P contents at the five-leaf stage (whole plant) and at silking (ear leaf). Sampling corn at the four- to six-leaf stage has been shown to be more appropriate than ear-leaf sampling for assessing P nutrition *(1)*. We measured corn grain yields by harvesting three, 13-foot rows of corn in each subplot.

Results and discussion

At both sites, yields of corn following unfertilized hairy vetch were equivalent to those of corn fertilized with about 100 pounds N/acre; other cover crops resulted in yields equivalent to those of corn fertilized with about 70 pounds N (Figures 1 and 2). However, for plots of hairy vetch on the silt loam site, potassium (K) may have limited corn yields because ear-leaf levels were below the critical level of 1.2% *(3)*. Percent N in the ear leaf exhibited relationships similar to those for grain yield in respect to cover crops and fertilizer N effects (data not shown). At the five-leaf stage on the sandy loam site, there were trends of increased N and P content following legume cover crops while oilseed radish resulted in significant reductions of N and P. There was a high correlation between leaf N and P at this stage (Figure 3). These trends were maintained at the ear-leaf stage, except for corn following oilseed radish that also exhibited increases in N and P compared with no cover crop controls *(3)*.

Differences between the legumes and oilseed radish are probably due to higher carbon (C)/N and C/P contents of oilseed radish at plow-down, which caused transitory immobilization of soil nutrients. Hairy vetch is a soft, leafy plant with a C/N ratio of about 12:1, while oilseed radish has a hard stock and more cellulose and lignin-like products [no C/N ratio could be found for oilseed radish but a value of 26:1 has been reported for white mustard *(2)*].

In 1931, Crowther and Mirchandani *(2)* studied the effects of vetch and mustard residues and found that vetch liberated its N extremely rapidly while mustard residue initially results

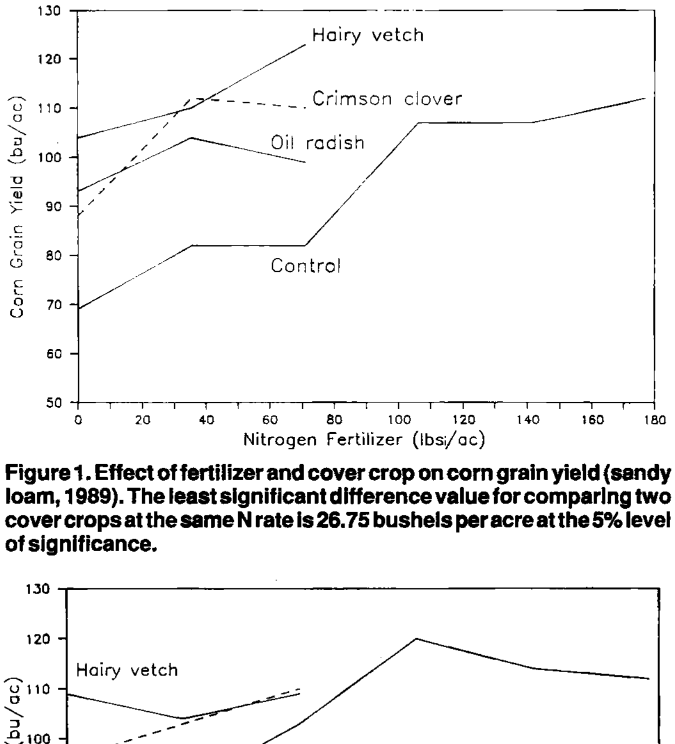

Figure 1. Effect of fertilizer and cover crop on corn grain yield (sandy loam, 1989). The least significant difference value for comparing two cover crops at the same N rate is 26.75 bushels per acre at the 5% level of significance.

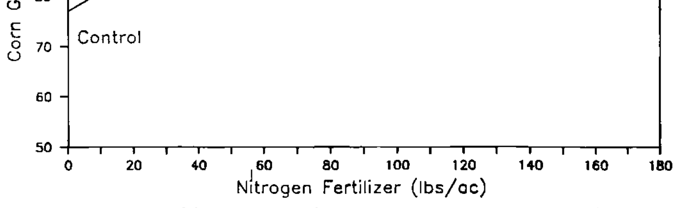

Figure 2. Effect of fertilizer and cover crop on corn grain yield (silt loam, 1989). The least significant difference value for comparing two cover crops at the same N rate is 12.31 bushels per acre at the 5% level of significance.

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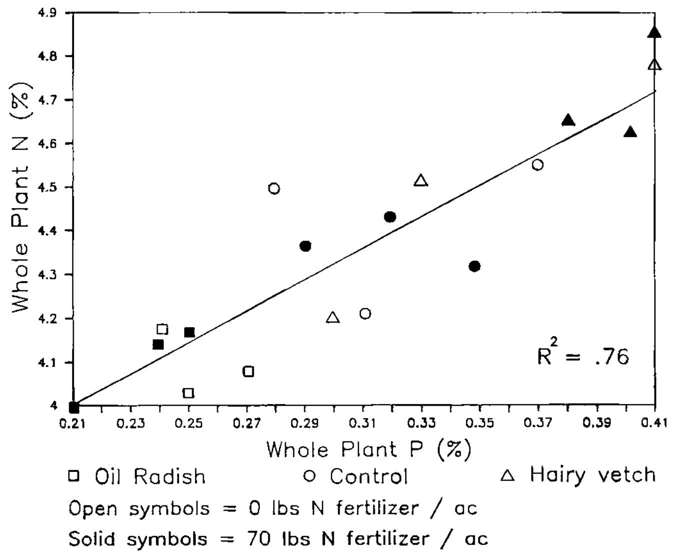

Figure 3. Effect of cover crop on whole plant N and P at corn five-leaf stage (sandy loam, 1989).

in immobilization of available N, which is later mineralized. Likewise, we observed a lower percentage of N in corn following oilseed radish when corn was sampled at the five-leaf stage, but by the ear-leaf stage the percent N was above that of controls *(3)*.

Cash crop farmers in Ontario are now evaluating the winter cereal-hairy vetch-corn sequence as an alternative to traditional practices. On livestock farms, farmers are using oilseed radish as a N sink for late-summer liquid manure applications after winter cereals. European studies indicate that this species reduces nitrate leaching by an average of 50% (4).

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