Assessing and Predicting the Effect of Cover Crops and Reduced Tillage on Nitrogen Management

Final Report

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Executive Summary

This report summarizes the results from a two year study examining the ability of cover crops established after winter wheat to sequester soil nitrate and to provide nitrogen to a succeeding corn crop in either a no-till or plow tillage system. The ability and/or reliability of the soil nitrate test to accurately predict nitrogen requirements was also examined.

Each of the cover crops examined (red clover, oilseed radish, oats, and fall rye) reduced soil nitrate amounts during the post wheat harvest period when they were actively growing. However, only red clover provided a significant nitrogen contribution to the succeeding corn crop. This project calls into question the economic viability of non-legume cover crops in providing nitrogen to a following corn crop.

Allowing an over-wintering cover crop (ie. fall rye, red clover) to regrow in the spring before killing in a no-till system actually decreased the nitrogen contribution of the cover crop to the succeeding corn crop. Applying 40 Kg N ha^{-1} at planting did not increase corn yield relative to applying 10 Kg N ha^{-1} in either conventional or no-till systems.

Mineralization of nitrogen from cover crop biomass occurred at a faster rate in a plow tillage system than in no-till. Following red clover, and to a lesser degree after oilseed radish and fall rye, the corn yield response to added nitrogen was smaller in the plow system than in no-till. The greater yield response to added N within the no-till system may, in part, be due to slower rates of nitrogen mineralization observed in early June. It appears that both the soil tests and yield data would indicate a requirement for more nitrogen in a no-till system than in a tilled system.

The results from the nitrogen contribution survey following red clover indicated that a planting time soil nitrate test may, on average, over estimate actual nitrogen requirements by 100% and producers should, therefore, adjust planting time recommendations accordingly. Sampling for soil nitrate levels close to sidedress time provided a good estimation of actual N requirements for corn following red clover. Averaged over two years across 25 sites around the province corn required 50 kg N/ha of nitrogen fertilizer to produce maximum economic yield. This value was significantly lower than what producers would have arrived at by: using a fixed red clover credit of 45 kg N/ha (OMAFRA Publication 296), by performing a planting time soil nitrate sample, or by guessing.

PART A: ASSESSMENT OF COVER CROPS

Research objectives and background

The objectives of the research conducted under Part A are to evaluate 1) the ability for various cover crops (red clover, fall rye, oilseed radish and oats) to establish and sequester nitrogen during the post wheat harvest period, 2) the availability of nitrate to a following corn crop in a plow and no-till system; and 3) the effect that cover crop, tillage system and timing (fall vs. spring) of cover crop kill in the no-till system has on the accuracy and/or interpretation of the soil nitrate test.

Experimental sites and co-operators

This work was performed at the following two sites:

Ayr Site
Jamie McRae
Brant County

Kirkton Site
Bill Denham
Perth County

Experimental treatments and methodology

The field experiments described in this section are replicated field trials. The experimental design was a randomized block strip-block with 4 replications. Due to problems with drainage at the Ayr site, one of the blocks was abandoned. Therefore the Ayr site is replicated 3 times.

The treatments were comprised of various combinations of cover crops (red clover, fall rye, oilseed radish, oats, or no cover); tillage systems (plow, or no-till) and starter nitrogen application rate (10 or 40 kg-N ha^{-1}). The fall rye and red clover no-till treatments were duplicated in order to examine the effect of timing of cover crop kill (fall or spring).

Red clover was established into standing soft white winter wheat by underseeding in late March at a seeding rate of 12 kg ha^{-1}. Fall rye, oats and oilseed radish were established by drill seeding shortly following wheat harvest.

Cover crop effects on spring nitrogen release patterns and a subsequent corn crop were evaluated with two tillage systems. The tillage systems at Ayr were fall chisel plow with spring secondary tillage and no-till. The tillage systems at Kirkton are fall moldboard plow with secondary tillage and no-till.

Timing of kill for fall rye and red clover in the no-till system occurred both in the fall (October 20) and spring (early May).

On all cover crop/tillage combinations, 10 kg-N ha^{-1} was applied as starter fertilizer (11-52-0). The fall kill no-till red clover, fall plow red clover, no cover no-till and no-till fall plow treatments were duplicated and an additional 30 kg-N ha^{-1} of N in the form of U.A.N. was applied in close proximity to the row shortly after planting. The total amount of N applied as starter was 40 kg-N

The actual combination of treatments were as follows:
Red clover, no-till, fall kill.

1. Red clover, no-till, spring kill.
2. Red clover, fall plow.
3. Fall rye, no-till, fall kill.
4. Fall rye, no-till, spring kill.
5. Fall rye, fall plow.
6. Oilseed radish, no-till.
7. Oilseed radish, fall plow.
8. Oats, no-till.
9. Oats, fall plow.
10. No cover, no-till.
11. No cover, fall plow.

In the above treatments, (1 to 12) corn was planted with 10 kg-N applied as starter fertilizer. In the following treatments (13 to 16), an additional 30 kg-N ha^{-1} was applied as U.A.N., resulting in a total of 40 kg-N ha^{-1} applied as starter fertilizer.

1. Red clover, no-till, fall kill.
2. Red clover, fall plow.
3. No cover, no-till.
4. No cover, fall plow.

Cover crop establishment, growth, and nitrogen sequestering

Data from this set of experiments generally supported previous cover crop research which demonstrated that substantial growth of the cover crops was consistently obtained only with the red clover option (Table 1).

Table 1. Total cover crop biomass (living and dead material) determined in mid-November 1993 (Ayr) and 1994 (Kirkton).

Cover Crop	Crop Biomass Ayr	Kirkton
Mid-November (1993)	-- kg ha^{-1}--	
Red clover	3.73 a+	1.89 a
Fall rye	1.61 b	0.61 b
Oilseed radish	1.12 b	1.27 b
Oats	0.99 b	1.63 ab

\+ Within a site, values followed by the same letter are not different according to a protected LSD test at the 5% level of probability.

By November of the establishment year most cover crops had an impact on the soil nitrate levels when compared to the no cover crop option. Table 2 outlines the reduction in soil nitrate possible with the use of cover crops. One interesting observation was the significant reduction in soil nitrate levels at Ayr under the oat cover crop in a year when oats produced 35% more biomass than we normally have observed. In general, it appears that the capacity for cover crops to sequester soil nitrate under Ontario conditions is inhibited by the low biomass accumulation. Indications are that red clover has the ability to consistently produce more biomass than fall seeded cover crops and, despite its role as a potential fixer of nitrogen from the atmosphere, it can use residual nitrogen from the soil profile as well - or better than other - non-fixing cover crops.

Table 2. Estimated amount of soil nitrate in the surface 60 cm on various fall sample dates .

Cover Crop	Kirkton November 16	Ayr November 25
	kg-N ha^{-1}	
Red clover	23 b	28 a
Fall rye	24 b	26 ab
Oilseed radish	28 b	33 a
Oats	27 b	13 b
No cover	46 a	39 a

\+ Within column means followed by the same letter are not different according to a protected LSD test at the 5% level of probability. Cover crop means are a composite of treatments containing the same cover crop.

Spring soil nitrate amounts

In 1994, soil nitrate-N amounts measured on May 27 (considered the planting sample date) were unexpectedly low for an end of May sample date (Table 3). The unusually cool wet weather conditions for the 3 weeks that preceded this sample date may in part explain the relatively low soil nitrate-N amounts. Significant differences in soil nitrate-N amounts among cover crops for a particular tillage system or tillage for a particular cover crop could not be identified. 1995 results showed significant treatment effects as no-till plots were generally lower in soil-nitrate levels than their plowed counterparts. Spring chemical kill of over-wintering cover crops also resulted in significantly lower soil nitrate status than when these plots were fall killed.

Side-dress sampling was performed at Ayr on June 10, 1994 and soil nitrate amounts had increased, particularly in the fall chisel plow system - regardless of the cover crop - and for fall killed red clover in the no-till system. On this sample date, soil nitrate-N amounts following chisel plowed red clover were at least 1.7 times greater than following either oats or no cover.

Table 3. Estimated amount of soil nitrate-N in the surface 60 cm following corn planting (Ayr, 1994 and Kirkton, 1995).

Tillage System/ Cover Crop	Ayr May 27	Kirkton May 25
No-till	kg-N ha^{-1}	
Red clover (Fall kill)	25	55
Red clover (Spring kill)	23	27
Fall rye (Fall kill)	26	50
Fall rye (Spring kill)	15	22
Oilseed radish	17	53
Oats	16	37
No cover	26	59
Fall plow		
Fall rye	27	62
Oilseed radish	29	66
Oats	20	55
No cover	30	60
Tillage LSD $_{P=0.05}$)+	ns	14.9

\+ Least significant difference for tillage comparisons within the various cover crop treatments (ns is not significant).

In the no-till system, soil nitrate amounts following fall killed clover were at least 1.5 times greater than following either oats, oilseed radish, spring killed fall rye and no cover (P=0.10).

1995 data (Table 4) showed similar results with red clover generally having soil nitrate levels 20-40% higher than other cover crop options within either tillage system. At Kirkton, at the June 14 date the spring killed cover crop plots continued to lag considerably behind other no-till plots in terms of nitrogen mineralization.

Table 4. Estimated amount of soil nitrate-N in the surface 60 cm on side-dress sample dates following corn planting (Ayr, 1994 and Kirkton, 1995).

Tillage System/ Cover Crop	Ayr June 10	Kirkton June 14
No-till	kg-N ha^{-1}	
Red clover (Fall kill)	63	99
Red clover (Spring kill)	42	62
Fall rye (Fall kill)	42	76
Fall rye (Spring kill)	20	38
Oilseed radish	31	74
Oats	28	65
No cover	39	79
Fall plow		
Red clover	89	142
Fall rye	64	94
Oilseed radish	72	119
Oats	48	101
No cover	51	96
Tillage LSD $_{P=0.05)}$+	26	22

+ Least significant difference for tillage comparisons within the various cover crop treatments (ns is not significant).

Corn growth and yield

In the absence of nitrogen fertilizer, corn yields were higher following red clover than for any other cover crop option (see Tables 5 and 6). This was true both within no-till and fall tillage systems except where corn followed chisel plowed red clover at Ayr where yields were similar to the no cover (U.A.N.) treatment. Where no nitrogen was added corn yields following cover crops other than red clover were generally no better than corn following the no cover treatments.

Spring killing of red clover in a no-till situation resulted in yields which were lower than other red clover treatments when 0 N was applied. However, when 150 kg N was applied yields of the spring killed plots where similar to other red clover treatments. Spring killing of fall rye plots within the no-till system resulted in yields lower than the fall kill counterpart and were the lowest overall yielding plots when no nitrogen was added.

Table 5. Cover crop effects on grain corn yield and the yield response to 150 kg-N ha^{-1} (adjusted to 15.5% moisture) at Ayr (1994).

	Yield		
Tillage System/ Cover Crop	0 N	150 N	Response
	-------------------- Mg ha^{-1} --------------------		
No-till			
Red clover (Fall kill)	7.68	9.59	1.92
Red clover (Fall kill)(U.A.N.)+	8.46	9.63	1.16
Red clover (Spring kill)	6.96	9.74	2.78
Fall rye (Fall kill)	5.58	9.09	3.51
Fall rye (Spring kill)	4.16	8.44	4.28
Oilseed radish	5.43	8.79	3.36
Oats	4.84	8.59	3.75
No cover	5.50	9.21	3.71
No cove (U.A.N.)	5.45	9.32	3.88
Chisel Plow			
Red clover	7.75	9.30	1.55
Red clover (U.A.N.)	7.84	9.43	1.60
Fall rye	6.45	9.83	3.38
Oilseed radish	6.99	9.75	2.76
Oats	5.29	9.19	3.90
No cover	6.77	9.30	2.53
No cover (U.A.N.)	7.70	9.69	1.99
Tillage LSD $_{P=0.05)}$ ++	1.76	ns	1.51

\+ U.A.N. applied shortly after planting, in the row area.

\+ + Least significant difference for tillage comparisons within the various cover crop treatments (ns is not significant).

Table 6. Cover crop effects on grain corn yield and the yield response to 150 kg-N ha^{-1} adjusted to 15.5% moisture at Kirkton (1995).

Tillage System/ Cover Crop	Yield 0 N	150 N	Response
	--------------------- Mg ha^{-1}		--------------
No-till			
Red clover (Fall kill)	8.40	9.75	1.35
Red clover (Fall kill) (U.A.N.)[+]	8.50	9.66	1.16
Red clover (Spring kill)	8.31	9.78	1.47
Fall rye (Fall kill)	6.79	9.98	3.19
Fall rye (Spring kill)	5.24	9.15	3.91
Oilseed radish	7.29	9.59	2.30
Oats	6.43	9.40	2.97
No cover	7.52	8.96	1.44
No cover (U.A.N.)	6.93	9.08	2.15
Moldboard Plow			
Red clover	9.29	9.75	0.46
Red clover (U.A.N.)	9.23	9.95	0.72
Fall rye	8.08	9.59	1.51
Oilseed radish	8.05	9.37	1.32
Oats	8.18	9.62	1.44
No cover	7.90	9.80	1.90
No cover (U.A.N.)	7.75	9.81	2.06
Tillage LSD $_{P=0.05)}$[++]	1.02	0.68	1.02

\+ U.A.N. applied shortly after planting, in the row area, at the rate of 30 Kg N ha^{-1}

++ Least significant difference for tillage comparisons within the various cover crop treatments (ns is not significant).

Corn yield response to nitrogen

In order to better understand the potential for various cover crops to contribute nitrogen to a succeeding corn crop, an examination of the yield response to added nitrogen is more useful than actual corn yields in the absence of added nitrogen since actual yields are affected by non nitrogen effects as well.

Corn yields achieved when 150 kg N ha^{-1} was added were similar for all treatment combinations (Tables 5 and 6). The yield response however was much less for red clover treatments than for other cover crop options. On average, no-till plots responded more to the additional nitrogen than tilled plots.

Both the N-test and yield response data would indicate that the no-till system requires a greater amount of N fertilizer to maximize yields than does chisel or moldboard systems.

The fall killed red clover no-till, fall chisel plow red clover, no cover no-till and no cover chisel plowed treatments were duplicated to examine the effect of increasing the rate of N in the starter fertilizer from 10 to 40 kg-N ha^{-1}. In the absence of any additional nitrogen, increasing the amount of starter fertilizer N resulted in slightly higher yields. When additional nitrogen was applied, yield differences between the 10 and 40 kg-N ha^{-1} treatments were relatively small. The latter indicated that increasing the amount of nitrogen in the immediate row area at planting will have minimal effects on corn performance when adequate amounts of nitrogen fertilizer are applied pre-emergence in either a plow or no-till system.

PART B: COVER CROP NITROGEN CONTRIBUTION SURVEY

An across the province demonstration site survey was conducted for the purpose of evaluating how accurately the soil nitrate test can determine actual nitrogen requirements for corn planted following cover crops that were established after cereal harvest.

In 1994, 12 of the 13 sites were conducted on fields where corn followed a cereal underseeded with red clover. The other site was following oilseed radish that was seeded following wheat harvest. Similar demonstration sites were conducted in 1995 following red clover only. The 1995 survey consisted of 13 sites with many of the same cooperators who participated in the 1994 survey.

Methodology

Corn production practices at each of the sites was similar to the production practices utilized by the cooperating farmer in the surrounding corn field, except for nitrogen fertilizer application. Each demonstration site consisted of various nitrogen application rates (0, 30, 80, 130 and 180 kg-N ha^{-1}) . In addition to these rates, each site had a treatment where nitrogen was applied based on the planting time soil nitrate test using a 30 cm sample. Some sites also had a treatment where the recommended nitrogen application rate based on the planting soil nitrate test was applied as a split treatment; 30 kg-N ha^{-1} band applied over the row shortly following planting with the remainder applied when corn was at the 6 to 7 leaf stage.

Soil samples were taken (at planting and 1 to 2 dates following planting) where no nitrogen fertilizer was added to a depth of 30 cm to determine soil nitrate amounts. Where nitrogen was added, it was applied as a side-dress treatment when corn was 20 to 30 cm high as U.A.N.

Results

Corn grain yields from the demonstration sites in 1994 and 1995 are outlined in Tables 7 and 8 respectively.

Table 7. Actual corn yields for the various nitrogen rates at demonstration sites in 1994.

Cooperator	County	Nitrogen Rate Applied (Kg N/ha)				
		0	30	80	130	180
		Corn yield in tonnes/ha				
Barrie	Durham	9.51	9.86	10.88	10.81	9.88
Blackler	Perth	5.73	8.54	8.98	9.30	9.38
Bousfield	Wellington	8.06	8.37	8.62	9.35	9.66
Cowbrough	Wellington	7.67	7.53	8.04	7.00	7.73
Devries	Perth	5.51	7.63	8.18	9.17	8.51
Gredig	Elgin	10.20	10.27	11.58	10.98	10.44
Hooker	Elgin	7.12	8.01	10.82	10.75	10.95
MacMaster	Durham	10.07	10.79	11.11	10.22	10.77
Marshall	Halton	5.37	5.40	4.92	5.49	6.09
McRae	Waterloo	5.12	6.78	8.54	8.59	7.98
Perriman	Waterloo	4.87	5.80	8.35	9.33	8.06
Radstake	Wellington	6.69	6.61	8.05	8.04	7.23
Robson	Middlesex	9.21	8.57	8.91	8.40	8.72
Duplicate sites with manure applied:						
Barrie		10.01	9.47	10.02	9.83	10.58
Radstake		6.59	7.95	7.02	8.06	6.56

To convert tonnes/ha to bushels/acre multiply by 15.9.

Table 8. Summary of corn yields at the 1995 demonstration sites for each of the nitrogen fertilizer treatments applied. Yields are adjusted to 15.5% moisture content.

Cooperator	N Rate Applied						
	0	30	80	130	180	Plant [1]	Test [2]
	tonnes/ha						
Barrie	10.50	9.93	10.17	10.51	10.19	10.02	9.94
Bousfield	7.12	7.92	8.97	8.52	8.41	7.37	7.69
DeVries	9.23	9.13	10.92	10.64	10.88	10.32	11.38
Gammie	9.85	10.85	10.51	10.53	10.59	10.66	11.22
Gredig	5.61	7.14	7.41	8.27	8.22	8.63	7.82
Hooker #1	8.70	8.89	8.00	8.74	8.49	7.72	8.80
Hooker #2	8.85	9.25	8.42	9.19	8.29	9.13	8.95
MacMaster	10.76	10.68	10.99	10.23	10.87	10.71	10.73
McRae	9.08	11.53	11.54	10.94	10.93	12.05	11.10
Perriman	8.76	9.27	9.94	10.04	10.38	9.74	10.06
Radstake	9.02	9.90	9.49	9.15	9.53	10.26	9.94
Robson #1	8.65	10.84	11.33	11.73	10.94	11.13	10.85
Robson #2	6.97	8.99	9.26	8.79	8.50	8.68	8.75

[1] 130 Kg N/ha applied near planting times, the remainder (according to soil N-test) was side-dress applied.

[2] Nitrogen side-dress applied according to soil N-test done at planting.

Tables 7 and 8 illustrate yields at the demonstration sites for all nitrogen rates applied. This data was analyzed to produce the critical values outlined in Table 9 and 10, namely the most economical yield goal for each site, and the actual nitrogen fertilizer required to obtain that corn yield.

Table 9. 1994 grain corn yields estimated for situations where no nitrogen was applied and where the economic optimum nitrogen fertilizer rate was applied.

Cooperator	Corn [1] Yield (0 kg N/ha)	Corn [2] Yield (Optimum)	N-Rate (Optimum)
	tonnes/ha		kg N/ha
Barrie	9.44	10.45	71
Blackler	5.73	9.22	52
Bousfield	8.06	ne	ne
Devries	5.51	8.61	65
Gredig	10.08	10.91	57
Hooker	6.86	10.90	116
MacMaster	10.07	10.72	20
Marshall	5.37	5.37	0
McRae	5.08	8.35	85
Perriman	4.64	8.70	104
Radstake	6.49	7.66	87
Robson	9.15	9.15	0
Duplicate red clover sites with manure			
Barrie	10.10	10.10	0
Radstake	6.59	7.40	19
Oilseed Radish	7.67	7.67	0

[1] Estimated yields at 0 N rate.

[2] Estimated most economical yield and corresponding N rate if Nitrogen/corn price ratio is 5.

ne Not estimated

Table 10. 1995 grain corn yields estimated for situations were no nitrogen was applied and were the economic optimum nitrogen fertilizer rate was applied.

Cooperator	Corn [1] Yield (0 kg N/ha)	Corn [2] Yield (Optimum)	N-Rate (Optimum)
	tonnes/ha		-- Kg N/ha --
Barrie	10.26	10.26	0
Bousfield	7.09	8.60	73
DeVries	8.97	10.77	115
Gammie	9.85	10.61	22
Gredig	5.82	8.15	123
Hooker-a	8.56	8.56	0
Hooker-b	8.80	8.80	0
MacMaster	10.71	10.71	0
McRae	9.08	11.23	23
Perriman	8.79	10.19	130
Radstake	9.02	9.52	16
Robson-a	8.65	11.33	50
Robson-b	6.97	8.89	26

[1] Estimated yields at 0 N rate.

[2] Estimated most economical yield and corresponding N rate if Nitrogen/corn price ratio is 5.

Table 11 and 12 illustrate the relative accuracy with which cooperators could predict their nitrogen fertilizer requirements using both planting time and side-dress time soil-nitrate testing. Due to the slow release (mineralization) of the nitrogen from the red clover, the nitrate soil test done at planting time usually detected much less nitrate-N in the soil than would eventually become available. This resulted in fertilizer recommendations which were too high. Soil sampling in early June in order to obtain a side-dress recommendation was generally much more accurate. If side-dress applications of N are impractical for a particular farm operation it appears that the producer should perform a planting-time sample and, in the case of a red clover cover crop, divide the recommendation by 2 in order to get a better estimate of the actual nitrogen required. This recommendation applies to situations where red clover was killed or incorporated late the previous fall and where corn planting occurs before mid-May.

Table 11. Relative accuracy of various methods of determining nitrogen requirements for corn following red clover based on 1994 demonstration sites.

	Actual N Required	Planting time Soil Nitrate Test Recommendation	Side-dress time Soil Nitrate Test Recommendation
	---------------------------- Kg N / ha	-------------------------------	
Average of 15 sites	55	114	69

Table 12. Relative accuracy of various methods of determining nitrogen requirements for corn following red clover based on 1995 demonstration sites.

Actual Nitrogen Required	Cooperator Estimate	Yield Expectation less 45 Kg ha^{-1}	Soil N-Test (Planting)	Soil N-Test (Side-dress)
-------------------------- Nitrogen rate (kg N/ha) -------------------------------				
45	75	110	85	30

In general corn required an average of 50 Kg N/ha of nitrogen fertilizer to produce the maximum economic yield on the 26 sites investigated in 1994 and 1995. Applying more nitrogen than this may have produced higher yields, but at a fertilizer cost that would have been greater than the value of the additional corn.

Applying nitrogen fertilizer at high rates on corn following red clover lowered profitability and generally left excessive soil nitrate in the soil at the end of the growing season (where it would be susceptible to leaching and ground-water contamination).