Appendix 4

Greenhouse Gas Mitigation Program for Canadian Agriculture
Soil Conservation Council of Canada

Demonstration and Awareness Activities

Final Report - April 2006

to

Ontario Greenhouse Gas Mitigation Committee

by

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Cover Crops for Carbon Sequestration and Nitrogen Management in Field Crops

Agriculture and Agri-Food Canada

Agriculture et Agroalimentaire Canada

Cover Crops for Carbon Sequestration and Nitrogen Management in Field Crops

Executive Summary

This report summarizes the results of an 18 site-year project designed to evaluate Cover Crop growth and soil/manure nitrogen (N) sequestration when established following wheat where manure was applied soon after harvest in August. The various sites were established in wheat stubble fields in August of 2003(6), 2004(6) and 2005(6) throughout the counties of Middlesex, Oxford, Perth and Wellington. Most sites evaluated a number of different Cover crops with the predominant Cover Crops being Oats, Oilseed Radish, Field Peas, Annual Ryegrass and Buckwheat. A "No Cover" treatment was the standard at each site. The general results and conclusions are as follows:

1. Application of manure associated with relatively high rates of ammonium N (over 50 kg-N/ha) often resulted in the doubling of non-legume Cover Crop growth (i.e. Oats, Oilseed Radish and Annual Ryegrass). The quantity of N in Cover Crop biomass was often doubled when manure with high rates of ammonium N was applied. Oats and Oilseed Radish were the most effective non-legume Cover Crop species with respect to growth and N sequestration with biomass N quantities often exceeding 80 kg-N/ha where manure associated with a relatively high rate of ammonium N was applied.
2. Applying manure associated with relatively low ammonium N rates (less than 50 kg-N/ha) did not significantly increase growth and N sequestration of Cover crops and there is little benefit to planting non-legume Cover crops when manure associated with low ammonium N rates was applied.
3. Field peas were successfully established at many of the sites. Peas often contained more N than did an Oat Cover crop, especially when manure was not applied. This is not surprising since peas are a legume and have the capacity to fix atmospheric N when soil N is not available. Peas may be a good Cover Crop choice when soil and/or manure N availability is not high. Peas also demonstrated an ability to sequester soil mineral N, but often did not reduce soil mineral N levels as low as Oat or Oilseed Radish.
4. Oat, Oilseed Radish and Pea Cover crops rarely reduced apparent fertilizer N requirement by more than 30 kg-N/ha where manure was applied the previous fall. The size of the apparent Cover Crop credit was usually comparable to values predicted by Ontario's Nutrient Management assumptions regarding the increase in manure N availability when Cover crops are planted following late summer applications of manure.
5. Potential economic returns for corn, determined by corn yield minus the costs of Cover Crop establishment and required fertilizer N, was rarely increased by use of a Cover crop. This suggests that at these sites, the increase in corn yield and/or reduction of fertilizer N requirements associated with use of Cover crops was not large enough to offset the added cost of establishing a Cover crop. There may be other indirect economic benefits, such as reduced erosion risk, but on these sites it appears that the use of Cover crops could not be economically justified when only taking into consideration corn yield response and reduction in fertilizer N requirements.
6. Cover crops demonstrated an ability to sequester large amount of manure and/or residual soil N when manure was applied in wheat stubble fields in August. Unfortunately, a relatively low amount of this Cover Crop N appeared to be transferred to the next corn crop. There is a need for research to determine the fate of apparent Cover Crop N that is not available to the next crop and the impact of this unutilized free Cover Crop N on production of Greenhouse Gases and potentials for leaching.

Cover Crops for Carbon Sequestration and Nitrogen Management in Field Crops

Final Report

Introduction

This project was initiated to evaluate the BMP for the value of various Cover Crop species to determine their ability to sequester soil nitrogen following cereal harvest where manure was applied. Red clover has been the predominate Cover Crop in Ontario under seeded to winter wheat and left to flourish following wheat harvest in mid summer. Producers have been experiencing poor Red Clover stands following winter wheat. This has been attributed to increasing yields of wheat having a greater competitive effect on the weak under seeded Red Clover crop.

This project set out to demonstrate the value or opportunities that may exist with Cover Crop species that are seeded following wheat harvest. The thinking is that the Cover Crops should help sequester manure applied nitrogen which is typically applied following wheat harvest. Application of manure at this time is not the best from the standpoint of making the applied manure nitrogen available to the succeeding corn crop, but has benefits in terms of suitability of soil for withstanding equipment stress, time available to the producer, ground suitable for incorporation amoung others.

Methodology

This project consisted of 18 sites located in Middlesex, Perth, Oxford and Wellington counties where the Cover crops were established in August of 2003(6), 2004(6) and 2005(6). Manure was applied in the middle of August and the various fall seeded Cover Crop species were established within 1 week of manure application. The Cover Crop species evaluated were: Annual Ryegrass, Buckwheat, Oats, Oilseed Radish, Peas, and Red Clover. Red clover was evaluated at five sites and was established by underseeding into the cereal crop in early spring prior to the fall establishment of the other annual Cover crops.

Sites were chosen with Farmer Cooperators who were interested in evaluating Cover Crops as a means of capturing more value for their applied manure in terms of reduced input costs in the succeeding corn crop and reduction in environmental losses associated with manure application in late summer following a winter wheat harvest.

Depending on the particular producer’s situation, Cover Crops were established following wheat either before or after a manure application. In most cases, all Cover Crops were evaluated in the presence and absence of applied manure. The types of manures, application methods and incorporation systems varied by cooperator. All the Cover Crops were seeded using typical seed drill equipment. Some were established in conventional tillage systems while others were no tilled. Evaluation of seeding methods other then drilling were not part of the project but will be considered in future work because of the impact of seeding method on success of establishment and system costs.

Assessments consisted of spring and fall soil N testing, Cover Crop biomass volume and Cover Crop N content. In some locations corn response to Cover Crop and manure treatment combinations was followed with and without commercial N fertilizer supplementation.

Figure 1. Various Late Summer Seeded Cover Crops Biomass Production by Mid Fall

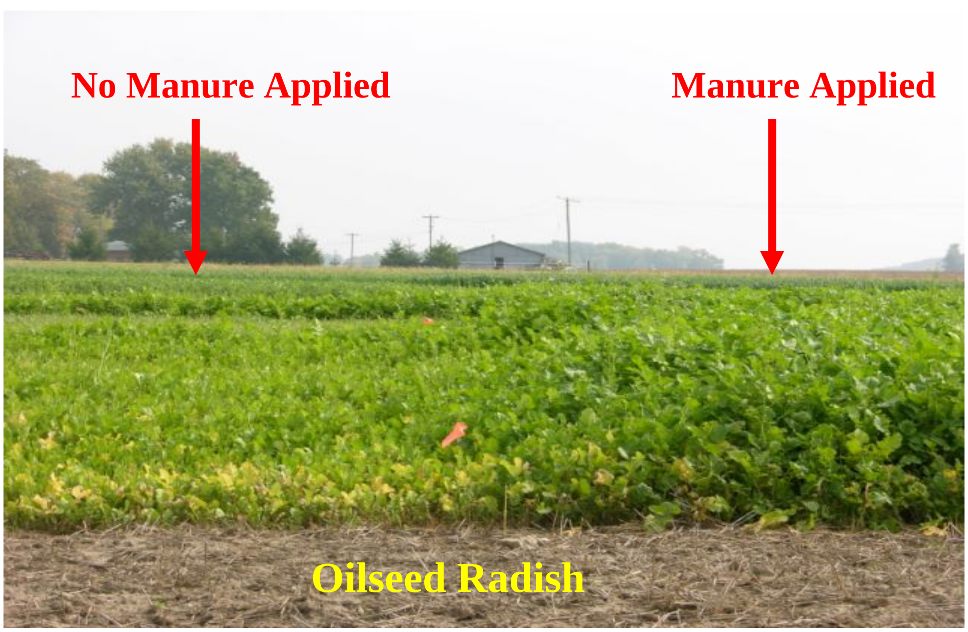

Figure 2. Impact of Manure Application on Biomass Growth of Oilseed Radish

The figures above provide an excellent snap shot of the types of Cover Crop growth that was achieved (Figure 1.) and the impact on Cover Crop growth by the application of manure either before or after planting (Figure 2.)

Results

Cover Crop Growth, N Sequestration, and Late Fall Soil Mineral N

The combination of Cover crops, manure types and application rates of readily available manure N were not the same across the various sites. However, at sites where fall seeded Cover crops were evaluated, an oat Cover Crop was always present. In order to minimize the effect that differences in the type and rate of manure had on individual Cover Crop responses, the average response for each Cover Crop was compared against the average response for Oats at the same site.

Annual Ryegrass

Annual ryegrass was evaluated at six sites with an average ammonium (NH4) application rate of 83 kg-N/ha (Range: 38 to 119 kg-N/ha) and an average total N application rate of 171 kg-N/ha (range: 101 to 243 kg-N/ha). Application of manure on average doubled annual ryegrass biomass production (Table 1). In comparison, manure application increased oat biomass by 50%. For both Cover crops, above ground biomass N was increased by 2.3 to 2.5 times compared to where manure had not been applied. Both Cover crops effectively reduced soil mineral N content in the surface 30cm by about 50%; with an actual reduction of 27 kg-N/ha where manure was not applied and 65 kg-N/ha where manure had been applied.

Buckwheat

Buckwheat was evaluated at four sites with an average NH4 application rate of 83 kg-N/ha (Range: 38 to 107 kg-N/ha) and an average total N application rate of 231 kg-N/ha (range: 149 to 366 kg-N/ha). Application of manure increased buckwheat biomass production by 30% (Table 1). In comparison, manure application increased oat biomass by 50%. The oat Cover Crop contained more above-ground biomass N than did buckwheat with application of manure increasing biomass N by 60% for buckwheat and doubling biomass N for Oats. Both buckwheat and Oats reduced late fall soil mineral N where manure was not applied by about 25 kg-N/ha. Where manure was applied, buckwheat reduced soil mineral N by 47 kg-N/ha (37%) while oat reduced soil mineral N by 62 kg-N/ha (53%).

Oilseed Radish

Oilseed Radish was evaluated at 15 sites with an average NH4 application rate of 79 kg-N/ha (Range: 8 to 173 kg-N/ha) and an average total N application rate of 177 kg-N/ha (range: 89 to 366 kg-N/ha). Oilseed Radish and oat Cover crops produced similar biomass in the presence and absence of manure (Table 1). Application of manure increased biomass production of both Cover crops, with an average biomass increase of 1.2 Mg/ha (68%) for Oilseed Radish and 0.8 Mg/ha (38%) for Oats. Both Cover crops contained similar biomass N with application of manure increasing average biomass N yield by 35 kg-N/ha (75%). Soil mineral N levels was reduced by both Cover crops where manure was applied, with an average reduction of 20 kg-

N/ha (30%). Where manure was applied, Oilseed Radish and Oats both reduced soil mineral N by about 45 kg-N/ha (48%).

Field Peas
Field Peas was evaluated at 13 sites with an average NH4 application rate of 86 kg-N/ha (Range: 19 to 173 kg-N/ha) and an average total N application rate of 192 kg-N/ha (range: 89 to 366 kg-N/ha). Manure application did not significantly increase field Pea biomass production or biomass N yields (Table 1). In contrast, manure application increased oat biomass at these sites by 0.9 Mg/ha (42%) and biomass N yields by 33 kg-N/ha (80%). On average, Oats reduced late fall soil mineral N to a greater extent than peas An oat Cover Crop reduced soil mineral N by 35 to 40% (23 to 42 kg-N/ha) while field peas reduced soil mineral N by 15-21% (10 to 21 kg-N/ha).

Red Clover
Red clover was evaluated at four sites with an average NH4 application rate of 38 kg-N/ha (Range: 8 to 87 kg-N/ha) and an average total N application rate of 149 kg-N/ha (range: 89 to 243 kg-N/ha). Manure application increased red clover biomass by 0.6 Mg/ha (29%) on average and biomass N yield by 22 kg-N/ha (38%) (Table 1.). In contrast, manure application at these sites increased oat biomass by 1.2 Mg/ha (67%) and biomass N yield by 37 kg-N/ha (115%). Red clover and Oats reduced late fall soil mineral N content similarly with reductions of 31 kg-N/ha (40%) where manure was not applied and 52 kg-N/ha (51%) where manure was applied.

Cover Crop Fall Nitrogen Sequestration Synopsis

On average, biomass production of annual ryegrass, buckwheat, Oats and Oilseed Radish was increased by application of manure (Table 1). However, biomass production of field peas was not significantly increased by application of manure. The lack of significant increase in field Pea biomass associated with manure application is not surprising since field peas can fix atmospheric N and therefore pea's ability to produce biomass in the absence of manure application would not be limited by the lack of available N.

When the various Cover crops were compared relative to the average response observed for Oats at the same sites, Oilseed Radish and annual ryegrass had similar biomass accumulation and N sequestration patterns as Oats (Table 1). Buckwheat biomass was not increased to the same extent as Oats when manure was applied and as a consequence was not able to sequester soil N as effectively as Oats. Although field peas were associated with reduced late fall soil mineral N content relative to where a Cover Crop was not established, where manure was applied the reduction in soil mineral N was not as great as where Oats was planted. This suggests that a field Pea Cover Crop may not be as effective at soil mineral N sequestration following manure application as an oat, and probably Oilseed Radish or annual ryegrass, Cover crop.

On the limited sites that evaluated red clover, it appeared that red clover was as effective as Oats at sequestration of soil mineral N following manure application.

The extent of Cover Crop yield increase associated with application of manure differed across sites. Cover Crop biomass production of the non legume Cover crops (annual ryegrass, buckwheat, Oats and Oilseed Radish) tended to have larger responses to applied manure when the application of manure was associated with relatively high rates of plant available N (i.e. Ammonium N). This effect usually occurred at sites that received liquid manure or poultry manure. Application of manure with relatively high amounts of plant available N had non-legume Cover Crop biomass increases that were as much as 2 to 3 times greater then where manure was not applied. Alternatively, Cover Crop biomass increases associated with application of manures with relatively low plant available N content (less 50 kg-N/ha of ammonium N) tended to be relatively small and often not significant. This tended to occur when low rates of manure were applied or following solid cattle manure.

Table 1. The effect of manure application on average Cover Crop biomass, above ground Cover Crop biomass nitrogen content and residual soil mineral N in the surface 30cm measured in early November (2-3 months after manure application). Comparisons are comprised of Cover Crop averages across sites compared to average responses for oats at the same sites.

	Soil Mineral N		Biomass		Biomass-N	
Cover Crop	**No Manure**	**Manure**	**No Manure**	**Manure**	**No Manure**	**Manure**
	--kg-N/ha--		**--Mg/ha--**		**--kg-N/ha--**	
Annual Ryegrass	45	57	1.32	2.55	31	79
Oats	46	58	1.92	3.07	39	87
No Cover	72	123				
se	3.9		0.130		3.8	
LSD(p=5%)+	11		0.38		11	
Buckwheat	52	73	2.05	2.64	37	63
Oats	47	54	2.38	3.57	49	98
No Cover	75	116				
se	8.4		0.096		4.5	
LSD(p=5%)	24		0.28		13	
Oilseed Radish	45	45	1.81	3.05	44	82
Oats	42	50	2.17	3.00	46	78
No Cover	64	93				
se	3.3		0.112		3.6	
LSD(p=5%)	9		0.31		10	
Field Peas	58	75	2.23	2.31	82	92
Oats	45	54	2.08	2.96	41	74
No Cover	68	96				
se	4.2		0.115		4.1	
LSD(p=5%)	12		0.32		11	
Red Clover	45	51	2.11	2.71	57	79
Oats	42	50	1.83	3.05	32	69
No Cover	75	103				
se	7.7		0.192		4.3	
LSD(p=5%)	22		0.58		13	

+Least Significant Difference at the 5% level of probability.

Field pea Cover crops demonstrated an ability to accumulate above ground biomass N contents that was over 100 kg-N/ha by early November. Similarly, oat and Oilseed Radish Cover crops also demonstrated an ability to accumulate up to 80 - 100 kg-N/ha in the above ground biomass by early November; provided that they were seeded where a manure with relatively high plant available N was applied.

Corn response to Cover crops and manure application

For a Cover Crop to be truly effective in reducing manure N contribution to greenhouse gas formation there must be an effective (or efficient) transfer of Cover Crop biomass N to a succeeding crop. Corn response to Cover crops and manure application was evaluated in 2004 and 2005 on six of the sites where Cover Crop response to manure was evaluated in the fall of 2003 and 2004. The plots were split so that two rates of fertilizer N could be applied in order to better evaluate the N contribution of the various Cover crops and manure treatments to corn. The corn response will be discussed separately for each site.

Liquid Dairy Manure
Corn yield response to Cover Crop and liquid dairy manure was evaluated on a silt loam soil (OM 3.6%) near Embro, Oxford County. Soil-test K was 171 ppm in 2004 and 121 ppm in 2005 and plant-available P was 35 ppm in 2004 and 41ppm in 2005; therefore yield responses to manure application were likely not due to application of these nutrients when manure was applied.

For both sites, liquid dairy manure was applied at 2 rates with the higher rate two times greater than the low rate. The manure was not incorporated in either year and the Cover crops were seeded soon after application in 2003. In 2004 the manure was applied into standing Cover crops. In late summer of 2003 the low rate of dairy manure at 37.5 kl/ha supplied 101 kg-N/ha of ammonium and 265 kg-N/ha of total N. According to Ontario nutrient management assumptions, plant available N provided to the 2004 corn crop from the low rate was 71 kg-N/ha without a Cover and 85 kg-N/ha with a Cover crop. In late summer of 2004 the low rate of liquid dairy manure was 40.2 kl/ha which supplied 72 kg-N/ha ammonium and 109 kg-N/ha total N. According to Ontario nutrient management assumptions, plant available N for the low rate of manure to the 2005 corn crop was 35 kg-N/ha with a Cover Crop and 30 kg-N/ha without a Cover crop.

Application of fall manure generally increased spring soil nitrate N levels in the surface 30cm at the Embro sites; especially in the May and/or June sampling dates (Table 2). Where manure had been applied the soil nitrate N concentrations were most affected by Cover Crops at the May sampling dates suggesting that significant amounts of Cover Crop N may have been released in late April or early May at these sites. By early June, differences in soil N concentrations between the No Cover and Cover Crop treatments were less than for the May sampling date. The soil nitrate N concentrations above 20 ppm in both years where the manure was applied consistently. Based on pre sidedress (June) soil nitrate N values, Cover crops did not appear to significantly enhance N availability to corn.

Table 2. Manure application effects on Cover Crop biomass N, apparent fertilizer N required to optimize corn yield and the relative efficiency of biomass N to reduction in corn fertilizer requirements for sites where corn response was evaluated the following year.

Site	Cover Crop	No Manure			Manure Normal Rate			Manure High Rate		
		Biomass N	Fertilizer N Requirement	Efficiency	Biomass N	Fertilizer N Requirement	Efficiency	Biomass N	Fertilizer N Requirement	Efficiency
		kg-N/ha	kg-N/ha		kg-N/ha	kg-N/ha		kg-N/ha	kg-N/ha	
Embro 2005	No Cover		91			63			45	
	Oats	32	56	1.10	44	52	0.24	58	0	0.78
	Oilseed Radish	26	79	0.46	40	53	0.25	55	59	-0.25
	Peas	71	55	0.50	66	40	0.34	71	21	0.34
	LSD (p=5%)	25								
Embro 2004	No Cover		99			71			69	
	Oats	48	76	0.50	64	35	0.56	84	14	0.66
	Oilseed Radish	54	54	0.84	72	52	0.26	101	27	0.42
	Peas	47	110	-0.22	53	26	0.85	68	1	1.00
	LSD (p=5%)	27								
Mitchell 2004	No Cover		51			66				
	Oats	39	85	-0.86	55	32	0.61			
	Oilseed Radish	39	102	-1.31	57	87	-0.36			
	Peas	33	36	0.46	50	39	0.54			
	LSD (p=5%)	28								
St. Mary's 2004	No Cover		71			5				
	Buckwheat	24	45	1.06	27	29	-0.87			
	Oats	20	89	-0.90	39	28	-0.58			
	Oilseed Radish	19	69	0.09	27	49	-1.60			
	Peas	76	0	0.93	103	62	-0.55			
	LSD (p=5%)	19								
Lucan 2005	No Cover		90			79				
	Oats	18	127	-1.99	30	106	-0.89			
	Oilseed Radish	23	80	0.43	16	87	-0.50			
	Red Clover	47	48	0.89	67	67	0.18			

+ Apparent fertilizer N requirement to optimize corn yields is based on corn price of $3.36/bu and N cost of $0.45/lb-N (price ratio 7.5).
++ Efficiency calculation is biomass N/reduction in fertilizer N relative to No cover.
+++ Least Significant Difference at the 10% level of probability.

Application of manure increased corn yields in both years even when 170 kg-N/ha of fertilizer N was applied with an average yield increase of 1.2 Mg/ha (13%) in 2004 and 0.5 Mg/ha (4%) in 2005 (Figure 3).

The use of Cover crops reduced the yield response to fertilizer nitrogen (FN) in both years (Fig. 1). When manure was not applied, fertilizer N requirement at these sites ranged from 90 to 100 kg-N/ha with Oat and Oilseed Radish Cover crops reducing apparent FN requirement by 25 to 40 kg-N/ha (Table 3). Field peas did not consistently reduce fertilizer N requirements where manure was not applied.

When high rates of manure were applied, using either an Oat or pea Cover Crop minimized the need for significant amounts of FN to optimize yields in both years The estimated FN requirement was less than 20 kg-N/ha following a pea or Oat Cover Crop when the high rates of dairy cattle manure were applied (Table 3). Similar trends were observed for the low manure rate with a slightly greater requirement for FN to optimize yields. Use of either pea or Oat Cover crops when manure was applied reduced apparent FN requirements by, on average, 40 kg-N/ha relative to where a Cover Crop was not established. The reduction in FN requirements by Oat or pea Cover crops was somewhat comparable to those predicted by Ontario Nutrient Management Available N Assumption.

Oilseed Radish did not as consistently reduce apparent FN requirements at these sites when manure was applied compared to either Oats or Oilseed Radish (Table 3). Corn yields without

FN following Oilseed Radish were usually the lowest of the three Cover crops (Figure 3), suggesting that N availability following Oilseed Radish tended to be lower than either Oats or peas.

Liquid Hog Manure
Corn response to Cover crops and liquid hog manure was evaluated on a silt loam soil (5.3% OM) near Mitchell, Perth County. Soil-test K was 163 ppm and plant-available P was 61 ppm; therefore yield responses to manure application were likely not due to application of these nutrients when manure was applied.
Liquid hog manure was applied at 37.3 kl/ha supplying rates of 95 kg-N/ha ammonium and 101 kg-N/ha of total N. Estimated plant-available N to the next corn crop was 20 kg-N/ha where a Cover Crop was not established and 35 kg-N/ha where a Cover Crop was present. Manure was not incorporated and Cover crops were seeded soon after manure application.

Spring soil nitrate-N concentrations increased with later spring sample dates. The use of either an Oat or Oilseed Radish Cover Crop had little effect on soil nitrate-N concentrations for each of the dates (Table 2). Concentrations following peas were evaluated only in June with the highest June soil nitrate-N concentration measured for peas where manure was applied. Generally, June soil nitrate-N concentrations exceeded 20 ppm at this site; suggesting that N availability was close to sufficiency regardless of the Cover Crop and manure treatment.

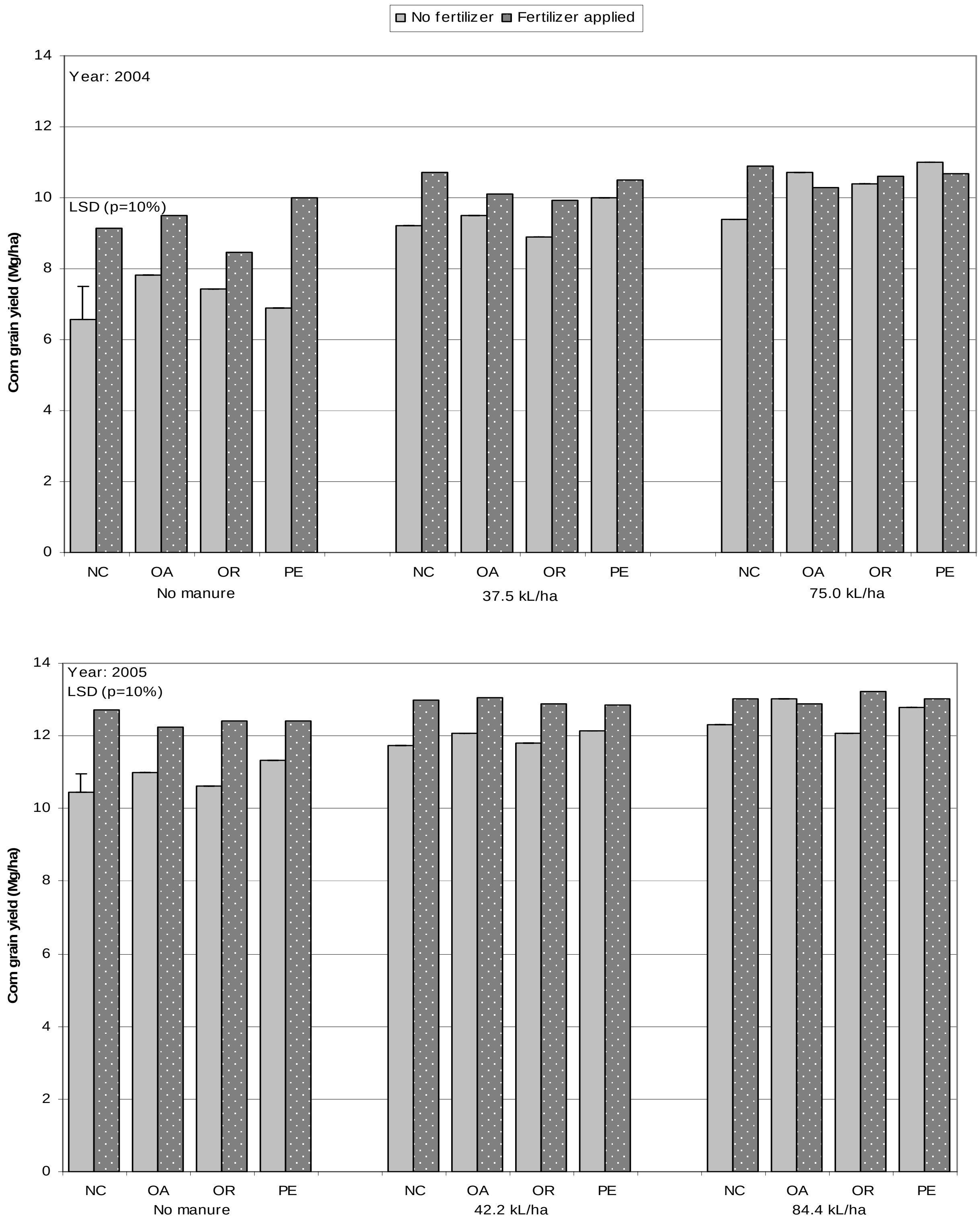

Figure 3. Corn yield response to application of liquid dairy cattle manure, Cover crops, and 170 kg-N/ha nitrogen fertilizer on silt loam soil near Embro, Oxford County (2004-2005). Cover crops evaluated were Oats(OA), Oilseed Radish(OR), Field Peas(PE), and No Cover Crop(NC).

Application of liquid hog manure increased corn yield even with the high rate of fertilizer with an average yield increase of 0.6 Mg/ha (7%) (Figure. 4). Apparent FN requirements to optimize yields without a Cover Crop were about 50 to 65 kg-N/ha, with application of manure not significantly reducing apparent FN requirement (Table 3). Apparent FN requirements following peas were slightly lower at about 35 to 40 kg-N/ha; an effect that occurred when manure was and was not applied.

Table 3. Manure and Cover Crop effect on spring soil nitrate-N concentration (ppm) in the surface 30 cm on sites that were seeded to corn in 2004 and 2005.

Site	Cover Crop	No Manure	Manure	No Manure	Manure	No Manure	Manure
		April 21, 2004		May 19, 2004		June 11, 2004	
Embro, 2003-2004	No Cover	6.4	9.7	9.8	13.3	15.0	26.6
	Oilseed Radish	7.2	10.4	10.6	16.3	13.3	26.2
	se	1.35		1.99		3.47	
	LSD(P=0.10)	4.0		5.8		10.1	
		April 13, 2005		May 11, 2005		June 8, 2005	
Embro, 2004-2005	No Cover	11.6	12.9	10.3	12.3	22.5	23.0
	Oats	12.5	11.7	16.4	18.7	24.2	24.9
	Oilseed Radish	10.1	12.4	15.4	23.5	23.8	27.2
	Peas	12.6	14.7	18.6	28.9	24.0	24.6
	se	1.88		3.13		1.50	
	LSD(P=0.10)	4.4		7.4		3.5	
		April 29, 2004		May 19, 2004		June 11, 2004	
Mitchell, 2003-2004	No Cover	8.5	7.8	13.0	13.7	20.2	20.9
	Oats	9.9	8.5	13.1	15.2	22.6	23.8
	Oilseed Radish			14.7	14.5	19.3	23.6
	Peas					21.4	27.0
	se	1.81		1.78		2.93	
	LSD(P=0.10)	5.3		5.2		6.9	
		April 13, 2005		May 11, 2005		June 9, 2005	
St. Mary's, 2004-2005	No Cover	13.7	11.4	12.0	13.9	21.3	18.1
	Oats	13.3	10.1	13.8	16.4	16.2	17.1
	Oilseed Radish	13.0	12.4	16.2	16.2	18.5	22.4
	Peas	14.5	13.2	18.3	18.2	23.6	24.4
	se	1.50		1.41		3.20	
	LSD(P=0.10)	2.8		3.0		7.5	
		April 27, 2005		May 18, 2005		June 9, 2005	
Lucan, 2004-2005	No Cover	16.5	15.3	14.6	18.7	15.5	19.8
	Oats	14.3	15.4	15.8	18.8	14.8	19.8
	Oilseed Radish	16.5	13.2	20.8	20.4	21.9	17.6
	Red Clover	15.7	15.3	14.9	14.2	20.3	23.1

Least Significant Difference at the 10% level of probability.

The use of either Oat or Oilseed Radish Cover crops following manure increased corn yield without fertilizer by 0.9 Mg/ha (Figure.4). Assuming whole plant N content of 1%, a 0.9 Mg/ha grain yield increase equates to about 15 kg-N/ha which is comparable to the increase in available N predicted by Ontario Nutrient Management assumptions.

Oilseed Radish did not reduce apparent FN requirements at this site (Table 3). Where manure was applied, corn planted following Oilseed Radish with fertilizer N produced higher yields than the other Cover Crop treatments, which probably accounts for high FN requirements following Oilseed Radish.

Corn response to liquid hog manure applied into red clover was also evaluated on a loam (3.5% OM) near Princeton, Oxford County. Soil-test K was 92 ppm and plant-available P was 4 ppm. Liquid Hog manure was applied at 28 kl/ha which supplied 86 kg-N/ha of ammonium and 163 kg-N/ha of total N. Estimated plant-available N to the next corn crop was 33 kg-N/ha without a Cover Crop and 57 kg-N/ha when applied into red clover.

Corn yields without fertilizer nitrogen were 6.6 Mg/ha without manure and 8.7 Mg/ha with manure. Application of 150 kg-N/ha of FN increased yield to 8.6 Mg/ha (30%) without manure and 10.6 Mg/ha (22%) with manure. The yield response to FN was similar between manure treatments with an estimated apparent FN requirement of 85 kg-N/ha. The large yield responses associated with manure application were probably due to P and K additions from the manure since soils were at low enough levels of these nutrients where yield responses to P and K additions could be expected. Also, similar yield responses to FN between manure treatments suggest that the addition of manure N did not enhance N availability to corn over what the red clover could have provided without manure.

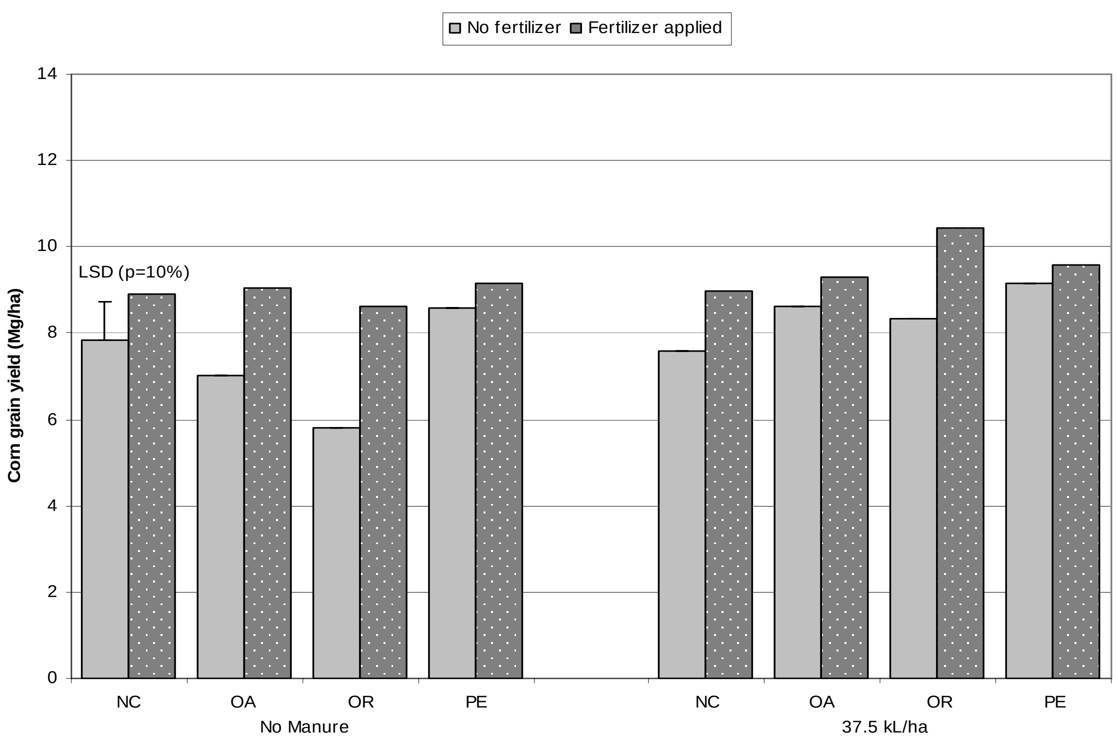

Figure 4. Corn yield response to application of liquid hog manure, Cover crops, and 170 kg-N/ha nitrogen fertilizer on silt loam soil near Mitchell, Perth County (2004). Cover crops evaluated were Oats(OA), Oilseed Radish(OR), Field Peas(PE), and No Cover Crop(NC).

Solid Beef Manure
Corn response to Cover crops and solid beef cattle manure was evaluated on a silt loam soil (3.0% OM) near St. Mary's, Perth County. Soil-test K was 146 ppm and plant-available P was 12 ppm; therefore yield responses to manure application were likely not due to the manure available K when manure was applied.

Solid beef manure was applied at 96 Mg/ha which supplied 91 kg-N/ha of ammonium and 366 kg-N/ha of total N. Estimated plant-available N to the next corn crop was 99 kg-N/ha where No Cover Crop was established and 109 kg-N/ha where a Cover Crop was been established.

Spring soil nitrate-N concentrations at the St. Mary's' site also increased with later spring sampling dates. The highest spring soil nitrate N concentrations where found in May and June following peas which tended to be higher than after Oats (Table 2). June soil nitrate-N concentrations were relatively high, especially following Oilseed Radish and peas which suggested that native N availability was sufficiently high to almost completely meet corn requirements.

Application of solid beef manure did not influence corn yields when the high rate of fertilizer N was applied (Figure. 5). The apparent fertilizer nitrogen requirement to optimize corn yields without a Cover Crop was about 70 kg-N/ha when no manure was applied (Table 3). Manure application did not affect corn yields of the "No Cover" treatments when fertilizer was not applied, but yields with nitrogen and manure were 1.6 Mg/ha lower than No Cover yields without manure and with fertilizer N. The low "No Cover" yields with manure and fertilizer N probably are not representative and provide a false indication of the FN requirement estimate presented in Table 3. When manure was applied, corn grain yields without fertilizer N were essentially the same suggesting that Cover crops did not apparently increase N availability where manure was applied.

Corn response to Cover crops and solid beef cattle manure was also evaluated on a silt loam soil (4.3% OM) near Lucan, Middlesex County. Soil-test K was 204 ppm and plant-available P was 26 ppm; therefore yield responses to manure application were likely not due to application of these nutrients in the manure was applied.

Solid beef manure was applied at 25 Mg/ha which supplied 9 kg-N/ha ammonium and 124 kg-N/ha of total N. Estimated plant-available N to the next corn crop was 33 kg-N/ha and was not significantly affected by planting a Cover crop. This site consisted of only 1 replication and therefore any comparisons can not be statistically justified.

There was a tendency for lower soil nitrate concentrations following Oats when compared to the other Cover Crop treatments (Table 2). Otherwise, there were No significant differences in tendencies among Cover Crop and manure treatments.

Table 3. Manure and Cover Crop effect on spring soil nitrate-N concentration (ppm) in the surface 30 cm on sites that were seeded to corn in 2004 and 2005.

Site	Cover Crop	No Manure	Manure	No Manure	Manure	No Manure	Manure
		April 21, 2004		May 19, 2004		June 11, 2004	
Embro, 2003-2004	No Cover	6.4	9.7	9.8	13.3	15.0	26.6
	Oilseed Radish	7.2	10.4	10.6	16.3	13.3	26.2
	se	1.35		1.99		3.47	
	LSD(P=0.10)	4.0		5.8		10.1	
		April 13, 2005		May 11, 2005		June 8, 2005	
Embro, 2004-2005	No Cover	11.6	12.9	10.3	12.3	22.5	23.0
	Oats	12.5	11.7	16.4	18.7	24.2	24.9
	Oilseed Radish	10.1	12.4	15.4	23.5	23.8	27.2
	Peas	12.6	14.7	18.6	28.9	24.0	24.6
	se	1.88		3.13		1.50	
	LSD(P=0.10)	4.4		7.4		3.5	
		April 29, 2004		May 19, 2004		June 11, 2004	
Mitchell, 2003-2004	No Cover	8.5	7.8	13.0	13.7	20.2	20.9
	Oats	9.9	8.5	13.1	15.2	22.6	23.8
	Oilseed Radish			14.7	14.5	19.3	23.6
	Peas					21.4	27.0
	se	1.81		1.78		2.93	
	LSD(P=0.10)	5.3		5.2		6.9	
		April 13, 2005		May 11, 2005		June 9, 2005	
St. Mary's, 2004-2005	No Cover	13.7	11.4	12.0	13.9	21.3	18.1
	Oats	13.3	10.1	13.8	16.4	16.2	17.1
	Oilseed Radish	13.0	12.4	16.2	16.2	18.5	22.4
	Peas	14.5	13.2	18.3	18.2	23.6	24.4
	se	1.50		1.41		3.20	
	LSD(P=0.10)	2.8		3.0		7.5	
		April 27, 2005		May 18, 2005		June 9, 2005	
Lucan, 2004-2005	No Cover	16.5	15.3	14.6	18.7	15.5	19.8
	Oats	14.3	15.4	15.8	18.8	14.8	19.8
	Oilseed Radish	16.5	13.2	20.8	20.4	21.9	17.6
	Red Clover	15.7	15.3	14.9	14.2	20.3	23.1

Least Significant Difference at the 10% level of probability.

When manure was not applied and No Cover Crop was planted, the apparent fertilizer requirement at this site was 90 kg-N/ha (Table 3). Application of manure had little effect on apparent FN requirements without a Cover Crop. Corn planted following Oat and Oilseed Radish Cover Cops without FN generally did not produce yields that were significantly greater than the No Cover treatment (Figure 6); therefore it can be concluded that N contribution from Oats or Oilseed Radish Cover Crops at this site also were small. Red Clover did increase corn yields over the No Cover treatment when no fertilizer was applied; but this effect only occurred where no manure was applied.

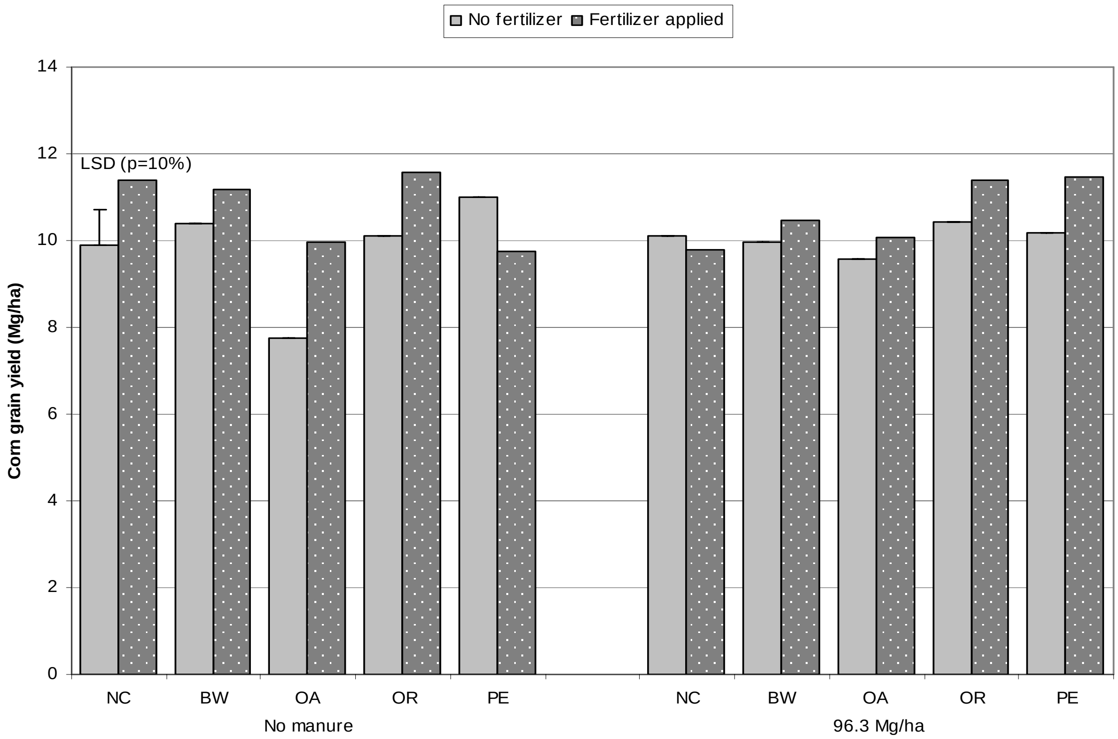

Figure 5. Corn yield response to application of solid beef cattle manure, Cover crops, and 170 kg-N/ha nitrogen fertilizer on silt loam soil near St. Mary's, Perth County (2005). Cover crops evaluated were buckwheat (BW), oats (OA), Oilseed Radish (OR), field peas (PE), and No Cover Crop (NC).

Economic Returns by Cover Crops

A simple economic analysis was conducted at the 5 sites that evaluated multiple Cover Crops and were followed by corn. Oat and Oilseed Radish Cover Crops were evaluated at each of these 5 sites and Field Peas at 4 of the sites. The economic analysis consisted of calculating the value of the corn yield obtained on the manure and Cover Crop treatments at the various sites and deducting the cost of the maximum economic rate of nitrogen (MERN) and cost of establishing the Cover Crop. The base scenario assumed a corn price of $132/Mg, corn fertilizer cost of $0.99/kg-N, a fertilizer application cost (when required) of $24.70/ha ($10.00/ac) and a cost of establishing the various Cover Crops as outlined in Table 4. Three other scenarios were also calculated including:

1) a 50% reduction in seeding of Cover Crop;
2) 50% increase in corn price ($198/Mg) and
3) a 50% increase in price of fertilizer N ($1.49/kg-N).

Since sites that received liquid manure (Embro and Mitchell) had slightly different yield responses to manure and Cover Crops than did the solid manure sites (Lucan and St. Mary's'), the economic analysis was averaged across sites based on the type of manure applied. Cover Crop effects on net returns could not be declared significant at a probability level of 10%.

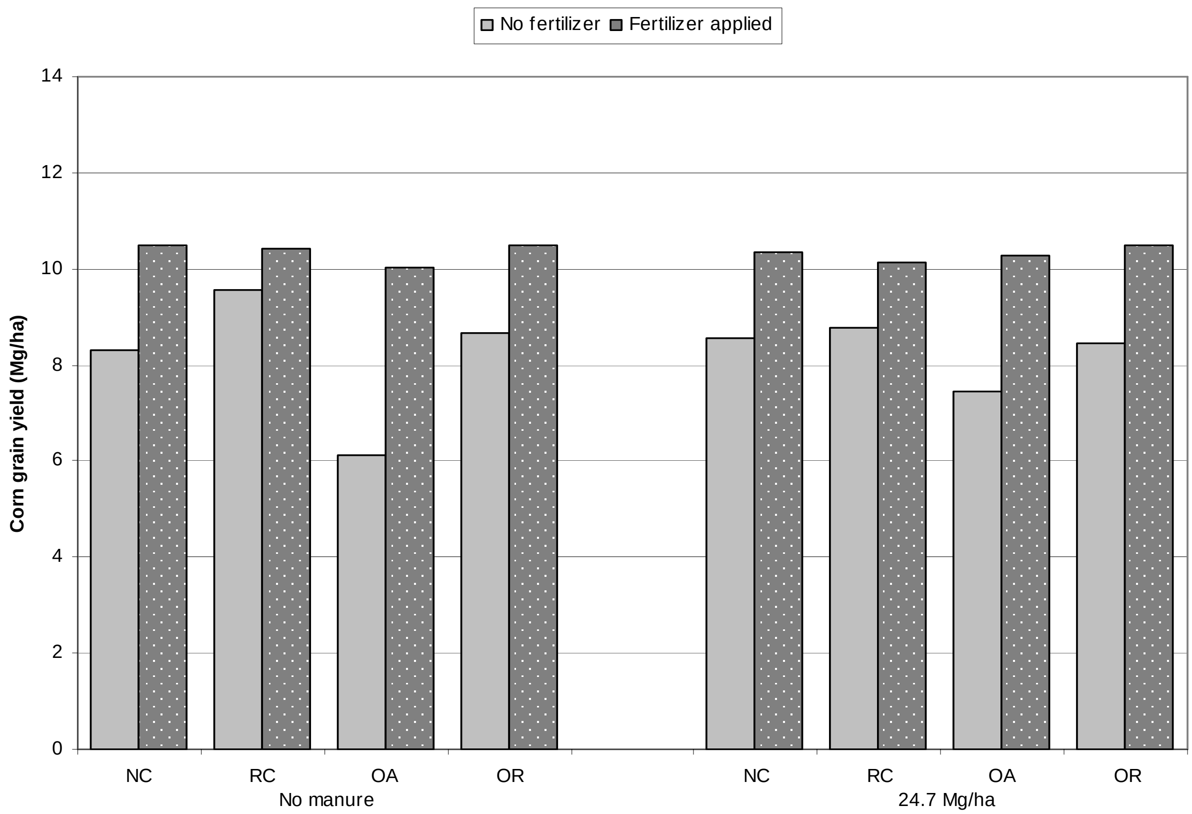

Figure 6. Corn yield response to application of solid beef cattle manure, Cover crops, and 170 kg-N/ha nitrogen fertilizer on silt loam soil near Lucan, Middlesex County (2005). Cover crops evaluated were red clover (RC), oats (OA), Oilseed Radish (OR), and No Cover Crop (NC).

Table 4. Seeding rates and costs associated with Cover Crop establishment.

Cover Crop	Seeding Rate kg/ha	Seed $/kg	Planting $/ha	Total $/ha
No Cover	0	0.00	0.00	0.00
Oats	78	0.21	37.05	51.87
Oilseed Radish	11	2.47	37.05	61.75
Peas	50	0.74	37.05	70.40

The higher yields associated with applying liquid manure on the Embro and Mitchell sites (Figures. 3 and 4) increased returns (after FN costs are deducted) by about 6% (Table 5). The No Cover treatment returns presented in Table 5 are the actual value of the grain corn yield less the cost associated with the purchase and application of FN. The relative increase in economic returns was relatively stable across the two scenarios which altered corn price or N cost with application of manure increasing net returns by 6 to 7%.

Table 5. Cover Crop and manure effects on net returns for corn.

Manure	**Cover Crop**	**Corn: \$132/Mg Nitrogen: \$0.99/kg-N Est. Cost: Full**	**Corn: \$132/Mg Nitrogen: \$0.99/kg-N Est. Cost: Half**	**Corn: \$199/Mg Nitrogen: \$0.99/kg-N Est. Cost: Full**	**Corn: \$132/Mg Nitrogen: \$1.49/kg-N Est. Cost: Full**
Liquid		**\$/ha**			
None	No Cover	1258.69	1258.69	1939.72	1220.94
	Oats	-55.98	-30.04	-61.02	-51.60
	Oilseed Radish	-133.25	-102.37	-167.62	-131.84
	Peas	-37.68	-2.48	-25.65	-30.56
Applied	No Cover	1338.80	1338.80	2055.35	1308.39
	Oats	-28.06	-2.12	-35.83	-15.23
	Oilseed Radish	-29.82	1.05	-16.33	-28.74
	Peas	-2.02	33.18	14.20	16.97
	se	28.25	28.25	42.70	28.23
Solid		**\$/ha**			
None	No Cover	1333.42	1333.42	2054.24	1296.04
	Oats	-206.71	-180.78	-270.48	-220.37
	Oilseed Radish	-45.62	-14.74	-40.47	-42.69
Applied	No Cover	1290.77	1290.77	1967.56	1278.10
	Oats	-86.50	-60.57	-91.45	-105.05
	Oilseed Radish	-7.58	23.30	35.74	-25.80
	se	35.69	35.69	55.23	37.62

+ No Cover returns are the value of the corn grain yield less the cost associated with applying the MERN rate of fertilizer nitrogen.
++ The returns for the Cover Crop treatments are the difference in returns relative to No Cover after accounting for the cost of applying the MERN rate of fertilizer N and Cover Crop seeding costs described in Table 4.

The return values associated with the Cover Crop treatments are the increase in returns associated with the Cover Crop relative to the No Cover treatment. Comparisons of Cover Crops were made against the No Cover treatment that received the same rate of manure and a negative return suggests that there was a net loss associated with use of Cover Crops.

Without the application of liquid manure, clearly use of an Oat or Oilseed Radish Cover Crop resulted in a loss of returns (Table 5). The Pea Cover Crop was the only Cover Crop which came close to breaking even economically, however seeding costs would need to be 50% less than those suggested in Table 4.

Even when liquid manure was applied there was a loss of net returns associated with Oat and Oilseed Radish Cover Crops; however the extent of the loss was not as great as when manure was not applied. The use of a Pea Cover Crop was generally not associated with a loss of returns, however the profitability of this Cover Crop is more dependant on reduction in seeding costs rather than a change in FN costs.

Application of solid cattle manure did not increase net returns where a Cover Crop was established, regardless of the scenario (Table 5). An Oat Cover Crop was generally associated with greater loss in net revenue than an Oilseed Radish Cover Crop. The Oilseed Radish Cover Crop established under a lower seeding costs scenario, or with higher corn price, actually resulted in a slight increase in the calculated net revenue over the No Cover treatment when manure was applied.

Fall Residual Soil N Following Corn.

End of season soil testing in the corn crop clearly demonstrated that failing to reduce FN rates following manure and/or Cover Crops can result in unacceptably high soil N concentrations in the fall. Figure 7 shows that soil mineral N concentrations do not increase when FN application rates are less than what is needed to optimize corn yields (represented as a negative N application rate). However, once application rates exceed corn crop requirements the soil mineral N levels increase. Figure 7 demonstrates that producers failing to reduce FN rates following manure application and/or some Cover Crops which enhance N availability can result in unacceptably high residual soil mineral N levels at the end of the growing season. This unutilized (or residual) soil N is subject to loss into the environment as nitrogenous greenhouse gases under situations resulting in denitrification and/or through leaching in the absence of a living crop.

Synopsis of Corn Response

Generally, enhancement of manure N contribution to the next corn crop was relatively small and rarely exceeded 40 kg-N/ha. This level of enhancement from manure N contribution to the next crop is comparable to those calculated by Ontario's Nutrient Management assumptions for a late summer manure application followed by an actively growing fall Cover Crop. In this scenario the calculated enhancement of manure N availability is rarely assumed to exceed 30 kg-N/ha. Cover Crops rarely increased yields, or reduced N requirements, sufficiently to cover seeding costs. Only the Pea Cover Crops demonstrated a potential for higher net returns, but only when relatively low seeding costs are assumed and FN requirements are precisely estimated.

This study indicates that further work is required to evaluate the economic and environmental impact of using Cover Crops to minimize manure N losses to the environment. Cover Crops exhibited a much larger capacity to sequester available manure N in the fall when compared to the amount of that N which was apparently made available for corn uptake the next season.

The fate of the Cover Crop N that is not taken up by the next corn crop is unclear and requires further investigation. It is important to determine the potential environmental fate of the apparently unutilized Cover Crop biomass-N. Is there a significant potential for N leaching into ground water and/or volatilization as greenhouse gasses?

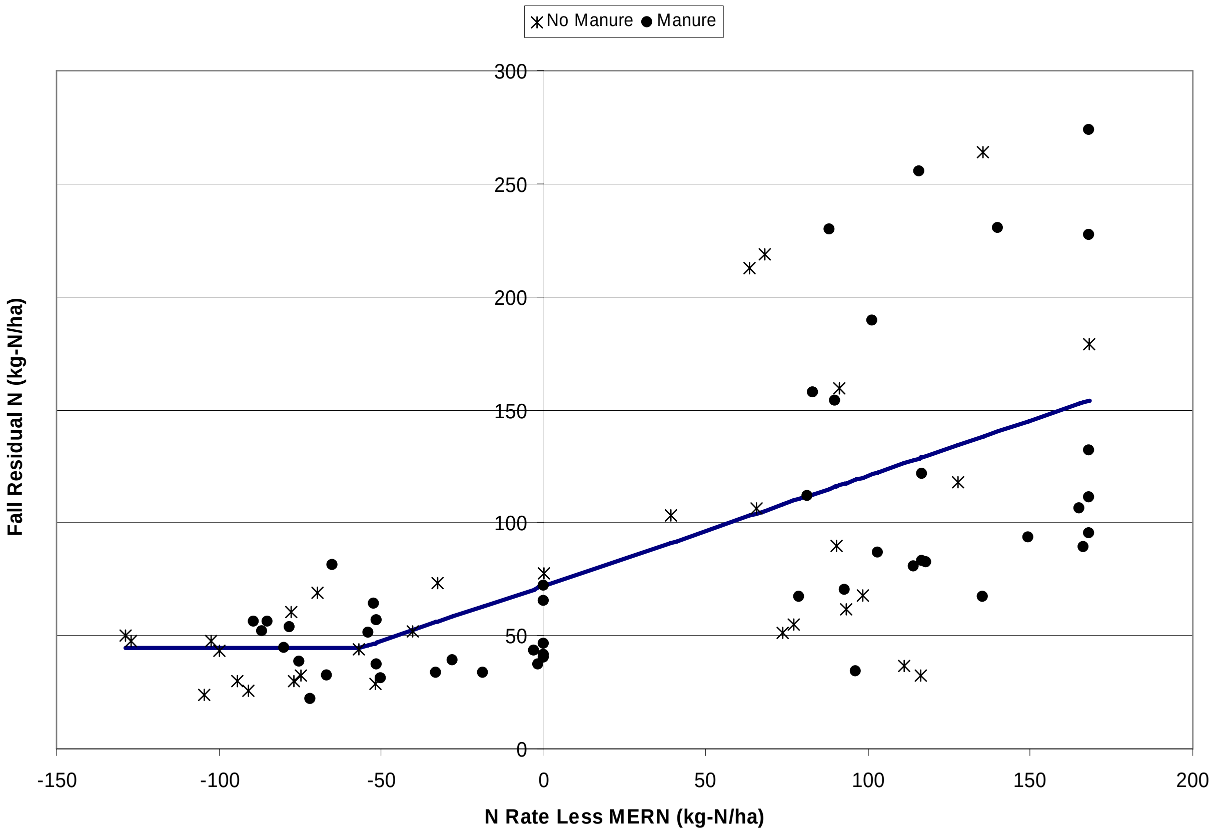

Figure 7. The effect of applying fertilizer nitrogen rates to corn over MERN on fall residual soil nitrogen in the surface 30 cm for the sites seeded to corn in 2004.

Since the economic return to the use of Cover Crops in these tests failed to cover the economic costs of establishment, it will be difficult to persuade producers to adopt the use of Cover Crops based solely on the ability to capture easily identifiable economic gain. There are other long term benefits to the use of Cover Crops but in the absence of defined dollar values to include in the equation it makes the decision difficult to defend. However, more work to define these benefits including soil health, soil water holding capacity, reduced susceptibility to erosion, reduced weed competition, improved organic matter may come in time.

An additional societal consideration is the environmental benefit that the results suggest in terms of draw down of fall soil N levels and potentially reduced rates of commercial fertilizers. Taking these factors into account may suggest that governments should financially encourage the use of Cover Crops by farmers for overall societal benefit as is done in Britain and other European countries.