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**Cost efficient Tillage and Rotation options for Mitigating GHG Emissions from
Agriculture in Eastern Canada**

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Poster

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Abstract

The economic efficiency of cropping options to mitigate GHG emissions with agriculture in Eastern Canada was analyzed. Data on yield response to tillage (moldboard plow and chisel plow) and six corn based rotations were obtained from a 20-year field experiment in Ontario. Budgets were constructed for each cropping system while GHG emissions were measured for soil carbon and were estimated for nitrous oxide according to IPCC methodology. Complex crop rotations with legumes, such as corn-corn-soybeans-wheat with red clover underseeded, have higher net returns and substantially (more than $1 \text{ Mg ha}^{-1} \text{ year}^{-1}$) lower GHG emissions than continuous corn. Reduced tillage reduces GHG emissions due to lower input use but no sequestration effect could be found in the soil from tillage. Rotation had a much bigger effect on the mitigation potential of GHG emissions than tillage. However, opportunity costs of more than \$200 per $\text{Mg CO}_2 \text{ eq ha}^{-1} \text{ year}^{-1}$ indicate the limits to increase the mitigation potential beyond the level of the economic best cropping system.

1. Introduction

The integration of legumes into cropping systems can reduce the reliance of cropping systems on non-renewable resources and therefore potentially reduce the use of such inputs along with GHG-emissions. Increasing energy prices may increase the competitiveness of legumes compared to other crops, which rely more on nitrogen fertilizer and energy inputs. However, the integration of legumes has complex effects on cropping systems in terms of carbon sequestration in the soil (Yang and Kay, 2001), yield of following crops (Raimbault and Vyn, 1991), and fluxes of C and N in the soil (Drinkwater et al., 1998). The aim of this paper is to analyze the profitability and GHG mitigation potential of integrating legumes into corn-based rotations for conditions in Eastern Canada. The legumes considered are soybeans, alfalfa and red clover underseeded into wheat or barley.

2. Material and Methods

The data for this study were taken from an experiment established in 1980 at the University of Guelph. Average annual rainfall for the region is 800mm with rainfall distribution

approximately uniform over the year. Average monthly temperatures for January, April and July are -4.7 , 8.3 and 22.2°C , respectively.

The experiment provides data on crop and soil response to two levels of tillage and seven different corn-based crop rotations. An eighth rotation consisted of continuous alfalfa. Aside from continuous corn, the other corn-based rotations consisted of two years of corn, followed by either soybeans, alfalfa, barley or soybeans with winter wheat. The rotations involving barley or wheat were implemented with and without red clover underseeded into the cereal. Each rotation plot of the field experiment was split into two levels of tillage alternatively with a moldboard plow or a chisel plow. Plots were uniformly maintained such that fertility, weeds, insects etc. were not limiting. N-fertilization was oriented at the general recommendations for fertilizer applications for Ontario (OMAF, 2002) without considering rotation specific fertilizer saving potentials (N-credits). The experiment was designed in a split plot design with four replications for each tillage-rotation combination.

2.1 Net GHG emissions of the cropping systems

The carbon sequestration potential of the tillage-rotation combinations was based on measurement of organic matter content in the soil of each experimental plots in 1999 and 2000. Five soil cores were taken prior to tillage operations in the fall from each plot at depths of 0-5, 5-10, 10-20, 20-40, and 40-60 cm. The composite depth samples for each plot were analyzed for bulk density and organic carbon. Soil carbon storage on an equivalent soil mass basis was calculated as per Yang and Wander (1999). Organic carbon was calculated as the difference between total carbon content and inorganic carbon determined by a Leco SC-444 method. Carbon sequestration rates of all management options were compared to the continuous corn rotation with conventional tillage, since this was the management prior to the experiment on the field and a common practice at that time. The difference was divided by the number of years of the experiment to arrive at annual sequestration rates of carbon.

The N₂O emissions from crop production were calculated based on biological nitrogen fixation, crop residues, synthetic fertilizer inputs and indirect emissions, according to IPCC methodology (IPCC, 1997) with some adjustments as proposed for the GHG inventory in Canada (Matin et al., 2004). The GHG-relevant emission coefficients due to fuel consumption, machinery repair, and the manufacturing of fertilizer were taken from the assumptions of Canada's Greenhouse Gas Inventory (Matin et al., 2004) and Kulshreshtha and MacDonald (2000). GHG emissions from pesticide manufacturing and from seed production were ignored as were other on-farm energy uses and induced energy use which are marginally affected by the choice of cropping system.

2.2. Profitability analysis

Net returns for each cropping system were obtained by subtracting the costs of production from gross revenue, which was obtained by multiplying observed yields by the 1999 to 2003 average crop prices. Prices were \$130 Mg⁻¹ for corn, \$277 Mg⁻¹ for soybeans, \$127 Mg⁻¹ for soft white wheat, \$119 Mg⁻¹ for barley and \$85 Mg⁻¹ for alfalfa hay (OMAFRA, 2005a). Costs of production were based on the 2005 Field Crop Budgets for Ontario (OMAFRA, 2005b) with some adjustments for the cover crop and additional pesticide applications which were necessary in some of the rotations (Table 1). Assumed annual fertilizer N rates were 160 kg N ha⁻¹ for corn, 8 kg N ha⁻¹ for soybeans, 110 kg N ha⁻¹ for winter wheat, 60 kg N ha⁻¹ for barley, and 10 kg N ha⁻¹ for alfalfa in the first year. The fertilizer rates to corn after a crop other than corn were adjusted according to N-credits as suggested by Janovicek and Stewart (2004). Fuel expenses for the different tillage systems were estimated according to the work rates of the implements and the fuel consumption of the tractor. Chisel plowing was assumed to need 6 l ha⁻¹ less fuel for the tillage operation than moldboard plow, with a fuel price of \$0.69 l⁻¹. Drying charges were assumed to be \$16 Mg⁻¹ for corn and \$8 Mg⁻¹ for soybeans. Further yield dependent costs such as storage, trucking and marketing fees were calculated

according to values from the Crop Budgets (OMAFRA, 2005b). The estimated costs were subtracted from the calculated revenue to obtain net returns to land, labour and management for an individual crop in a given tillage system. The net returns for each crop were averaged over each four-year rotation period in order to obtain the yearly net revenue associated with each rotation-tillage combination.

3 Results

3.1 *Net GHG emissions*

The calculated N₂O-emissions expressed in CO₂ equivalents of the crops planted in the experiment are presented in Figure 1. The estimated emission values are highest for corn, when planted after a red clover cover crop. Even though the red-clover cover crop lowers the fertilization requirement of the following corn crop and thus reduces the emissions from fertilization by more than 200 kg CO₂ eq. ha⁻¹, these gains are more than offset by the emissions from N-fixation of the legumes and crop residues of the cover crop. The lowest N₂O emissions are from barley because the fertilizer input is moderate and no N-fixation contributes to high N-inputs into the system. For wheat, soybeans and alfalfa, the estimated N₂O emissions are approximately the same even though the source of emissions differs between the legumes and wheat.

GHG-emissions from on-farm fuel use and induced emissions due to the manufacturing of fertilizers and the machinery for the considered crops are illustrated in Figure 2. For corn these emissions on average over all treatments sum up to 1200 kg CO₂ eq ha⁻¹ because of high energy requirements of fertilizer processing and high emissions due to crop drying. The lower fertilizer requirement of corn, when planted after red clover results in about 250 kg CO₂ eq ha⁻¹ lower emissions from this cropping option, which more than offsets the higher N₂O emissions due to the legume cover crop (Figure 1). However, this very much depends on the N-fixation of the legume, which can substantially vary. The emissions from

fuel use vary between the crops from 250 kg to 550 kg CO₂ eq ha⁻¹. The highest emissions from fuel use were in the alfalfa systems due to high-energy requirements during multiple harvests. Substitution of the moldboard plow with the chisel plow results in an additional 30 kg ha⁻¹ CO₂ eq for all crops.

While rotation had a significant impact on carbon sequestration at the 10% level of significance, no significant effect was found for tillage. Compared to continuous corn, the continuous alfalfa rotation had the highest sequestration rates of 513 kg C yr⁻¹. To a lesser extent, the integration of cereals and red clover underseeded into the cereals had some sequestration effect. The inclusion of soybeans into the rotation did not affect sequestration rates significantly.

The average annual GHG-emissions over the rotations of the analyzed cropping systems are compiled in Table 2. N₂O emissions (1433 kg CO₂ eq ha⁻¹) are lowest for the corn-corn-barley-barley rotation with the chisel plow and highest for continuous corn under conventional tillage (2082 kg CO₂ eq ha⁻¹). Emissions from direct and indirect energy use vary from 509 kg CO₂ eq ha⁻¹ for continuous alfalfa to 1278 kg CO₂ eq ha⁻¹ for continuous corn. Sequestration only partially offset total GHG emissions from N₂O and energy sources in contrast to agriculture in the Great Plains region of North America where sequestration potential is greater and other emission levels lower. In eastern Canada, GHG emissions can be reduced by more than one Mg CO₂ eq ha⁻¹ GHG compared to a continuous corn rotation through crop selection.

3.2. Net return of cropping systems

Net returns were affected by tillage and rotation as well as by interaction effects between tillage and rotation. Rotations containing wheat had the highest annual net returns. Compared to continuous corn, corn-based rotations with wheat were \$53 ha⁻¹ and \$82 ha⁻¹ more profitable under a moldboard system and \$110 ha⁻¹ and \$114 ha⁻¹ with a chisel plow tillage

system (see Table 3). Including soybeans in the rotation increased profitability of the corn-based cropping systems in both tillage systems but the response was greater in the chisel system. Overall, net returns for rotations that included barley did not differ from continuous corn. Tillage differences for all rotations other than continuous corn were relatively small and did not differ by more than \$18 ha⁻¹.

3.3. Trade-offs between GHG emissions and farm returns

Net GHG emissions and farm returns are illustrated together for all cropping systems in Figure 3. The highest net return is realized with a corn-corn-soybean-wheat rotation that is underseeded with red clover. Under conventional tillage, the net GHG emissions are 2428 kg CO₂ eq ha⁻¹, where 2597 kg CO₂ ha⁻¹ stem from the production process of which 169 kg CO₂ eq ha⁻¹ is sequestered in the soil. Compared to continuous corn with this management option more than one Mg CO₂ eq ha⁻¹ year⁻¹ of GHG emissions are mitigated and returns are approximately \$100 ha⁻¹ greater. The same corn-soy-wheat rotation without the cover crop is slightly less profitable and emits higher net GHG levels and is thus considered inefficient. GHG levels can be reduced by replacing wheat and soybeans with either alfalfa or barley. The steepness of the trade-off curve indicates that such mitigation will be costly as average abatement costs are \$200 to \$1000 per Mg of abated CO₂ eq GHGs.

4 Conclusions

The integration of legumes into corn based cropping systems provides multiple benefits, including higher yields, cost savings and the mitigation of GHGs. Diversifying a corn rotation with soybeans and wheat underseeded with red clover results in \$100 ha⁻¹ higher net returns and a mitigation of more than a ton of CO₂ eq GHG compared to continuous corn. Even though legumes contribute considerably to the emissions of GHG by fixing nitrogen in the soil, these emissions are offset by reduced emissions from less fertilizer use and the reduced

induced emissions from manufacturing the fertilizer. However, a further mitigation of GHGs requires significant opportunity costs to the farmer.

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Table 1. Cost structure of corn, soybeans, wheat, barley and alfalfa production in the different tillage systems

Input	Production costs									
	Corn		Soybeans		Wheat		Barley		Alfalfa	
	Moldboard	Chisel	Moldboard	Chisel	Moldboard	Chisel	Moldboard	Chisel	Moldboard	Chisel
	----- \$ ha ⁻¹ -----									
Seed	150		93		91		80		68	
Fertilizer	210		66		207		135		99	
Herbicides	86		79		15		76		24	
Custom Work for fertilizer and pesticides	44		44		44		44		66	
Energy related yield variable costs ^a	187		39		28		22		-	
Fuel and lubricants	31	27	20	16	26	21	26	21	56	54
Variable machine costs and overhead expenses ^b	264	262	210	208	249	248	236	235	279	278
Sum	972	966	551	545	660	654	619	613	593	589

^a Drying and trucking costs assuming average yield for each crop (corn: 8.5 t ha⁻¹, soybeans: 2.7 t ha⁻¹, wheat: 5.1 t ha⁻¹, barley: 3.7 t ha⁻¹, alfalfa: 7 t ha⁻¹)

^b Including costs on interest on operating capital, rent, marketing fees, storage and labour costs

Table 2. Average annual emissions from different crop rotations in CO₂ eq ha⁻¹ year⁻¹

	CCCC		CCBB		CCBrCBrC		CCSS		CCSW		CCSWrc		CCAA		AAAA
	MP	CP	MP	CP	MP	CP	MP	CP	MP	CP	MP	CP	MP	CP	MP
<hr/> N ₂ O emissions from the soil															
Crop Residues	718	677	517	508	618	608	564	553	573	576	681	673	368	367	0
Fertilizer	1364	1364	916	916	767	767	610	610	912	912	763	763	469	469	21
N-Fixation	0	0	0	0	91	91	441	437	232	241	333	340	647	634	1358
Sum	2082	2041	1433	1424	1476	1466	1615	1600	1717	1729	1777	1776	1484	1470	1379
Emissions from direct and indirect energy use															
Crop Drying	361	341	180	180	182	182	206	201	192	191	199	193	185	185	0
Fuel use	131	114	121	104	121	104	111	94	116	99	116	99	183	171	199
Fuel manufacturing	175	153	162	140	162	140	148	126	155	133	155	133	246	229	266
Machine Manufacturing	18	18	20	20	20	20	18	18	19	19	19	19	30	30	35
Fertilizer Manufacturing	592	592	398	398	333	333	265	265	396	396	331	331	204	204	9
Sum	1277	1218	881	842	818	779	748	704	878	838	820	775	848	819	509
GHG Mitigation from C-Seq	0	0	71	71	193	193	-73	-73	130	130	169	169	289	289	513
Net GHG emission mitigation from all sources															
	3359	3259	2243	2195	2101	2052	2436	2377	2465	2437	2428	2382	2043	2000	1375

Table 3. Rotation and tillage effects on yearly net revenue

Rotation	Tillage	
	Moldboard Plow	Chisel Plow
	----\$ ha ⁻¹ ----	
C-C-C-C ^a	70	24
C-C-B-B	53	48
C-C-B(rc)-B(rc)	63	45
C-C-S-S	113	103
C-C-S-W	123	134
C-C-S-W(rc)	152	138
C-C-A-A	87	84
A-A-A-A	88	
<u>SE</u>		
C-C-C-C and A-A-A-A (n = 20)	14.5	
Rotation (n = 40)	11.8	
<u>LSD (Tillage x Rotation, 0.05)</u>		
C-C-C-C and A-A-A-A	41	
Rotations	34	

^a C = corn, B = barley, rc = underseeded red clover, S = soybean, W = winter wheat, A = alfalfa

Figures:

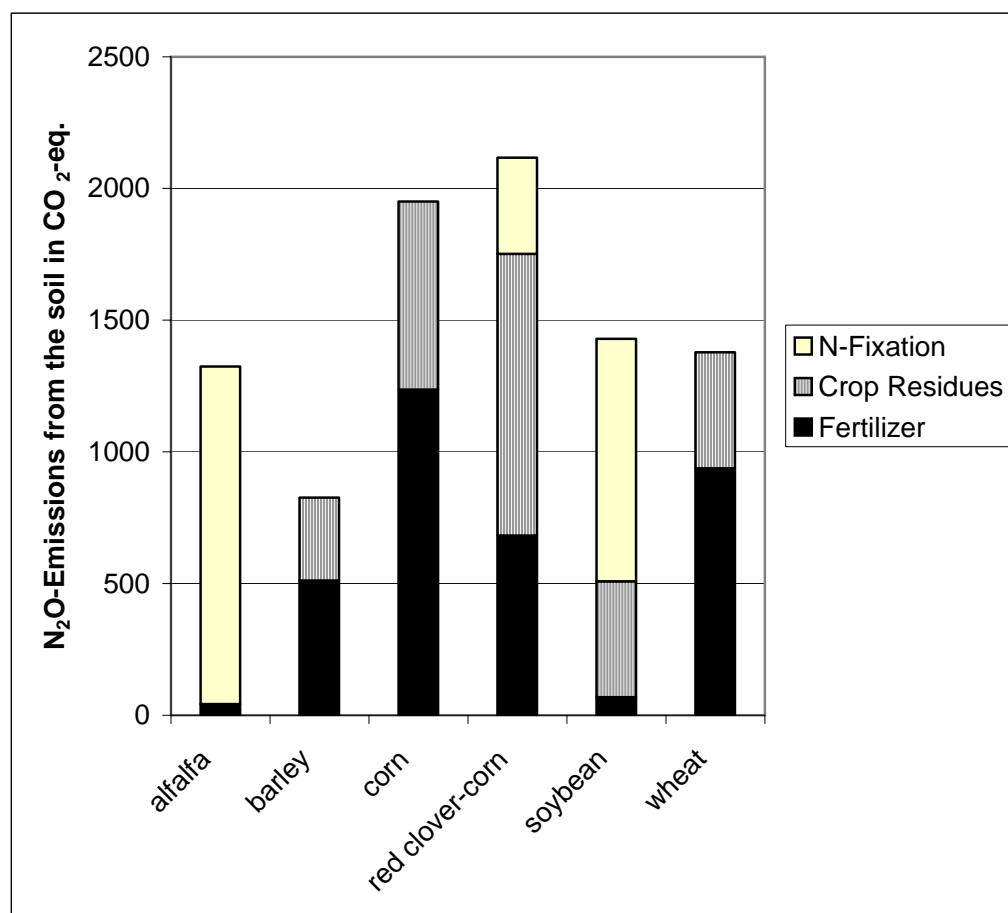


Fig. 1. Estimated 20 years average N₂O emissions (direct and indirect) of the crops over all treatments from nitrous fertilizer, crop residues and nitrogen fixation according to IPCC accounting methodology

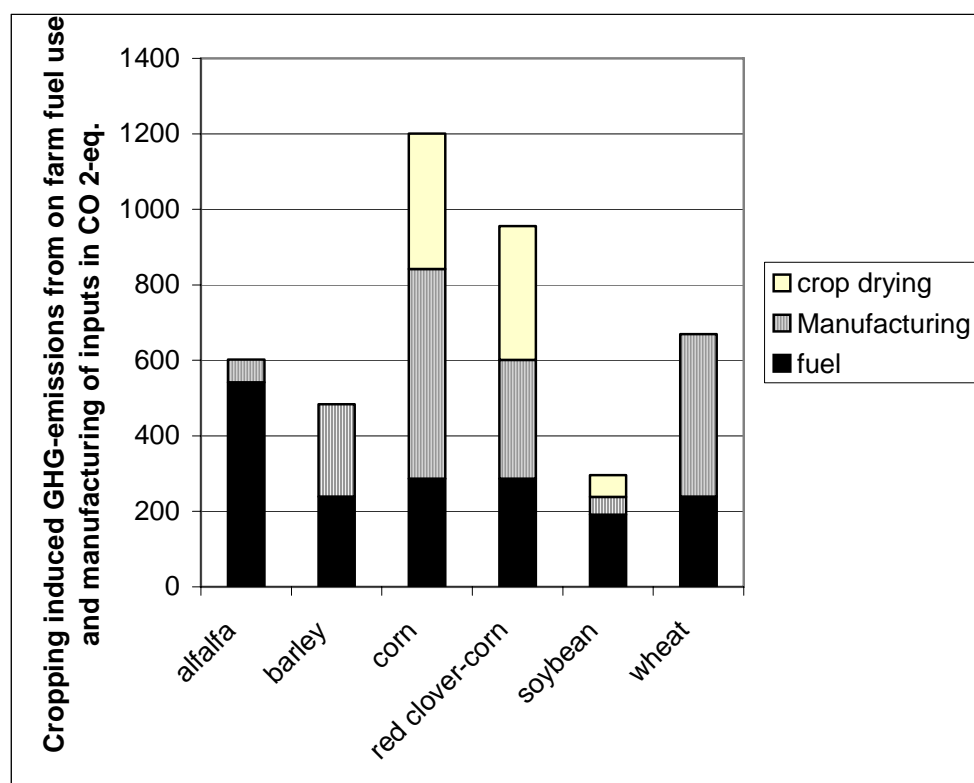


Fig.2. Contribution of cropping to GHG emissions in other sectors

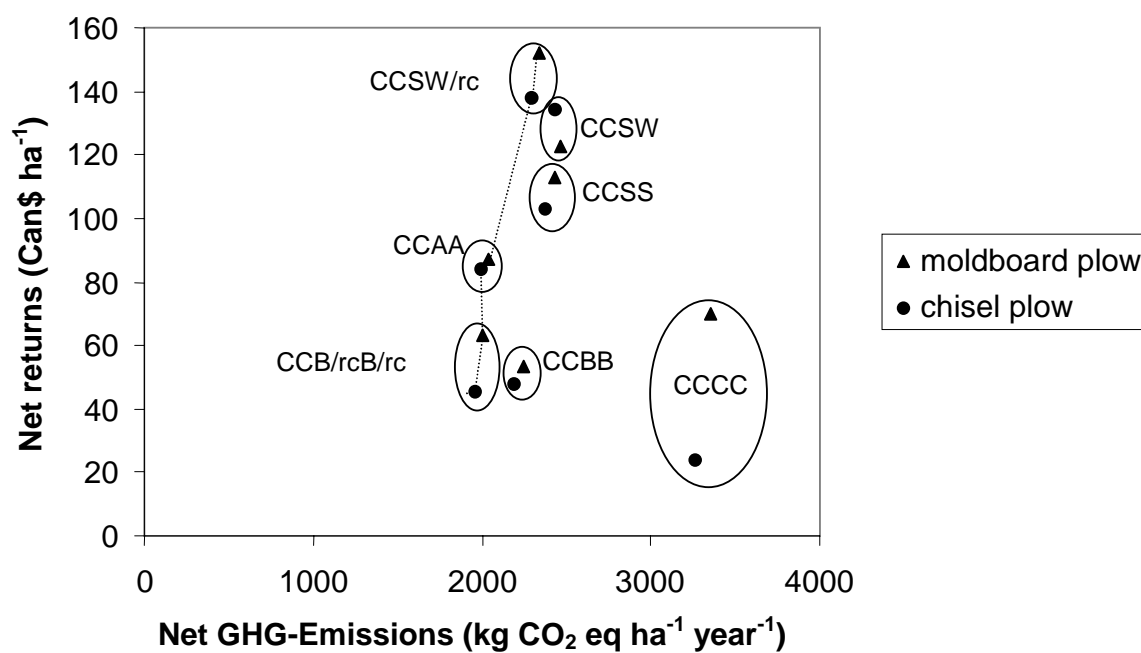


Fig 3. Trade off of GHG emissions versus Net return to the farmer