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ENHANCING YIELD, PROFITABILITY AND NITROGEN MINERALIZATION IN CORN-BASED INTEGRATED CROPPING SYSTEMS

By

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ABSTRACT

ENHANCING YIELD, PROFITABILITY AND NITROGEN MINERALIZATION IN CORN-BASED INTEGRATED CROPPING SYSTEMS

By

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Cropping systems that emphasize high productivity while causing minimal environmental degradation are currently being developed. Integrated cropping systems focus on biological interactions within combinations of crop species, in contrast to continuous cropping of a single species. Crop diversity is achieved through the use of crop rotations, and with cover crops. To ensure farmer adoption of these systems, more information is needed on their economic productivity.

In corn (*Zea mays L.*) -based cropping systems in Michigan, an adequate level of mineralized soil N is essential early in the growing season in order to obtain optimum growth and productivity. This study evaluated the changes in corn productivity through the combination of rotation and cover crops using commercial fertilizer or dairy manure compost as a fertility source. Net economic returns at alternate price ratios for the first three years of a cropping system were also studied.

In consecutive years of transition from alfalfa to corn in rotation, first-year corn following wheat (*Triticum aestivum* L.). produced the highest yield and net economic return. This effect occurred under both fertilizer and compost management systems. In the second year of transition, the advantage of corn following wheat was enhanced by overseeded red clover (*Trifolium pratense* L.) in wheat, especially under compost management. When net returns for continuous corn and for a corn-corn-soybean-wheat rotation were averaged over the three years, the rotation produced the best economic returns when the price of corn was low relative to soybean and wheat.

Mineralized N available to a corn crop was greatly affected by the previous crop sequence. Soil nitrate levels in June were highest following wheat in year two, and following a soybean wheat sequence in year three. This resulted in higher corn grain plus stover biomass N. In an ancillary N fertilizer rate study conducted for two growing seasons, annual ryegrass (*Lolium multiflorum* Lam.) overseeded into corn did not reduce uptake by corn of available N, but reduced fall soil NO_3 levels. Integrated cropping systems that incorporate rotation and cover in crop production are economically beneficial and reduce environmental impact.

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PREFACE

Chapter 1 written in publication format for *Journal of Production Agriculture*

Chapter 2 written in publication format for *Agronomy Journal*

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CHAPTER 1

CROP YIELD AND NET ECONOMIC RETURN OF CORN, SOYBEAN AND WHEAT AS AFFECTED BY POSITION IN ROTATION, FERTILITY SOURCE, AND COVER CROP

ABSTRACT

Corn (*Zea mays L.*) is the most commonly grown cash grain crop in Michigan. Although most corn is grown in rotation with another crop, little published data is available on corn grown in rotation with soybean [*Glycine max* (L.) Merr.] and wheat (*Triticum aestivum* L.). Cover crops have been used as a N source and to tie up residual N after crop harvest. A long-term experiment was established in 1993 on a Kalamazoo/Oshtemo sandy loam in southwestern Michigan to compare grain yields and net economic return of a corn-corn-soybean-wheat rotation with those of continuous corn. Each of the four rotation crops was started in 1993, to have each crop grown each year. Corn, soybean, and wheat were grown with or without annual ryegrass (*Lolium multiflorum* Lam.) and/or hairy vetch (*Vicia villosa* Roth), or Michigan mammoth red clover (*Trifolium pratense* L.) Crop and cover combinations were grown under two fertility management systems, one using commercial fertilizer, the other using composted dairy manure as the only nutrient source. First-year corn following wheat produced yields 32% higher than corn following corn in 1994, and 17% higher in 1995. Corn following wheat overseeded with red clover increased this effect in 1995 to 35% under integrated compost management. The effect of cover was less under fertilizer management. Under both fertility management systems, and in both years of transition, first-year corn produced higher net returns than corn following corn. In the integrated compost system in 1994, first-year corn net returns were $143.00/acre higher than net returns from corn following corn. In 1995, the margin between returns for first-year corn and corn following corn was less if cover was in the system. When crop rotation was compared with continuous corn

over the three years of the experiment, net returns fluctuated with corn to soybean and wheat price ratios. Crop rotation produced higher net returns when the price of corn was low relative to soybean and wheat. Continuous corn produced higher net returns when the price of corn was high relative to soybean and wheat.

INTRODUCTION

The need for highly productive cropping systems that reduce undesirable environmental impact has been underscored in several publications (Hatfield and Karlen, 1993, Francis et. al., 1990, Liebhardt et al, 1989). A common theme throughout the literature is the importance of increased diversity in a cropping system because of its influence on soil microbial activity which in turn affects nutrient cycling and crop uptake (Doran and Linn, 1994). This diversity can be achieved with the use of crop rotations and cover crops. Several cropping systems currently being utilized incorporate the benefits of crop rotation, cover crops and other management practices that allow for more efficient use of inputs. Reported benefits of crop rotation include improved soil structure (Raimbault and Vyn, 1991), potential increased water use efficiency (Pierce and Rice, 1988), increased soil nutrient uptake (Stecker et al., 1995, Copeland and Crookston, 1992) and lower incidence of insect pests (Benson, 1985) and diseases (Edwards et al., 1988). Cover crops, heavily relied upon as a legume N source before the advent of commercial fertilizers in monocropped systems, have been used to reduce soil erosion (Langdale, et al 1985); as both a N source (Power, 1987, Stute and Posner, 1993), and to tie up residual soil N after grain harvest (Ditsch et al., 1993, Brinsford and Staver, 1991). Other advantages attributed to cover crops include improved soil structure and increased organic matter content (Bruce et al, 1990), increased water penetration (Benoit et al, 1962), weed suppression (Worsham, 1991) and increases in beneficial insect populations (Roberts and Cartwright, 1991) In livestock systems, forage cover crops can also be recycled as nutrient sources through manure (Hoveland, et al, 1988).

Much of the research on crop rotations in the upper midwest involves the corn-soybean rotation (Crookston, 1984), and focuses on the effects of tillage or N rates (Meese, et al. 1991, Peterson and Varvel, 1989). While some research has been reported on corn-soybean and wheat in rotation (Lund and Oplinger, 1993, Peterson et al., 1991), few studies include the effects of cover crops in this cropping pattern. In Wisconsin, Mallory and Posner (1994) found that overseeding red clover into wheat increased yields of corn grown the following year. Similar findings were reported in Ontario by Raimbault and Vyn (1991). In the cash-grain crop regions of Michigan, more information is needed on the potential for cropping systems that include corn, soybean and wheat with overseeded cover crops. Although corn is the cash grain crop grown on the most acreage in Michigan, it is often rotated with another crop (Landis and Swinton, 1994). Acreage for both soybean and wheat have increased since 1993 (Ferris, 1995) and 1995 yields for both crops were at record highs (Michigan Agricultural Statistics, 1996).

To ensure farmer interest in these cropping systems, it must be demonstrated that these systems are profitable as well as environmentally beneficial. Reluctance to implement a system that integrates cover crops into a rotation, for instance, has been associated with the risk that the cover will compete for moisture, and that the cost of seeding the cover will not be recovered in net return (Robertson et al, 1991). In the case of legume covers in corn-based systems of the Coastal Plain, Kentucky, and the Appalachian region, the economic concerns have been addressed (Hanson, et al, 1993, Ott and Hargrove, 1989, Frye, et al, 1985). In Michigan, Roberts and Swinton (1995) report on-farm results which conclude that cover crops in corn-soybean-wheat rotations reduced environmental contamination while maintaining farm profitability.

The purpose of this study was to quantify the incremental changes in corn productivity brought about by the combination of rotation and cover crops under a fertility management utilizing (i)commercial fertilizer, or (ii) dairy manure compost. This paper presents crop yield and net economic returns over the first three years of transition to cropping systems that increase in crop diversity and complexity. The overall goal is to demonstrate short-term net economic return from these cropping systems, while the longer-term effects (soil enhancing factors such as soil organic matter, aggregate stability, microbial activity, etc.) of crop diversity are established over time.

MATERIALS AND METHODS

This research is part of the Living Field Laboratory (LFL), a long-term crop rotation experiment established in 1992 at the Kellogg Biological Station in Hickory Corners, MI. The LFL is designed to test varying combinations of rotation and cover crops under several agronomic management regimes. The site soil type is a Kalamazoo/Oshtemo sandy loam (coarse-loamy, mixed, mesic Typic Hapludalf), and had been in mixed alfalfa grass-hay for six years. The design is a split-split plot with four replications, (Figure 1). The main plots that comprise the portion of the LFL reported here are two levels of agronomic management:

(i) integrated compost management: minimal pesticides; banded herbicide plus cultivation for weed control; dairy manure/straw or sand compost as a fertility source

(ii) integrated fertilizer management: minimal pesticides; banded herbicide plus cultivation for weed control; commercial fertilizer as a fertility source

Sub-plots are the entry points of a corn-corn-soybean-wheat rotation, plus continuous corn; each crop in the rotation is grown every year. The second year corn entry point is included for research purposes to document an anticipated decreasing yield phenomenon (Crookston et al., 1991,Benson, 1985,). Prior to enactment of the Fedaeral Improvement and Reform Bill of 1986, Michigan corn growers often included second year corn to maintain base acres in government commodity programs (Landis and Swinton, 1994). All crops in the rotation are grown with and without an overseeded cover crop except soybean, which are not grown with a cover crop. The cover crop sequence for the entry points is as follows:

(i) first-year corn: legume (hairy vetch in 1993, red clover thereafter + annual ryegrass

(ii) second-year corn: annual ryegrass

(iii) continuous corn: legume (hairy vetch in 1993, red clover thereafter) + annual ryegrass

(iv) wheat: red clover frost seeded in March

Primary tillage is chisel-plowing followed by a disk and field-cultivator. Plots are 50 by 15 ft with corn and soybean planted in 30 in. rows and wheat planted in 7 in. rows. Corn hybrid 'Pioneer 3751' was planted each year at about 27,000 seeds/acre. Soybean variety 'BSR 101' was planted each year at 1 bu/a. The spring wheat variety 'Butte 86' was planted in late April 1993 because it was too late to establish winter wheat. The winter wheat variety 'Augusta' was planted in subsequent years at 130 lbs/acre. Cover crops in corn were sown at second cultivation with a hand seeder in 1993, or with a pto driven Orbit-air seeder in subsequent years. Red clover was seeded at 12 lbs/acre, and annual ryegrass at 25 lbs/acre. In the cover sub-plots of wheat, red clover was seeded with an Orbit-air seeder in early March at 15 lbs/acre. After seeding the main crop, herbicides were banded pre-emergence at the recommended rates.

Nitrogen was applied to corn plots based on a 130 bu/acre yield goal and pre-sidedress-nitrate-test (PSNT) levels (Magdoff, 1991). In 1995, a 60 lb N credit was given to first-year corn following wheat that had been frost-seeded with red clover. Phosphorus and potassium for all fertilized plots were applied based on soil test recommendations (Vitosh et al., 1995). In wheat plots, N was sidedressed at 50-60 lbs in early April. Soybean plots received no fertilizer N. Each year, composted dairy manure from a companion research project was applied on a dry weight basis to the integrated compost management plots in April (corn) and October (wheat) with a manure spreader. An attempt was made to supply N from the compost to meet corn yield goals, assuming 15% N available in the first year of application. Because of the low N availability, and a sand content in the bedding greater than 50%, the decision was made to apply a larger amount of compost than the 5-10 tons/a commonly used in manure applications. This resulted in an application rate in corn of 25 tons/acre in 1993, 47 tons/acre in 1994 followed by a reduction down to two tons/acre in 1995. The plots in wheat and soybean in 1993 received the higher compost amount in a subsequent corn crop. No compost was applied in any year immediately preceding soybean. Compost application rate and analysis is shown in Table 1.

Corn grain yield was calculated from a 20 ft. section of two rows in each plot. Final grain yield was adjusted to 15.5% moisture. After harvest, the remaining rows were combined and stalks chopped. Soybean and wheat plots were machine harvested, and grain yield adjusted to 13 and 13.5% moisture content, respectively. Analysis of variance was performed on yield data for each of the three data years.

Product income, which is the price paid per bushel times the grain yield, and net economic return were determined for each crop and rotation on a per acre basis using the PLANETOR economic planning program, version 2.0 (Center for Farm Financial Management, 1995). Net economic return represents the return to fixed costs such as land, capital and labor, and is defined as the product income minus the variable costs, which include the purchased inputs such as seed, fertilizer and herbicide. The input values used in PLANETOR to calculate variable costs for each crop were actual prices paid each year and are listed in Table 2. There was no charge for making the dairy manure compost itself. Only the cost of spreading was included. Machinery, fuel, and implement costs per acre were calculated by PLANETOR. Cover crop seed costs were charged within the year they were overseeded into the main crop except in the case of wheat, which was charged to the following corn crop. Grain prices are approximate average prices obtained by Michigan farmers from 1992-1995 (Ferris, 1995). In addition to the average prices of $2.50 for corn, $6.25 for soybean, and $4.00 for wheat, alternative price ratios were used to analyze the three-year comparison between continuous corn, and corn in rotation. The alternatives were: a) corn 10% more valuable relative to soybean and wheat, 2) corn 10% less valuable relative to soybean and wheat.

In order to compare the crop rotation with continuous corn over the three years of the experiment, two net economic return scenarios were analyzed under each fertility management. In the first scenario, continuous corn is compared to the rotation that began with corn in 1993, followed by soybean in 1994, and wheat in 1995. In the second scenario, continuous corn is compared to the rotation that began with soybean in 1993, followed by wheat in 1994, and corn in 1995. This analysis was conducted to determine if there was an advantage in starting the rotation with corn as opposed to starting with soybean, based on net returns averaged over 1993-1995.

Net economic return data for 1995 was also summarized with the assumption that all crops in a corn-corn-soybean-wheat rotation were grown in equal acreage within the same year. The average net return for this rotation is compared with continuous corn. Data from 1995 are used because continuous corn is in the third year, and can be truly compared to second-year corn.

RESULTS AND DISCUSSION

Crop Yield

Mean grain yields and analysis of variance for each year are presented in Tables 3 and 4 for soybean, Tables 5 and 6 for wheat, and in Tables 7 and 8 for corn, respectively. In 1993, soybean under integrated compost management yielded higher than soybean under integrated fertilizer management (Table 3). In wheat, there were no significant differences in 1993 or 1994. In 1995, wheat under integrated fertilizer management yielded higher than wheat under integrated compost management (Table 5). Also in 1995, the no cover wheat plots yielded higher than wheat with cover (Table 5).

In corn, no differences in the three rotation entry points were detected in 1993. No differences were expected, as 1993 was the rotation establishment year, with all crops being planted into alfalfa/fallow soil. There was a significant management difference, however, with integrated fertilizer management yielding 21% higher than integrated compost management . This was thought to be due to low N availability from the spring 1993 compost application, which was 2.5 tons. An additional 25 tons was applied in the fall of 1993. The integrated fertilizer management plots still yielded 16% higher than the integrated compost management plots in 1994 (Figure 2). There was no significant management difference in 1995

The position in the rotation, or entry point, had a significant effect on corn yield in 1994 and 1995 (Table 7). In 1994, first-year corn yield following wheat was 187 bu/acre, at least 32% higher than both entry points of corn following corn (Fig. 3). In 1995, first-year corn yield was 155 bu/acre, 17% higher than continuous (third year) corn (Fig. 3).

There was a significant entry point x cover interaction in 1994 and 1995 (Table 7). In 1994, first-year corn with or without overseeded red clover yielded over 185 bu/acre. The next closest yield was second year corn with no cover, at 155 bu/acre (Fig. 4). The effect of annual ryegrass in 1994 is also shown in Figure 4, as second-year corn with no cover yielded significantly higher than second-year corn overseeded with the annual ryegrass. Second-year corn with no cover also yielded higher than the continuous corn rotation with or without overseeded red clover/annual ryegrass cover (Fig. 4). (Continuous and second-year corn in 1994 are both actually second-year corn, differing only in the types of cover crops overseeded). In 1995, first-year corn yield following wheat overseeded with red clover was 163 bu/acre, compared with 146 bu/acre for first-year corn without cover, and at least 21% higher than second-year or continuous corn with or without cover (Fig. 5).

There was a significant entry point x management difference in 1994 only, with integrated compost causing a yield depression in both second-year continuous corn crops. First-year corn yields were about 187 bu/acre for both fertility management types, second-year corn yields under the integrated fertilizer management were not significantly different from first-year corn (Fig. 6). However, second-year corn under integrated compost management yielded only 118 bu/acre (Fig. 6).

Net Economic Return

For both fertility management systems, product income, variable costs, and net economic return data for each year are summarized in Table 9 and 10. Net returns in 1995 represent the effect of the previous two years of the rotation on each entry point (Table 11).

Under both fertility management systems, and in both years of transition from long-term alfalfa, first-year corn produced higher net returns than corn following corn. In the integrated compost system in 1994, first-year corn net returns were $143.00/acre higher than net returns from corn following corn (Table 9). This ratio was consistent whether or not cover was present, even though cover crops add as much as $30.00/acre in variable cost. In 1994, the integrated fertilizer system net returns were higher for first-year corn than for corn following corn; but this difference was greater between the cover plots than between the no-cover plots (Table 10). Net returns in first-year corn with cover were $61.00/acre higher than net returns from corn following corn with cover, but net returns in the same comparison in the no cover plots reveal only a $15.00/acre advantage to first-year corn (Table 10).

In the integrated compost system with cover plots in 1995, first-year corn produced net returns $84.00/acre higher than second year corn; and $99.00/acre higher than continuous (third year corn, Table 11). In the no-cover compost plots, first-year corn produced net returns $25.00/acre higher than second year corn; and $51.00/acre higher than continuous corn. In 1995 in the integrated fertilizer plots with cover, first-year corn produced net returns $49.00 and $59.00 /acre higher than second-year or continuous corn, respectively. Net returns in the no-cover plots of first-year corn were $30.00 and $45.00/acre higher than second-year and continuous corn, respectively.

Data for the crop rotation net economic return scenarios under each fertility management is presented in Tables 12a-c and 13a-c. In the scenario comparing continuous corn with the corn-soybean-wheat rotation under average prices from 1993-1995, continuous corn with cover produced net returns higher than the rotation with cover (Table 12a). Continuous corn integrated compost with cover net returns were 13% higher than corn in rotation integrated compost with cover net returns. In both fertility management types, there was little difference in the net returns of continuous corn with no cover and the rotation with no cover. When corn was 10% more valuable relative to soybean and wheat, continuous corn with cover net returns were further enhanced. Continuous corn integrated compost with cover net returns were 22% higher than the rotation integrated compost with cover net returns (Table 12b.) However, when corn was 10% less valuable relative to soybean and wheat, the rotation with no cover produced net returns slightly higher than continuous corn without cover, regardless of fertility management type (Table 12c). There was little difference in the net returns of continuous corn with cover and the rotation with cover.

The second rotation scenario compared continuous corn with the soybean-wheat-corn rotation. Under average prices from 1993-1995, integrated fertilizer continuous corn with no cover produced net returns 16% higher than integrated fertilizer rotation with no cover (Table 13a). As was the case in the corn-soybean-wheat scenario, when corn was 10% more valuable relative to soybean and wheat, continuous corn net returns were further enhanced (Table 13 b). When corn was 10% less valuable relative to soybean and wheat, the advantage of the rotation over continuous corn was evident only under integrated compost management (Table 13c).

For the scenario that assumes all crops in a corn-corn-soybean-wheat rotation were grown in equal acreage within the same year, data is presented in Table 13a-c. Under average prices from 1993-1995, net returns between continuous corn and the rotation are similar for each management type (Table 14a). When corn was 10% more valuable relative to soybean and wheat, continuous corn net returns were slightly higher than the rotation net returns (Table 14b). When corn was 10% less valuable relative to soybean and wheat, rotation net returns were 17% higher than continuous corn, but only under integrated fertilizer management with no cover (Table 14c).

SUMMARY

In consecutive years of transition from long-term alfalfa, first-year corn following wheat produced the highest yield. This effect occurred under both compost and fertilizer management. In the second year of transition, the advantage of corn following wheat was enhanced by overseeded red clover in wheat, especially under compost management. The presence of overseeded cover crops in second-year corn drastically reduced yield and net returns in 1994. Cover in third-year corn reduced net returns in 1995.

When considering yield and net return data within each year, the benefits of rotation, especially corn following wheat overseeded with red clover are very clear. However, when considering net returns for the rotation over three years, the benefit of first-year corn is masked by lower soybean and wheat net returns in the other rotation years. The advantage of rotation is evident when the price of corn is low compared to wheat and soybean. This finding has also been reported elsewhere (Peterson et. al., 1991). The presence of overseeded cover in corn reduced net returns under both continuous corn and in the rotation, especially under compost management. Under the scenarios where the rotation produced lower net returns than continuous corn, leaving only the red clover overseeded into wheat as the only cover crop in the rotation may have increased the short-term benefits of rotation. The net return of first-year corn would increase by removing the cost of overseeding. Other factors adding to the net returns of rotation were not considered in this experiment, such as the profit from a hay crop taken from the clover in the fall after wheat harvest.

Under most scenarios discussed here, integrated compost management produced higher returns than integrated fertilizer management. Taken into consideration is the fact that the price of compost is a major determinant. In a cropping system where manure is available, or is a by-product of a livestock operation, the integrated compost system that utilizes first-year corn following wheat/red clover may prove to be advantageous. Roberts and Swinton (1995) found similar results in looking at on-farm data where the combination of manure and cover were used. In their study, manure enhanced the beneficial effect of multiple crops in rotation .

The rationale for crop rotation as opposed to monocropping is well defined. The current generation of questions have to do with selecting a particular rotation under the specific growing conditions. The potential for corn-soybean-wheat was analyzed in this experiment, and will be expanded to areas in Michigan where it may be an ideal mix. As mentioned previously, acreage for both soybean and wheat is increasing in Michigan, and there is impetus for obtaining higher yields as these crops become more prominent. Soils at the experimental site are coarse-textured and low in organic matter. We suggest that adding crop diversity on these soils via rotation and cover will increase crop yield and net returns over time. With this kind of rotation, poor returns in one year can be overcome with the next crop, as was the case in this experiment with wheat in 1993. A net return of $3.32/acre in 1993 integrated fertilizer wheat was followed by the highest net return of any crop in any of the three years, at $338.74/acre in 1994 first-year corn (no cover).

When growing crops in rotation with cover crops, several factors must be taken into consideration, such as the extra planting and harvesting equipment needed for different crops, and extra management decisions with respect to planting of cover crops. For example, the grower must consider what equipment is needed to plant the cover crops, and what method is to be used to kill the cover crop in the spring. Nutrient needs must be monitored when rotating from one crop to the next. The additional crops create more opportunities for fluctuation in profits and this is further affected by crop price ratios. Economic and agronomic evaluation of these scenarios will continue in this experiment.

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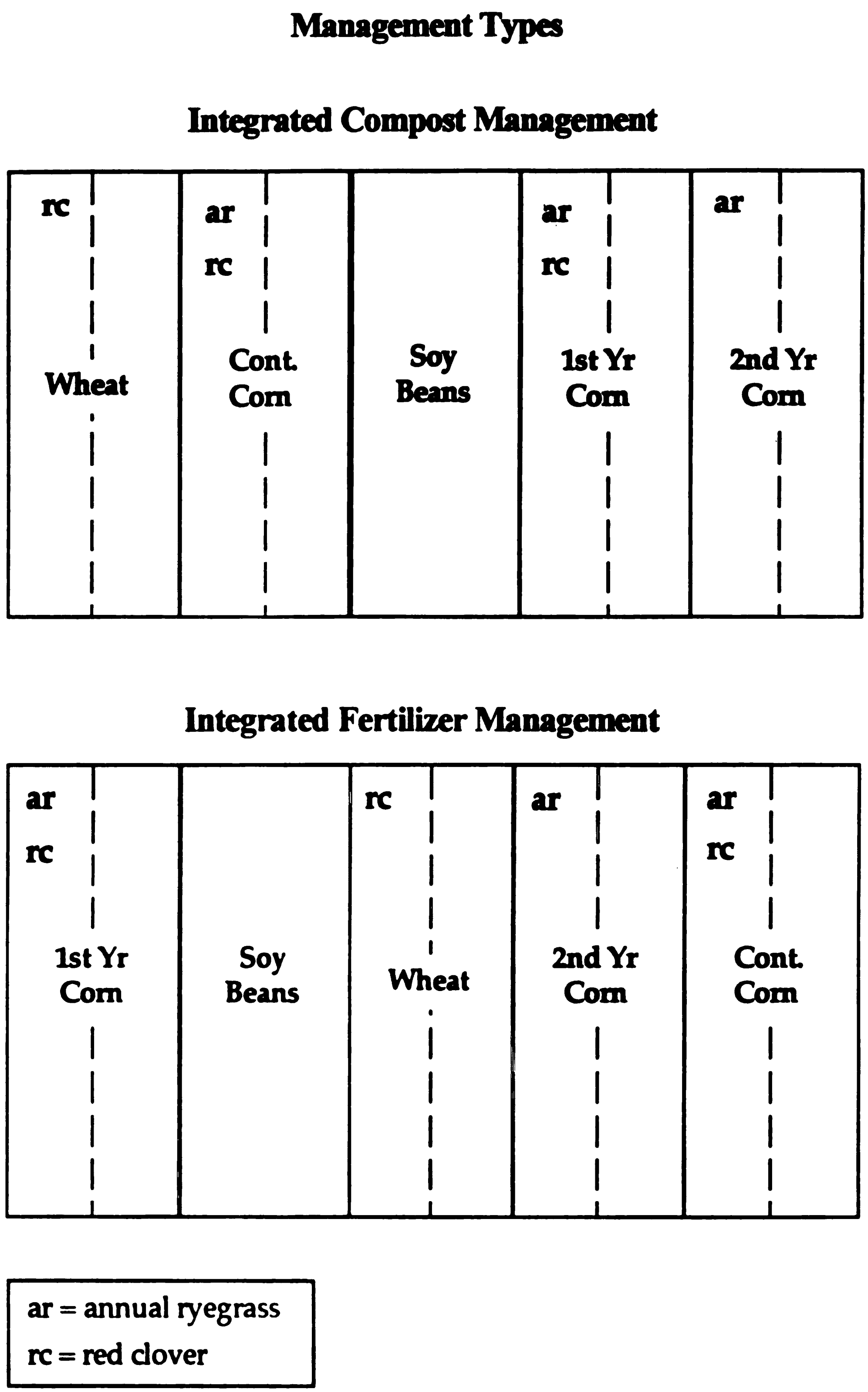


Figure 1. Living Field Laboratory plot design

Table 1. Compost analysis.

	APPLICATION DATE					
	4/22/93	10/18/93	4/21/94	10/4/94	4/28/95	10/22/95
Compost applied (dry lbs/a	3200	45500 [1]	39900	56800 [1]	4000 [1]	4000 [1]
Nitrogen supplied (lbs/a)	40	190	600	440	250	250
Estimated available lbsN/a[2]	<10	30	90	70	40	40
Nitrogen (%)	1.2	0.4	1.5	0.8	0.6	0.6
Carbon (%)	14.1	6.2	20.2	10.2	11.5	11.5
C:N ratio	12	15	13	13	19	19
Nitrate-Nitrogen (ug/ml)	-	-	4	13	28	28
		-----------------	---% ---	-----------------		
Phosphorus	0.5	0.2	0.4	0.2	0.2	0.2
Potassium	0.3	0.5	1.7	0.8	0.7	0.7
Calcium	1.0	2.2	2.3	14.0	2.4	2.4
Magnesium	0.4	0.6	0.5	1.8	0.6	0.6
		-----------------	---ppm---	-----------------		
Boron	10	20	50	40	14.4	14.4
Zinc	220	50			68.2	68.2
Manganese	210	100	190	420	191	191
Copper	130	20	-	-	29	29
pH	-	-	8.4	9.2	9.1	9.1
Electrical conductivity (mmhos/cm)			5.5	11.6	6.3	6.3
Moisture (%)	60	30	50	20	40	40

[1]compost applied on these dates had been made with dairy manure where sand had been used for bedding. Sand content was estimated to be 60%, by water sedimentation.

[2]assumes 15% estimated release in first year after application. Mineralization in subsequent years was not estimated.

Table 2. Input values for calculation of variable costs used in PLANETOR.

Inputs	Units	Price
Compost application	$/acre	15.00
Fuel	$/gal	0.90
Seed		
Corn	$/acre	24.00
Soybean	$/acre	12.00
Wheat	$/acre	20.00
Ann. ryegrass	$/acre	7.50
Red clover	$/acre	12.00
Fertilizer		
NH_4NO_3	$/lb	0.18
P_2O_5	$/lb	0.10
K_2O	$/lb	0.10
Herbicide		
Corn	$/acre	8.52
Soybean	$/acre	5.42
Insecticide		
Corn	$/acre	13.00
Operating interest	$/acre	10.00

Table 3. Soybean yield means within each year by fertility management type, and cover.

	1993	1994		1995	
	no cover	no cover	cover	no cover	cover
			bu/acre		
Integrated compost	50	50	43	37	39
Integrated fertilizer	45	40	38	32	34

Table 4. Analysis of variance for soybean grain yield, 1993-1995.

	1993	1994	1995
Source of variation	PR>F	PR>F	PR>F
Replication	0.021	0.830	0.697
Management	0.028	0.431	0.413
Cover	0.019	0.27	0.295
Management x cover	0.986	0.533	0.875

Table 5. Wheat yield means within each year by fertility management type, and cover.

	1993*	1994			1995		
	no cover	no cover	cover	Mean	no cover	cover	Mean
				---------bu/acre--------			
Integrated compost	23	48	46	47	58	48	53a**
Integrated fertilizer	18	47	47	47	66	57	62b
Mean	21	48	47	47	62a	52b	

*1993 wheat was spring wheat

**Numbers not followed by the same letter are significantly different at p= 0.05

Table 6. Analysis of variance for wheat grain yield in 1995.

Source of variation	PR>F
Replication	0.45
Management	0.055
Cover	0.019
Management x cover	0.986

Table 7. Corn yield means for each year by fertility management type, entry point, and cover.

	1993			1994			1995		
Overall means									
Management									
Integrated compost	no cover	cover	Mean	no cover	cover	Mean	no cover	cover	Mean
				----- bu/acre -------					
1st yr corn	134	131	133	186	187	187a	140	169	155
2nd yr corn	128	131	130	127	108	118c	130	126	128
continuous corn	120	132	126	118	125	122c	125	130	128
Integrated fertilizer									
1st yr corn	157	157	157	185	191	188a	152	158	155
2nd yr corn	166	156	161	178	157	168ab	140	133	137
continuous corn	158	153	156	137	141	139bc	139	139	139
Entry point									
1st yr corn	145	144	144	185a	189a	187a	146b	163a	154a
2nd yr corn	147	143	145	152b	132c	142b	135bc	130c	132b
continuous corn	139	142	141	127c	133c	130b	132c	135bc	133b
Management									
Integrated compost	127	131	130b	144	140	142b	132	142	137
Integrated fertilizer	160	155	157a	167	163	165a	144	143	144
Cover	144	143	144	156	152	154	138	143	141

*Numbers not followed by same letter are significantly different according to Duncan's Multiple Range Test (p= 0.05).

Table 8. Analysis of variance for corn grain yield, 1993-1995.

	1993	1994	1995
Source of variation	Pr. >F	Pr. >F	Pr. >F
Replication	0.748	0.573	0.528
Main effects			
Management	0.045	0.03	0.20
Entry point	0.665	0.0001	0.002
Cover	0.882	0.276	0.123
Interaction effects			
Management x entry point	0.839	0.038	0.556
Management x cover	0.309	0.97	0.136
Entry point x cover	0.781	0.006	0.026
Management x entry point x cover	0.637	0.828	0.346

Table 9. Product income, variable costs, and net economic return per acre for all crops under integrated compost management, 1993-1995.

	1993		1994		1995	
	cover	no cover	cover	no cover	cover	no cover
			----$/acre----			
First yr. corn						
Product income @ $2.50/bu	327.50	335.00	467.50	465.00	422.50	350.00
Variable costs	102.69	80.19	111.10	79.60	107.20	75.70
Net economic return	**224.81**	**254.81**	**356.40**	**385.40**	**315.30**	**274.30**
Second yr. corn						
Product income @ $2.50/bu	327.50	320.00	270.00	317.50	315.00	325.00
Variable costs	87.69	80.19	87.10	79.60	83.20	75.70
Net economic return	**239.81**	**239.81**	**182.90**	**237.90**	**231.80**	**249.30**
Continuous corn						
Product income @ $2.50/bu	330.00	300.00	312.5	295.00	325.00	312.50
Variable costs	102.69	80.19	99.10	79.60	108.20	88.70
Net economic return	**227.31**	**219.81**	**213.40**	**215.40**	**216.80**	**223.80**
Wheat						
Product income @ $4.00/bu	--	92.00	184.00	192.00	192.00	232.00
Variable costs	--	56.39	54.97	54.97	54.72	54.72
Net economic return	--	**35.61**	**129.03**	**137.03**	**137.28**	**177.28**
Soybean						
Product income @ $6.25/bu	--	312.50	268.75	312.50	243.75	231.25
Variable costs	--	51.99	50.47	50.47	50.71	50.71
Net economic return	--	**260.51**	**218.28**	**262.03**	**193.04**	**180.54**

Table 10. Product income, variable costs, and net economic return per acre for all crops under integrated fertilizer management, 1993-1995.

	1993		1994		1995	
	cover	no cover	cover	no cover	cover	no cover
			----$/acre----			
First yr. corn						
Product income @ $2.50/bu	392.50	392.50	477.50	460	395.00	380.00
Variable costs	135.38	115.88	152.76	121.26	143.83	123.13
Net economic return	**257.12**	**276.62**	**324.74**	**338.74**	**251.17**	**256.87**
Second yr corn						
Product income @ $2.50/bu	390.00	415.00	392.50	445.0	332.50	350.00
Variable costs	123.38	115.88	128.76	121.76	130.63	123.13
Net economic return	**266.62**	**299.12**	**263.74**	**323.24**	**201.87**	**226.87**
Continuous corn						
Product income @ $2.50/bu	382.50	395.00	352.50	342.50	347.50	347.50
Variable costs	135.38	115.88	140.76	121.76	155.63	136.13
Net economic return	**247.12**	**279.12**	**211.74**	**220.74**	**191.87**	**211.37**
Wheat						
Product income @ $4.00/bu	--	72.00	188.00	188.00	228.00	264.00
Variable costs	--	68.68	71.76	71.76	59.80	59.80
Net economic return	--	**3.32**	**116.24**	**116.24**	**168.20**	**204.20**
Soybean						
Product income @ $6.25/bu	--	281.25	237.50	250.00	212.50	200.0
Variable costs	--	36.99	47.75	47.75	35.71	35.71
Net economic return	--	**244.26**	**189.75**	**202.25**	**176.79**	**164.29**

Table 11. Net economic return for each entry point in the third year the rotation (1995).

	Integrated compost		Integrated fertilizer.	
	Cover	No cover	Cover	No cover
	----$/acre----			
First yr. corn	315.30	274.30	251.17	256.87
Second yr. corn	231.80	249.30	201.87	226.87
Continuous corn	216.80	223.80	191.87	211.37
Wheat	137.28	177.28	168.20	204.20
Soybean	193.04	180.54	176.79	164.29

Table 12a. 1993-1995 average net economic return of continuous corn and corn in rotation.

	Continuous corn		Corn-soybean-wheat rotation	
Management	cover	no cover	cover	no cover
			----$/acre---- *	
Integrated compost	220.28	225.78	195.40	225.81
Integrated fertilizer	220.18	239.02	204.96	230.46

* based on following prices: Corn@ $2.50/bu, soybean@ $6.25/bu and wheat@ $4.00/bu

Table 12b. 1993-1995 average net economic return of continuous corn and corn in rotation if corn becomes 10% more valuble relative to soybean and wheat

	Continuous corn		Corn-soybean-wheat rotation	
Management	cover	no cover	cover	no cover
			----$/acre---- *	
Integrated compost	220.28	225.78	180.04	207.62
Integrated fertilizer	220.18	239.02	189.45	230.46

* based on following prices: Corn@ $2.50/bu, soybean@ $5.63/bu and wheat@ $3.60/bu

Table 12c. 1993-1995 average net economic return of continuous corn and corn in rotation if corn becomes 10% less valuble relative to soybean and wheat.

	Continuous corn		Corn-soybean-wheat rotation	
Management	cover	no cover	cover	no cover
			----$/acre---- *	
Integrated compost	220.28	225.78	210.75	243.46
Integrated fertilizer	220.18	239.02	220.48	247.60

* based on following prices: Corn@ $2.50/bu, soybean@ $6.88/bu and wheat@ $4.40/bu

Table 13a. 1993-1995 average net economic return of continuous corn and corn in rotation.

	Continuous corn		Soybean-wheat-corn rotation	
Management	**cover**	**no cover**	**cover**	**no cover**
		----$/acre---- *		
Integrated compost	**220.28**	**225.78**	**234.94**	**223.94**
Integrated fertilizer	**220.18**	**239.02**	**203.89**	**205.79**

*** based on following prices: Corn@ $2.50/bu, soybean@ $6.25/bu and wheat@ $4.00/bu**

Table 13b. 1993-1995 average net economic return of continuous corn and corn in rotation if corn becomes 10% more valuble relative to soybean and wheat.

	Continuous corn		Soybean-wheat-corn rotation	
Management	cover	no cover	cover	no cover
		----$/acre---- *		
Integrated compost	220.28	225.78	218.39	207.13
Integrated fertilizer	220.18	239.02	188.25	190.15

* based on following prices Corn@ $2.50/bu, soybean@ $5.63/bu and wheat@ $3.60/bu

Table 13c. 1993-1995 average net economic return of continuous corn and corn in rotation if corn becomes 10% less valuble relative to soybean and wheat.

	Continuous corn		Soybean-wheat-corn rotation	
Management	cover	no cover	cover	no cover
		----$/acre---- *		
Integrated compost	220.28	225.78	251.49	239.76
Integrated fertilizer	220.18	239.02	219.53	221.43

* based on following prices Corn@ $2.50/bu, soybean@ $6.88/bu and wheat@ $4.40/bu

Table 14a. Net economic return of continuous corn and equal acreage of corn-corn-soybean-wheat in rotation in 1995.

	Continuous corn		Equal acreage of Corn-soybean-wheat rotation	
Management	cover	no cover	cover	no cover
		----$/acre---- *		
Integrated compost	216.80	223.80	219.35	220.35
Integrated fertilizer	191.87	211.37	199.50	213.05

* based on following prices: Corn@ $2.50/bu, soybean@ $6.25/bu and wheat@ $4.00/bu

Table 14b. Net economic return of continuous corn and equal acreage of corn-corn-soybean-wheat in rotation in 1995 if corn becomes 10% more valuable relative to soybean and wheat.

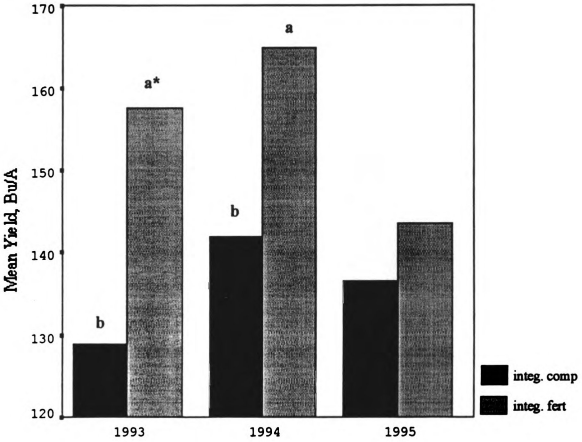
	Continuous corn		Equal acreage of Corn-soybean-wheat rotation	
Management	cover	no cover	cover	no cover
		----$/acre---- *		
Integrated compost	216.80	223.80	208.46	208.79
Integrated fertilizer	191.87	211.37	188.49	201.45

* based on following prices: Corn@ $2.50/bu, soybean@ $5.63/bu and wheat@ $3.60/bu

Table 14c. Net economic return of continuous corn and equal acreage of corn-corn-soybean-wheat in rotation in 1995 if corn becomes 10% less valuable relative to soybean and wheat.

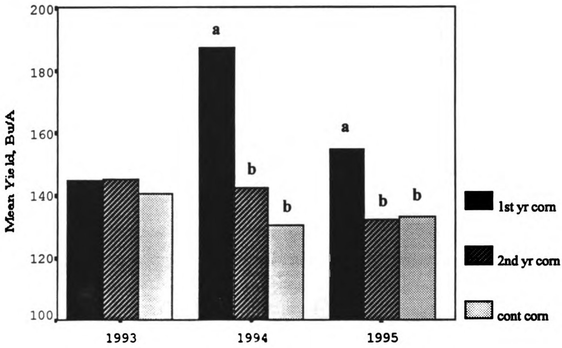
	Continuous corn		Equal acreage of Corn-soybean-wheat rotation	
Management	cover	no cover	cover	no cover
		----$/acre---- *		
Integrated compost	216.80	223.80	230.25	231.93
Integrated fertilizer	191.87	211.37	215.52	224.65

* based on following prices: Corn@ $2.50/bu, soybean@ $6.88/bu and wheat@ $4.40/bu



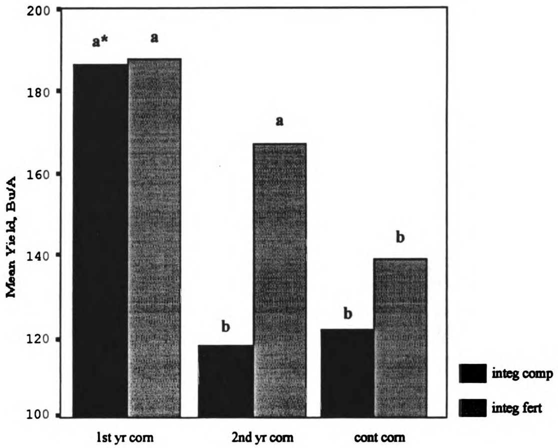
*Letters different from each other are significantly different at $p \leq 0.05$.

Figure 2. Corn grain yield within each of three years under integrated compost or integrated fertilizer management.



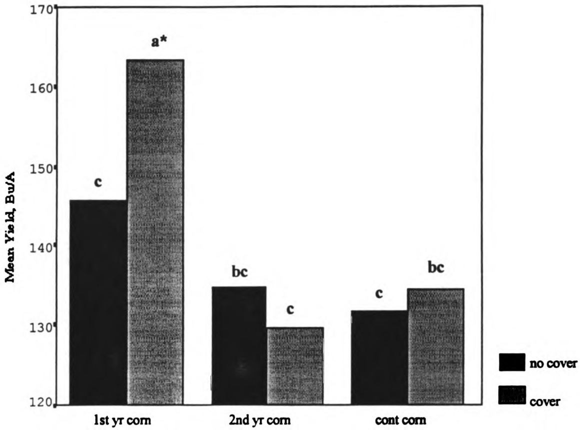
*Letters different from each other are significantly different at $p \leq 0.05$.

Figure 3. Effect of corn entry point within each year on corn grain yield (1993-1995).



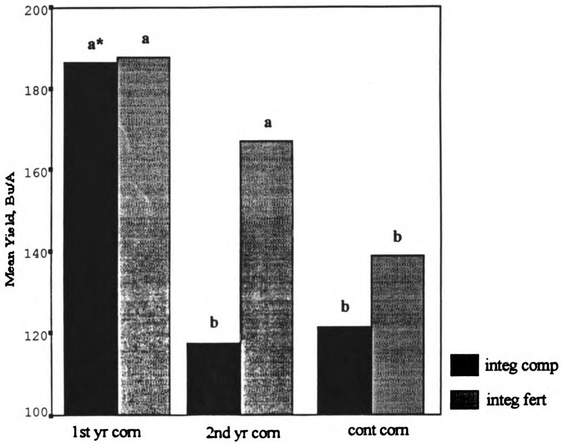
*Letters different from each other are significantly different at $p \leq 0.05$.

Figure 4 . Effect of corn entry point on grain yield under integrated compost and integrated fertilizer management in the second year of the rotation (1994).



*Letters different from each other are significantly different at $p \leq 0.05$.

Figure 5 . Effect of corn entry point and cover on corn grain yield in the third year of the rotation (1995).



*Letters different from each other are significantly different at $p \leq 0.05$.

Figure 6 . Effect of corn entry point on grain yield under integrated compost and integrated fertilizer management in the second year of the rotation (1994).

CHAPTER 2

EARLY AND LATE SEASON SOIL NITRATE LEVELS IN CORN AS AFFECTED BY ROTATION, FERTILITY SOURCE, AND COVER CROP

ABSTRACT

Crop rotation and cover crops have a direct effect on uptake and release of available soil N. In Michigan, soil N sufficiency in corn (*Zea mays L.*) is often determined using the pre-sidedress nitrate test (PSNT) at stage V-6 of corn growth. In order to evaluate the dynamics of soil N mineralization and related factors, a long-term crop rotation experiment, Living Field Laboratory (LFL), was established in 1993 at Hickory Corners, MI. The design is a split-block within a split-plot. Main plots are commercial fertilizer vs. dairy compost as a nutrient source. Sub-plots are the entry points in a corn-corn-soybean [*Glycine max* (L.) Merr.]-wheat (*Triticum aestivum* L.) rotation, and continuous corn. These are further split so that each entry point is grown with or without a cover crop. By 1994, the second year of rotation, the first-year corn treatment following wheat produced PSNT levels up to 62% higher than the corn following corn treatment. In 1995, rotation and cover crop showed similar effects. Red clover (*Trifolium pratense* L.) residue following wheat provided both the earliest and highest amount of mineralization. In both years, first-year corn biomass N levels were at least 33% higher than biomass N levels in corn following corn. These effects occurred under both compost and commercial fertilizer management systems. Early season soil N mineralization appears to be linked to several factors which influence corn productivity.

An ancillary experiment was established at a site adjacent to the LFL in 1994 to measure the effects of overseeded cover in corn. At three rates of N fertilizer, the presence of annual ryegrass (*Lolium multiflorum* Lam.) cover did not reduce biomass N accumulation in corn. However, in 1995, annual ryegrass reduced late-season soil NO_3 available for leaching.

INTRODUCTION

In order to obtain maximum corn grain production, an adequate supply of available N is needed early in the growing season. Ideally, this supply of N should be available just prior to the period of greatest N uptake, and can be measured using the PSNT (Magdoff, 1991). Soil samples are taken at 20-30 cm depths between growth stage V-5 and V-6 of corn growth. The rate of N to be applied is then calculated based on the amount of NO_3 present in the PSNT. Use of the PSNT enables producers to synchronize N demand with crop uptake, while avoiding heavy losses of leached NO_3 -N after crop harvest (Magdoff, 1991).

Various other strategies have been employed to manage early and late-season N levels. Cover crops have been used as both a legume N source (Power, 1987; Stute and Posner, 1993) and to tie up residual soil N after grain harvest (Ditsch et al., 1993, Brinsford and Staver, 1991). Few studies have looked at early and late-season N levels in a cropping system that includes corn grown in rotation with or without cover crops. There are opportunities to manage N levels in crops that precede corn, by the use of overseeded legume cover crops. Dou et al. (1995) reported that mineralized N concentrations from red clover that had been seeded into wheat peaked about four weeks after planting of a following corn crop, and that grain yields in corn were similar to those obtained where fertilizer N was applied without legume N. After removal of the corn crop, residual soil N levels were similar in both systems. Brown et al (1993) found that hairy vetch overseeded into continuous corn significantly increased soil NO_3 -N levels in the following crop 50 days after planting, but there was no difference in fall residual NO_3-N. These studies show that early-season N availability can be altered through use of cover crops and rotation. The goal is to obtain optimum grain yields while keeping residual fall soil NO_3 -N at low levels to avoid NO_3 leaching to ground-water.

Corn is the most commonly grown cash grain crop in Michigan, with most of it grown in rotation with other crops (Landis and Swinton, 1994). Cropping systems that incorporate the benefits of rotation and cover crops must be designed so that soil N levels coincide with crop uptake patterns while leaving little residual soil NO_3 -N after crop harvest.

More information is also needed regarding the amount of N recovered in the various components of a cropping system. Harris et. al (1994), in a crop rotation experiment using labeled N, found higher losses of fertilizer N than legume N. Varvel and Peterson (1990), using isotopic methods, found that N recovery for corn in rotation was significantly higher than N recovery in continuous corn.

Two experiments were conducted over a three year period to determine the potential for managing seasonal levels of soil NO_3 through rotation, cover crops and nitrogen source. The first experiment determined the influence of previous crop and input history on soil N and corn biomass N. The second experiment isolated the nitrogen partitioning effects of a cover crop overseeded into corn.

MATERIALS AND METHODS

This research is part of the Living Field Laboratory (LFL), a long-term crop rotation experiment established in 1993 at the Kellogg Biological Station in Hickory Corners, MI. The LFL is designed to test varying combinations of rotation and cover crops under several agronomic management regimes. The site soil type is a Kalamazoo/Oshtemo sandy loam (coarse-loamy, mixed, mesic Typic Hapludalf). Six years prior to the establishment of the experiment, the site was in a mixed stand of alfalfa and grass hay. The design is a split-block within a split plot with four replications. For this paper, the main plots that comprise this experiment are two levels of fertility management:

(i) integrated compost management: minimal pesticides; banded herbicide plus cultivation for weed control; dairy manure/straw or sand compost as a fertility source

(ii) integrated fertilizer management: minimal pesticides; banded herbicide plus cultivation for weed control; commercial fertilizer as a fertility source

Sub-plots are the entry points of a corn-corn-soybean-wheat rotation, plus continuous corn. Each crop in the rotation was started in 1993, with the appropriate crop sequence grown in each plot in subsequent years. In 1994, "continuous" corn was also second year corn, differing from the other second year corn rotation only in cover crop mix.. All crops in the rotation except soybeans were grown with and without an overseeded cover crop. The cover crop sequence for the rotation is as follows;

first year corn: overseeded red clover + annual ryegrass (ann. rye/rc)

second year corn: overseeded annual ryegrass (ann. rye)

continuous corn: overseeded (ann. rye/rc)

wheat: red clover frost seeded in March into overwintered wheat

A chisel-plow was used for primary tillage, followed by a disk and field-cultivator. Plots were 15.2 by 4.56 m with corn and soybeans planted in .76 m rows and wheat planted in 18 cm rows. Cover crops in corn were sown at second cultivation with a hand seeder in 1993, and with a pto driven Orbit-air seeder in subsequent years. Red clover was seeded at 13.4 kg ha-1, and annual ryegrass at 28 kg ha-1. In the cover sub-plots of wheat, red clover was seeded with an Orbit-air seeder in early March at 13.4 kg ha-1.

In the fertilizer treatment, N was applied as NH_4NO_3 to corn plots based on 8.15 Mg ha-1 yield goal and measured PSNT levels (Magdoff, 1991). In 1995, a 67 kg ha-1 N credit was given to first-year corn following wheat that had been frost-seeded with red clover, as the rotation effects became established. Application of P & K for all fertilized plots was based on soil test recommendations (Vitosh et. al., 1995). In wheat plots, N was broadcast as urea at 56-67 kg ha^{-1} in early April. Soybean plots received no fertilizer N. In the compost treatment, composted dairy manure from a companion research project was applied on a dry weight basis in April (corn and soybeans) and October (wheat) with a manure spreader. The goal was to supply N from the compost to meet corn yield goals, assuming 15% N available in the first year of application. Because of the low N availability in the early years of the rotation, and 60% sand content, a larger amount of compost was applied than the 11-22 Mg ha-1 rate commonly used by farmers in manure application . This resulted in an application rate in corn plots of 56 Mg ha^{-1} in 1993, 105 Mg ha^{-1} in 1994 followed by a reduction down to 4.5 Mg ha^{-1} in 1995. Compost application rate and analysis is presented in Table 1.

Soil samples at a 30 cm depth were taken periodically each year with a 1.9 cm dia. soil probe to coincide with early spring mineralization and fall residual soil N levels. Five cores per plot were taken from between rows and composited. After harvest in 1994 and 1995, samples were also taken to a depth of 90 cm with a Giddings 5 cm dia. hydraulic soil probe, and divided into 30 cm increments. Three cores per plot were taken and composited by depth. The samples were dried at 40 ^{o}C for 72-96 h, crushed and sieved through 10 mesh screen, extracted with 1N KCl and analyzed for NO3-N by a Lachat autoanalyzer (Lachat Instruments.)

Corn grain + stover biomass samples were taken each year at physiological maturity. Ten plants per 15.2 m row were weighed wet, field-chopped in a silage chopper, dried at 40 ^{o}C for at least 96 h, weighed dry, and ground for mass spectrometer analysis (Harris and Paul, 1989) for total N. Cover crop samples were taken in late fall, after main crop harvest. Two 77.4 sq cm areas were cut from each plot at a 2.5 cm height. The samples were weighed, dried and ground for mass spectrometer analysis for total N.

The second experiment, designed to measure the nitrogen effect of annual ryegrass overseeded into corn, was conducted during 1994-1995 and 1995-1996 seasons in an adjacent field that had been planted to soybeans. The soil type was similar to the LFL soil type. The experimental design was a split-plot with four replications. A 34 kg N ha^{-1} credit was given to corn in both years (Crookston, 1984). Main plots are three N rates. In 1994, the rates were 0, 67 kg N ha^{-1}, and 134 kg N ha^{-1}. In 1995, the rates were 0, 67 kg N ha^{-1}, and 179 kg N ha^{-1} The 179 kg N ha^{-1} rate was used in 1995 to increase N uptake by both the corn and cover crop In both years, the 0 N rate was used as a check plot, and the 67 kg ha^{-1} rate was used as a rate close to that applied to corn in the rotation experiment in the LFL plots (after the N credit from soybeans was added). Main plot size was the same as the LFL plots Sub-plots were annual ryegrass overseeded at the same time and rate as in the LFL plots. and a no-cover check. Enriched 15N (5 atom %) NH_4NO_3 was applied in 1.52 by 1.52 m microplots contained within the main plots. The labeled material was dissolved in one L of water and applied with a CO_2 backpack sprayer pressurized to 40 psi. The sprayer boom straddled the three microplot rows, and was held at constant height to distribute the solution in an even spray pattern. The corn biomass sampling row for the microplot was the middle row of three rows. Microplots were seeded such that there were eight equally spaced plants in 1.52 m of row. The four innermost plants in the eight plant middle row were sampled for stover and grain biomass

N and atom % 15N. Percent N derived from fertilizer (NDFF) was determined. The annual ryegrass was sampled in the same way as in the LFL plots, and analyzed for NDFF. After crop harvest, corn biomass was returned to the microplots, which were then covered with wire mesh to minimize labeled material movement from the microplots. In both years that the experiment was conducted, the annual ryegrass was sampled in the following spring to determine uptake of remaining N from the initial labeled N application .

RESULTS

Effect of rotation on soil NO_3-N in the LFL

Means for PSNT from 1993-1995 are shown in Table 2, the analysis of variance is shown in Table 3. Means for fall soil samples in 1994 and 1995 are shown in Tables 4 and 5, respectively. The analysis of variance for the fall samples in 1994 and 1995 is shown in Tables 6 and 7, respectively. In 1993, there were no treatment differences in the rotation experiment for soil NO_3-N in samples taken at stage V-6, the PSNT sampling (Table 2). No differences were expected at this stage, as the experiment had just been established and there was no treatment legacy.

In 1994, at the PSNT (June 10) sampling, first year corn following wheat had a NO_3-N level of 9.4 mg kg^{-1}, 58% higher than both rotations of corn following corn, indicating earlier N mineralization (Table 2). In the 1994 fall soil sampling, treatment differences varied with depth. In the 0-30cm depth, NO_3-N was significantly higher in the fertilizer plots (4.2 mg kg^{-1}) than in the compost plots (3.0 mg kg^{-1}), Table 4. There was also a significant cover by management interaction; the fertilizer with no cover plots had a NO_3-N level of 4.8 mg kg^{-1}, higher than the fertilizer with cover or the compost with or without cover plots (Table 4). In the 30-60 and 60-90 cm depths, the only significant treatment difference was due to cover. No-cover plots had higher NO_3-N than the cover plots at both of these depths (Table 4).

In 1995, NO_3-N levels at the PSNT (June 8) sampling were significantly higher in the cover plots (10.6 mg kg^{-1}) than in the no-cover plots (7.6 mg kg^{-1}), shown in Table 2. Also, first-year corn had NO_3-N levels of 12.0 mg kg^{-1}, 64% and 48% higher than continuous corn and second-year corn, respectively (Table 2). There was also a rotation by cover interaction in 1995. First-year corn with cover had NO_3-N levels of 15.2 mg kg^{-1}, higher than first-year, second-year or continuous corn with or without cover (Table 2). In the fall 1995 sampling, there was a significant rotation by cover by management interaction at all three sample depths (Table 5). At all three depths, NO_3-N in first-year corn with cover in the compost plots is found at the highest levels, significantly higher than in first-year corn with cover in the fertilizer plots. This indicates a potential for high residual fall N levels when compost and clover residue from the previous wheat crop are combined. These plots received 213 kg ha^{-1} in 1993, none in 1994, and 280 kg ha^{-1} in 1995. With an estimated 15% per year mineralization rate, N from compost was expected to be available in modest amounts.

Grain + Stover Biomass N

Means for grain+stover biomass N are shown in Table 8, analysis of variance is shown in Table 9. In 1993-1995, grain+stover biomass N was significantly higher in the fertilizer plots than in the compost plots (Table 8). This was probably due to low N availability in the compost plots, even though the amount of compost applied to corn in 1993 was nearly doubled in 1994.

In 1994, first-year corn produced biomass N levels of 236 kg N ha^{-1}, 33% higher than either second-year corn rotation (Table 8). There was a significant rotation by management interaction in 1994 First-year corn under either fertilizer or compost management, and also second-year corn under fertilizer management produced higher biomass N than second year corn under compost management (Table 8). Compost without the addition of a clover cover crop did not supply sufficient N for second-year corn. This effect is seen in 1994 corn grain yields, which are presented with overall corn yields for the rotation experiment in Table 10 A complete discussion on corn grain yield is given in another paper.

In 1995, first year corn produced biomass N levels of 227 kg N ha^{-1}, 33% higher than either second or third-year corn (Table 8). There was a significant cover by management interaction; the no-cover fertilizer plots produced biomass N levels of 219 kg N ha^{-1}, higher than the fertilizer plots with cover and the compost plots with or without cover (Table 8).

In 1995, after corn grain harvest, biomass N levels were also determined for each of the cover crop(s) overseeded in the corn at stage V-6. Analysis of variance for overseeded covers is shown in Table 11, means are shown in Table 11. There was a significant rotation effect for cover crop biomass N. The ann. rye/rc mix overseeded into first-year corn produced higher biomass N than either ann. rye overseeded seeded into second year corn or the ann.rye/rc mix overseeded into continuous corn (Table 11). There was also a cover crop by management interaction. The ann.rye/rc mix overseeded into first-year corn under fertilizer management produced higher biomass N than ann. rye overseeded into second year corn under fertilizer or compost management (Table 11). In the ann. rye/rc mix overseeded into continuous corn, biomass N was significantly higher in the compost plots than in the fertilizer plots. Compost may provide a beneficial environment for cover establishment in continuous corn.

Fertilizer N uptake by corn with overseeded annual
ryegrass in the two-year labeled N experiment

N derived from fertilizer (NDFF) was determined in the 5 ug plant samples as follows:

$$(\text{NDFF}) = \frac{\text{atom \% excess (plant)} - .3667 \text{ (atom \% 15N in unfertilized plants)}}{\text{atom \% labeled fertilizer (5\%)} - .3667 \text{ (atom \% 15N in unfertilized plants)}}$$

From NDFF, % N fertilizer efficiency (NFE)was determined from:

Total kg N ha-1 (grain or stover) X NDFF = kg N ha-1 from fertilizer

$$\text{Then: } \frac{\text{kg N ha-1 from fertilizer}}{\text{the kg N ha-1 application rate}} \times 100 = \text{\%NFE}$$

Grain and stover biomass N and %NFE data for 1994-1995 are presented in Table 12, analysis of variance is shown in Table 13. Analysis of variance for annual ryegrass cover biomass N is shown in Table 14, means and %NFE data are presented in Table 16. The significant difference in grain and stover biomass N between the three application N rates was expected (Table 12). The presence of overseeded ryegrass did not affect N (as measured by %NFE) uptake in corn grain or stover in either year, even though grain biomass N was less in 1995 than in 1994, and stover biomass N was greater in 1995 than in 1994 (Table 12). At all four sampling periods that annual ryegrass cover biomass was taken, N uptake was significantly different only at the highest N application rate (Table 15).

Fall 0-90cm soil NO_3 analysis of variance and corresponding means are shown for 1994 in Tables 17 and 18, and for 1995 in Tables 19 and 20. In both years, at all three sampling depths, differences in soil NO_3 for N rate occurs only at the highest rate. The 0 N rate is not different from the middle rate. In 1995, there was a reduction in soil NO_3 due to cover (Table 20). There was also a difference in soil NO_3 due to cover by N rate (Table 20). Soil NO3 levels in the no-cover plots at the 179 kg N ha-1 N application rate were twice as high as in the cover plots.

SUMMARY

Across fertilizer and compost fertility management, early season N available to a corn crop was greatly affected by the previous crop in rotation. Corn following wheat provided the highest NO_3-N levels at PSNT sampling for two consecutive years, and resulted in higher grain + stover biomass N. This effect on PSNT levels was enhanced by red clover residue overseeded into the preceding wheat crop. The effect was consistent as well in overseeded cover crops when their biomass was measured after corn grain harvest, suggesting that a sufficient level of N early in the growing season can adequately supply the main crop and the cover crop. Farmers are reluctant to use cover crops because of potential competition for nutrients. In the ancillary study using labeled N, neither biomass N in corn, or N efficiency were affected by the overseeded annual ryegrass. However this does not rule out the potential for cover crop competition when water, not N, is the limiting resource. Annual ryegrass caused a 50% reduction in soil NO_3 levels in the fall at the highest N application rate while only taking up less than 6% of the N available to corn. This suggests that at high levels of N application in corn, as occurs in the seed corn industry, overseeding annual ryegrass reduces the potential for NO_3 leaching. This is especially important when considering the coarse-textured soils in the region this experiment was conducted

Cover crops reduced residual soil N after harvest, in the fertilizer plots and in compost plots without red clover Compost plots with red clover residue resulted in higher residual soil N after harvest in one of the two experiment years. All other compost and cover combinations except red clover resulted in the lowest after harvest N levels, at all three sampling depths. Perhaps overseeding an alternative cover into corn following wheat would alter this effect of compost/red clover. Such scenarios are being considered in the LFL experiment.

The ideal combination of crop rotation and cover crops will result in higher early season N levels for uptake in synchrony with corn crop needs while reducing residual N after crop harvest.

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Table 1. Compost analysis.

	APPLICATION DATE					
	4/22/93	10/18/93	4/21/94	10/4/94	4/28/95	10/22/95
Compost applied (Mg ha-1)	3200	45500 [1]	39900	56800 [1]	4000 [1]	4000 [1]
Nitrogen supplied (Mg ha-1)	40	190	600	440	250	250
Estimated available (Mg ha-1)[2]	<10	30	90	70	40	40
Nitrogen (%)	1.2	0.4	1.5	0.8	0.6	0.6
Carbon (%)	14.1	6.2	20.2	10.2	11.5	11.5
C:N ratio	12	15	13	13	19	19
Nitrate-Nitrogen (ug/ml)	-	-	4	13	28	28
		---------------%	------------------			
Phosphorus	0.5	0.2	0.4	0.2	0.2	0.2
Potassium	0.3	0.5	1.7	0.8	0.7	0.7
Calcium	1	2.2	2.3	14	2.4	2.4
Magnesium	0.4	0.6	0.5	1.8	0.6	0.6
		---------------ppm	---------------			
Boron	10	20	50	40	14.4	14.4
Zinc	220	50			68.2	68.2
Manganese	210	100	190	420	191	191
Copper	130	20	-	-	29	29
pH	-	-	8.4	9.2	9.1	9.1
Electrical conductivity (mmhos	-	-	5.5	11.6	6.3	6.3
Moisture (%)	60	30	50	20	40	40

[1]compost applied on these dates had been made with dairy manure where sand had been used for bedding. Sand content was estimated to be 60%, by water sedimentation.

[2]assumes 15% estimated release in first year after application. Mineralization in subsequent years was not estimated.

Table 2. Pre-sidedress nitrate test means by fertility management type, entry point, and cover, 1993-1995.

Overall means	June 11 1993*	June 10 1994			June 8 1995		
Management							
Integrated compost	no cover	no cover	cover	Mean	no cover	cover	Mean
		mg kg^{-1} NO_3**					
1st yr corn	6.3	9.0	9.0	9.0	9.3	15.6	12.5
2nd yr corn	7.6	5.4	4.7	5.1	6.7	10.0	8.4
continuous corn	8.1	6.7	4.5	5.6	6.4	7.3	6.9
Integrated fertilizer							
1st yr corn	5.2	9.4	10.1	9.8	8.3	14.7	11.5
2nd yr corn	6.1	6.5	6.5	6.5	7.9	7.5	7.7
continuous corn	9.5	6.1	7.0	6.6	6.9	8.2	7.6
Entry point							
1st yr corn	5.8	9.2	9.6	9.4a	8.8b	15.2a	12.0a
2nd yr corn	6.9	6.0	5.6	5.8b	7.3b	8.8b	8.1b
continuous corn	8.8	6.4	5.8	6.1b	6.7b	7.8b	7.3b
Management							
Integrated compost	7.4	7.0	6.1	6.6	7.5	11.0	9.2
Integrated fertilizer	6.9	7.3	7.9	7.6	7.7	10.1	8.9
Cover	—	7.2	7.0	7.1	7.6a	10.6b	9.1

* There was no cover crop established at PSNT sampling in 1993.

**Numbers not followed by same letter are significantly different according to Duncan's Multiple Range Test (p= 0.05).

Table 3. Analysis of variance for pre-sidedress nitrate test, 1994 and 1995.

	June 10 1994	June 8 1995
Source of variation	Pr. >F	Pr. >F
Replication	0.30	0.93
Main effects		
Management	0.23	0.698
Entry point	0.0001	0.0001
Cover	0.717	0.0001
Interaction effects		
Management x entry point	0.855	0.653
Management x cover	0.245	0.45
Entry point x cover	0.816	0.01
Management x entry point x cover	0.653	0.438

Table 4. Fall NO_3 sample means for three incremental depths, November 8, 1994.

Overall means	0-30cm depth*			30-60cm depth			60-90cm depth		
Management									
Integrated compost	no cover	cover	Mean	no cover	cover	Mean	no cover	cover	Mean
					mg kg^{-1} NO_3				
1st yr corn	2.9	3.0	3.0	1.1	1.1	1.1	1.1	0.9	1.0
2nd yr corn	2.3	3.2	2.8	1.2	0.7	1.0	0.8	0.9	0.9
continuous corn	3.7	3.2	3.5	1.3	0.9	1.1	1.0	1.0	1.0
Integrated fertilizer									
1st yr corn	5.6	3.5	4.6	3.1	1.7	2.4	1.7	1.2	1.5
2nd yr corn	3.9	4.6	4.3	2.1	1.3	1.7	2.2	1.0	1.6
continuous corn	4.8	2.8	3.8	2.2	1.0	1.6	2.0	1.1	1.6
Entry point									
1st yr corn	4.2ab	3.2bc	3.7	2.1	1.4	1.8	1.4	1.1	1.2
2nd yr corn	3.1c	3.9abc	3.5	1.7	1.0	1.3	1.5	1.0	1.2
continuous corn	4.3a	3.0c	3.6	1.8	1.0	1.4	1.5	1.1	1.3
Management									
Integrated compost	3.0b	3.1b	3.0b	1.2	0.9	1.1	1.0	0.9	1.0
Integrated fertilizer	4.8a	3.6b	4.2a	2.5	1.3	1.9	2.0	1.1	1.5
Cover	3.9	3.4	3.6	1.8a	1.1b	1.5	1.5a	1.0b	1.2

*Within each depth, numbers not followed by same letter are significantly different according to Duncan's Multiple Range Test ($p = 0.05$).

Table 5. Fall NO_3 sample means for three incremental depths, November 13, 1995.

	0-30cm depth*			30-60cm depth			60-90cm depth		
Overall means									
Management									
Integrated compost	no cover	cover	Mean	no cover	cover	Mean	no cover	cover	Mean
					mg kg^{-1} NO_3				
1st yr corn	2.0c	3.1c	2.5	1.3c	3.1ab	2.2	1.1def	2.7a	1.9
2nd yr corn	2.0c	2.0c	2.0	1.4c	1.3c	1.4	1.3cdef	1.ef	1.2
continuous corn	2.9ab	2.1ab	2.5	1.2c	1.3c	1.3	1.3bcdef	1.0f	1.2
Integrated fertilizer									
1st yr corn	2.4abc	1.9abc	2.2	3.4a	2.0	2.7	1.8bc	1.6bcde	1.7
2nd yr corn	3.0a	2.1c	2.6	3.0ab	2.2	2.6	1.6bcd	1.9b	1.8
continuous corn	2.1c	2.2bc	2.2	1.6c	1.6	1.6	1.2cdef	1.4bcdef	1.3
Entry point									
1st yr corn	2.2	2.5	2.4	2.4	2.5	2.5a	1.4	2.1	1.8a
2nd yr corn	2.5	2.0	2.3	2.2	1.7	2.0b	1.5	1.5	1.5ab
continuous corn	2.5	2.1	2.3	1.4	1.4	1.4b	1.3	1.2	1.3b
Management									
Integrated compost	2.3	2.4	2.3	1.3	1.9	1.6	1.3	1.6	1.4
Integrated fertilizer	2.5	2.1	2.3	2.7	1.9	2.3	1.6	1.6	1.6
Cover	2.4	2.4	2.3	2.0	1.9	1.9	1.4	1.6	1.5

*Within each depth, numbers not followed by same letter are significantly different according to Duncan's Multiple Range Test ($p= 0.05$).

Table 6. Analysis of variance for NO3 samples at three incremental depths, November 8, 1994.

	0-30cm	30-60cm	60-90cm
Source of variation	Pr. >F	Pr. >F	Pr. >F
Replication	0.044	0.359	0.484
Main effects			
Management	0.005	0.085	0.638
Entry point	0.911	0.861	0.543
Cover	0.810	0.021	0.031
Interaction effects			
Management x entry point	0.479	0.277	0.484
Management x cover	0.037	0.292	0.074
Entry point x cover	0.019	0.699	0.866
Management x entry point x cover	0.383	0.976	0.522

Table 7. Analysis of variance for fall NO3 samples at three incremental depths, November 13, 1995.

	0-30cm	30-60cm	60-90cm
Source of variation	Pr. >F	Pr. >F	Pr. >F
Replication	0.868	0.514	0.179
Main effects			
Management	0.793	0.061	0.395
Entry point	0.919	0.004	0.036
Cover	0.260	0.807	0.445
Interaction effects			
Management x entry point	0.120	0.165	0.100
Management x cover	0.097	0.006	0.879
Entry point x cover	0.079	0.441	0.221
Management x entry point x cover	0.006	0.027	0.008

Table 8. Corn grain+stover biomass N means for each year by fertility management type, entry point, and cover.

	1993			1994			1995		
Overall means									
Management									
Integrated compost	no cover	cover	Mean	no cover	cover	Mean	no cover	cover	Mean
				----- kg N ha^{-1}* -------					
1st yr corn	69	68	69c	225	228	227a	209	230	220
2nd yr corn	76	73	75bc	127	84	106c	131	131	131
continuous corn	71	75	73c	136	113	125bc	139	172	156
Integrated fertilizer									
1st yr corn	137	115	126a	237	253	245a	248	217	233
2nd yr corn	94	95	95b	258	237	248a	223	182	203
continuous corn	136	100	118a	171	159	165b	187	193	190
Entry point									
1st yr corn	103	92	98	231	241	236a	229	224	227a
2nd yr corn	85	84	85	193	161	177b	177	157	167b
continuous corn	104	88	96	154	136	145b	163	183	173b
Management									
Integrated compost	72	72	72a	163	142	153b	160c	178bc	169b
Integrated fertilizer	122	103	113b	222	216	219a	219a	197b	209a
Cover	97	88	93	192	179	186	190	188	189

*Numbers not followed by same letter are significantly different according to Duncan's Multiple Range Test ($p = 0.05$).

Table 9. Analysis of variance for corn grain+stover biomass N, 1993-1995.

	1993	1994	1995
Source of variation	Pr. >F	Pr. >F	Pr. >F
Replication	0.307	0.416	0.58
Main effects			
Management	0.03	0.043	0.036
Entry point	0.144	0.0001	0.007
Cover	0.132	0.238	0.807
Interaction effects			
Management x entry point	0.041	0.04	0.261
Management x cover	0.127	0.473	0.009
Entry point x cover	0.591	0.30	0.099
Management x entry point x cover	0.339	0.976	0.749

Table 10. Overall corn yield means for each year by fertility management type, entry point, and cover.

	1993		1994		1995	
	no cover	cover	no cover	cover	no cover	cover
			yield Mg ha^{-1}			
Compost						
1st yr corn	8.4	8.2	11.7	11.7	8.8	10.6
2nd yr corn	8.0	8.3	8.0	6.8	8.2	7.9
cont corn	7.5	8.3	7.4	7.8	7.8	8.2
Fertilizer						
1st yr corn	9.8	9.8	11.6	12.0	9.5	9.9
2nd yr corn	10.4	9.6	11.2	9.8	8.8	8.3
cont corn	9.9	9.6	8.6	8.8	8.7	8.7

Table 11. Analysis of variance for cover crop biomass N, 1993-1995.

	1993	1994	1995
Source of variation	Pr. >F	Pr. >F	Pr. >F
Replication	0.522	0.065	0.888
Main effects			
Management	0.115	0.242	0.895
Cover crop	0.287	0.105	0.025
Interaction effects			
Management x cover	0.613	0.245	0.058

Table 12. Cover crop biomass N means for each year.

	1993	1994	1995
Overall means			
Management		----- kg N ha^{-1}-------	
Integrated compost			
ar/rc* in1st yr corn	3.8	23.0	10.6abc**
ar in 2nd yr corn	5.0	13.2	6.5bc
ar/rc in cont corn	5.6	26.1	11.1ab
Integrated fertilizer			
ar/rc in 1st yr corn	6.6	18.5	14.2a
ar in 2nd yr corn	10.2	22.8	7.5bc
ar/rc in cont corn	8.1	31.2	5.4c
Cover crop			
ar/rc in 1st yr corn	5.2	20.8	13.9a
ar in 2nd yr corn	7.6	18.0	7.8b
ar/rc in cont corn	6.9	28.7	9.2b
Management			
Integrated compost	4.8	20.5	9.4
Integrated fertilizer	8.3	23.7	9.0

*ar/rc= annual ryegrass/red clover, ar= annual ryegrass

**Numbers not followed by same letter are significantly different according to Duncan's Multiple Range Test (p= 0.05).

Table 13. Corn grain and stover biomass N and % N efficiency at three fertilizer N rates, with and without annual ryegrass cover in 1994 and 1995.

1994

Grain	No cover	Cover	Mean	No cover	Cover
	---Biomass kg N ha $^{-1}$---			%NFE	
0 rate	87	91	89	—	—
67 kg N ha^{-1}	138	132	135	56%	57%
134kg N ha^{-1}	146	159	153	47%	49%
Stover					
0 rate	30	32	31	—	—
67 kg N ha^{-1}	45	41	43	19%	19%
134kg N ha^{-1}	60	67	64	20%	21%
Grain+stover					
0 Rate	117	123	120c*		
67 kg N ha^{-1}	183	173	178b		
134kg N ha^{-1}	206	225	216a		

*Numbers not followed by same letter are significantly different according to Duncan's Multiple Range Test (p= 0.05).

1995

Grain	No cover	Cover	Mean	No cover	Cover
	---Biomass kg N ha $^{-1}$---			%NFE	
0 rate	39	44	42	—	—
67 kg N ha^{-1}	91	98	95	52%	59%
179 kg N ha^{-1}	130	120	125	52%	45%
Stover					
0 rate	37	36	37	—	—
67 kg N ha^{-1}	63	60	62	36%	39%
179 kg N ha^{-1}	104	93	99	38%	32%
Grain+stover					
0 Rate	76	80	78c*		
67 kg N ha^{-1}	154	158	156b		
179 kg N ha^{-1}	234	213	224a		

*Numbers not followed by same letter are significantly different according to Duncan's Multiple Range Test (p= 0.05).

Table 14. Analysis of variance for corn grain and stover biomass N and % N efficiency at three fertilizer N rates, with and without annual ryegrass cover in 1994 and 1995.

	1994	1995
Source of variation	Pr. >F	Pr. >F
Replication	0.197	0.725
N Rate	0.001	0.0001
Cover	0.591	0.706
N Rate x cover	0.477	0.574

Table 15. Analysis of variance for annual ryegrass biomass N at three N rates, 1994 and 1995.

	Fall 1994	Spring 1995	Fall 1995	Spring 1996
Source of variation	Pr. >F	Pr. >F		
Replication	0.159	0.753	0.484	0.725
N Rate	0.004	0.696	0.006	0.011

Table 16. Annual ryegrass biomass N means and %N efficiency at three N rates in 1994 and 1995.

	Biomass kg N ha $^{-1}$	%NFE
Fall 1994		
0 rate	5.5b*	—
67 kg N ha^{-1}	2.8b	0.50
134kg N ha^{-1}	13.8a	2.5
Spring 1995		
0 rate	6.0	—
67 kg N ha^{-1}	4.6	0.35
134kg N ha^{-1}	6.3	0.65
Fall 1995		
0 rate	1.3b	—
67 kg N ha^{-1}	3.2b	1.5
179kg N ha^{-1}	9.3a	2.4
Spring 1996		
0 rate	1.4b	—
67 kg N ha^{-1}	2.2b	0.23
179kg N ha^{-1}	4.9a	0.48

*Numbers not followed by same letter are significantly different according to Duncan's Multiple Range Test (p= 0.05).

Table 17. Analysis of variance for the fall 0-90 cm soil NO_3 samples at three N rates, with and without annual ryegrass cover, October 26,1994.

	0-30cm	30-60cm	60-90cm
Source of variation	Pr. >F	Pr. >F	Pr. >F
Replication	0.572	0.482	0.529
N Rate	0.009	0.018	0.066
Cover	0.317	0.832	0.639
N Rate x cover	0.287	0.937	0.176

Table 18. Fall 0-90 cm soil NO_3 levels at three fertilizer N rates, with and without annual ryegrass after corn grain harvest, October 26, 1994.

	no cover	cover	Mean
0-30cm depth	—— mg kg^{-1} NO_3* ——		
0 rate	1.2	1.4	1.3b
67 kg N ha^{-1}	1.5	1.2	1.4b
134 kg N ha^{-1}	4.3	3.2	3.6a
Mean	2.3	1.9	
30-60cm depth			
0 rate	1.0	1.2	1.1b
67 kg N ha^{-1}	1.0	0.9	1.0b
134 kg N ha^{-1}	2.7	2.8	2.8a
Mean	1.6	1.6	
60-90cm depth			
0 Rate	0.8	0.8	0.8
67 kg N ha^{-1}	0.9	1.2	1.1
134 kg N ha^{-1}	1.9	1.4	1.7
Mean	1.2	1.1	

*Numbers not followed by same letter are significantly different according to Duncan's Multiple Range Test (p= 0.05).

Table 19. Analysis of variance for the fall 0-90 cm soil NO_3 samples at three N rates, with and without annual ryegrass cover, November 13, 1995.

	0-30cm	30-60cm	60-90cm
Source of variation	Pr. >F	Pr. >F	Pr. >F
Replication	0.647	0.515	0.237
N Rate	0.162	0.016	0.0001
Cover	0.378	0.606	0.028
N Rate x cover	0.747	0.836	0.054

Table 20. Fall 0-90 cm soil NO_3 levels at three fertilizer N rates, with or without annual ryegrass cover, November 13, 1995.

	no cover	cover	Mean
0-30cm depth	--- mg kg^{-1} NO_3* ---		
0 rate	1.4	1.3	1.4
67 kg N ha^{-1}	1.3	3.4	2.4
179 kg N ha^{-1}	4.9	6.2	5.6
Mean	2.5	3.6	
30-60cm depth			
0 rate	1.2	0.8	1.0b
67 kg N ha^{-1}	1.2	1.2	1.2b
179 kg N ha^{-1}	6.5	4.7	5.6a
Mean	3.0	2.2	
60-90cm depth			
0 Rate	0.8b	0.8	0.8b
67 kg N ha^{-1}	1.1b	1.0b	1.05b
179 kg N ha^{-1}	2.9a	1.4b	2.15a
Mean	1.6a	1.1b	

*Numbers not followed by same letter are significantly different according to Duncan's Multiple Range Test (p= 0.05).