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Effectiveness of Best Management Cropping Systems to Abate Greenhouse Gas Emissions

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The Issue

Best management practices (BMPs) for cropping systems that involve conservation tillage and nutrient management are proposed as potential win-win solutions for both farmers and the environment. While originally targeted as a means for improving soil and water quality, these BMPs may also contribute to the mitigation of greenhouse gases (GHGs). Mitigation efforts have focused primarily on the ability of BMPs to sequester carbon and the subsequent potential revenue source carbon sequestration may represent to farmers. Increasingly, evidence from experimental stations calls into question the potential for C-sequestration with reduced tillage in soils in Eastern Canada. However, there are other ways in which BMPs can reduce GHG emissions: lowering fuel and nitrogen fertilizer consumption and, potentially, lowering emissions of nitrous oxide from the soil. This article examines the profitability and emission reduction potential of best management cropping practices for Ontario.

Implications and Conclusions

BMPs have the potential to increase both farm profits and environmental quality. For a corn-soybean-wheat cropping sequence, the use of no-till as opposed to conventional tillage, combined with improved fertilizer application and timing, results in a 9 percent reduction in costs. Both fixed and variable costs are about $30 per ha less under the BMP. Fixed costs are lower due to a reduction in implement use and variable costs are lower due to a reduction in fertilizer and fuel use. Yield decreases in response to the reduction in tillage and fertilizer use were shown only for corn, where the implementation of BMP resulted in 11 percent and 9 percent penalties in the years 2000 and 2003 respectively. On the other hand, in 2001, soybean yields increased by 49 percent with BMP. When averaged over the analyzed period of four years, net returns per hectare are 42 percent higher for the BMP system as compared to the conventional system.

Not only is the BMP system more profitable, but also it lowers nitrous oxide emissions by 130 kg of C equivalents per hectare annually. An additional reduction of 78 kg of C equivalents per hectare is achieved through lower fuel emission and fertilizer processing requirements under the BMP system. Additional carbon sequestration may occur through conservation tillage. These mitigation levels would not add significantly to farm returns if a carbon market developed under projected prices; however, adoption of BMPs might be encouraged further if fuel and fertilizer prices were to rise with the emergence of a carbon market, as has been suggested by McCarl and Schneider (2000). Despite the current and potential economic advantages of BMP systems, adoption rates are relatively low, and further research should be directed toward examining reasons for the resistance.

Background

Greenhouse gas emissions from agricultural production are estimated to comprise 9.5 percent of total Canadian GHG emissions (Desjardins and Riznek, 2000). Thus, agriculture will play a role in meeting Canada's commitment to the Kyoto Protocol either through acting as a sink for GHGs or through emission reduction. The potential for carbon sequestration in Canadian soils from reduced tillage is estimated by Dumanski et al. (1998) to be 50 to 75 percent of total agricultural emissions of CO_2 in Canada for the next 30 years. However, there is increasing evidence from experimental stations that questions the potential for carbon sequestration with reduced tillage in soils in Eastern Canada (Angers et al., 1997; Deen and Kataki, 2003; Yang and Kay, 2001). Furthermore, carbon sequestration in soils is only temporary and agriculture's contribution of CO_2 emissions is only 2 percent of the national total (National Climate Change Process, Analysis and Modelling Group, 1999). In contrast, agriculture contributes 63 percent of the national emissions of nitrous oxide and 35 percent of national emissions of methane. Given the important role agriculture has in the emissions of these potent GHGs and the fact that the consumption of nitrogen fertilizer has quintupled over the last five decades, there is pressure to determine cost-effective means of reducing nitrous oxide emissions.

Cropping Systems Analyzed

Two management systems were analyzed. One represents a typical, conventional corn–soybean–winter wheat crop rotation for southwestern Ontario; the other represents a best management practices system. The latter is based on the same crops as the former but incorporates best management practices to minimize negative impacts on the environment while maintaining the level of economic returns per hectare (table 1). The conventional system involves fall moldboard plowing followed by spring disking. Fertilizer is applied at rates according to general recommendations from the Ontario Ministry of Agriculture and Food (OMAFRA, 2002): 150 kg of N per hectare for corn, applied at planting, and 90 kg of N per hectare for wheat, broadcast in early spring. The BMP system used zero tillage with direct seeding. Fertilization rates were adjusted for corn to 50 kg of N per hectare in 2000 and 60 kg of N per hectare in 2003, based on a soil N test applied at the six-leaf stage. The amount of fertilizer for wheat was reduced to 60 kg per hectare after allowing for the nitrogen credit from the previous soybean crop. A cover crop of red clover was underseeded in the wheat to prevent nitrate leaching in the winter and reduce the fertilization requirement for the subsequent corn. These two cropping systems were established as a field experiment at the Elora Research Station of the University of Guelph beginning in the fall of 1999. Four plots of 1.5 hectares each were used (two treatments and two repetitions).

The experimental field plots provided the input and output data for the two systems. The costs of the inputs used were calculated based on enterprise budgets for conventional and no-till management systems for corn, soybeans and winter wheat, adjusted for the specific conditions in the experiment such as the amount of fertilizer applied and additional costs for soil tests (OMAFRA, 2003). The costs for soil tests ($20 per sample) were assumed to apply for a four-hectare field ($5 per ha). Costs of field operations were calculated using the year 2000 custom farmwork rates and then allocated to six categories (fuel, repairs, labour, depreciation, interest, and other overhead, which includes insurance and housing). To determine fuel consumption and labour requirements of the cropping practices for each operation sequence, total machine use was calculated based on the work rates of the implements used for a typical Ontario farm. The assessment of diesel fuel consumption in litres per hour (*DFC*) was based on the work rate of the implements used and the adequate maximum horsepower of the tractor (*PTO*) following $DFC = 0.167 \times PTO$ (Molenhuis, 2001).

Table 1 Practices of Conventional and Best Management Cropping Systems

	Corn		Soybean (Roundup Ready)		Winter wheat	
	Conv.	**BM**	**Conv.**	**BM**	**Conv.**	**BM**
Tillage & seeding	Plowing Disking Cultivating Conventional seeding	Burn-down of red clover cover crop Direct seeding	Plowing Disking Cultivation	Direct seeding	Disking Cultivating Conventional seeding	Direct seeding Underseeding of red clover (15 kg/ha) in April
Fertilizer mgt.	One application N (150 kg/ha) w/ seeding according to general recommendation	Adjusted application to 50-60 kg N/ha at 6-leaf stage according to soil nitrate test			One application of N (Urea, 90 kg/ha N) according to general recommendation	One application of Urea (60 kg/ha N) allowing 30 kg/ha N credit from soybean
Weeding mgt.	Chemical weeding (Prowl 400 [4.2 L/ha]; Banvel II [1.25 L/ha])		Chemical weeding Roundup (0.9 kg/ha)		Chemical weeding (Tropotox Plus [3 kg/ha])	

Analysis

Net Farm Returns

The costs of the two management systems for each crop are listed in table 2. Total costs averaged over a three-year period of one rotation are approximately $57 per hectare lower for the best management system compared to the conventional system. This represents a savings of 9 percent. About half of the cost savings originate from reduced variable costs associated with less fuel and fertilizer use in the BMP system. Based on standard values

Table 2 Cost Structures of Conventional and Best Management Systems

Crop	Costs ($/ha)	System			
		Conventional	BMP	Difference	(%)
Corn	Variable	$753	$699	-$54	(-7)
	Fixed	$151	$128	-$23	(-15)
	Total	$904	$828	-$76	(-8)
Soybean	Variable	$341	$317	-$24	(-7)
	Fixed	$141	$ 99	-$42	(-30)
	Total	$482	$415	$-67	(-14)
Wheat	Variable	$399	$398	-$ 1	(0)
	Fixed	$168	$141	-$27	(-26)
	Total	$568	$539	-$29	(-5)
Average	Variable	$498	$471	-$27	(-5)
	Fixed	$153	$123	-$30	(-20)
	Total	$651	$594	-$57	(-9)

Table 3 Gross Margin (returns above fixed costs) and Net Revenue (returns above all costs) of the Two Cropping Systems

		Conv.	BMP	p-Value	Significance[1]	Difference (%)	
Corn 2000	Yield (t/ha)	4.33	3.86	0.102	n.s.	-0.47	(-11%)
	Total revenue ($/ha)	$537	$479			-$58	(-11%)
	Total costs ($/ha)	$904	$801			-$93	(-10%)
	Gross margin ($/ha)	-$216	-$194	0.703	n.s.	$13	(6%)
	Net revenue ($ha)	-$148	-$322	0.309	n.s.	-$184	(-124%)
Soy 2001	Yield (t/ha)	2.38	3.54	0.0009	***	1.16	(49%)
	Total revenue ($/ha)	$787	$1,171			$384	(49%)
	Total costs ($/ha)	$482	$415			-$66	(-14%)
	Gross margin ($/ha)	$446	$854	0.0006	***	$408	(91%)
	Net revenue ($ha)	$305	$755	0.0003	***	$450	(147%)
Wheat 2002	Yield (t/ha)	6.81	7.61	0.13	n.s.	0.8	(12%)
	Total revenue ($/ha)	$1,394	$1,558			$164	(12%)
	Total costs ($/ha)	$568	$539			-$29	(-5%)
	Gross margin ($/ha)	$995	$1,160	0.12	n.s.	$165	(17%)
	Net revenue ($ha)	$334	$412	0.06	n.s.	$78	(23%)
Corn 2003	Yield (t/ha)	8.98	8.21	0.045	*	-0.77	(-9%)
	Total revenue ($/ha)	$1,114	$1,018			-$95	(-9%)
	Total costs ($/ha)	$904	$828			-$76	(-8%)
	Gross margin ($/ha)	$360	$319	0.374	n.s.	-$41	(-11%)
	Net revenue ($ha)	$209	$190	0.685	n.s.	-$19	(-9%)
Average over the four year period							
	Gross margin ($/ha)	$396	$535			$138	(35%)
	Net revenue ($ha)	$175	$259			$84	(48%)

[1] n.s.: not significant at the 5 percent level; * significant at the level p<0.05; ***significant at the level p<0.001.
Prices for corn, soybean and wheat were C$124, $330 and $205 per ton, respectively.

for the implements used, the BMP system has on average a 40 percent fuel saving potential compared to the conventional system. These calculations do not take into account different soil resistance. The absolute fuel consumption can vary substantially between tillage systems depending on the soil properties, but the relative savings are essentially the same between soil types. Sijtsma et al. (1998) found fuel savings of 14 to 64 percent with various minimum tillage practices compared to the conventional system.

Cost savings, particularly for fertilizer, vary from crop to crop. For corn, the additional costs of soil sampling are more than compensated for by the reduction in fertilizer costs. Nitrogen fertilizer use for corn is 90 kg per hectare less in the BMP system compared to the conventional system due to the nitrogen fixation and sequestration capacity of the red clover underseeded with in the preceding crop of winter wheat (Vyn et al., 2000). The seeding costs of the red clover are allocated to the wheat crop and almost completely override the fuel and nitrogen fertilization savings in the BMP wheat. There are no differences in fertilizer costs between the two systems for soybeans.

The proportional savings in fixed costs with the BMP system due to the reduction in machinery use compared to the conventional system are greater than the proportional savings in variable costs. The estimated savings in fixed costs with conservation tillage are similar to findings from several other studies, for example, Uri (1999), Uri, Atwood and Sanabria (1999), and Weersink et al. (1992); however, due to the combined effect of cost savings from reduced use of tillage implements and fertilizers, overall cost reductions in the BMP system are about twice as high as the savings reported in the studies citied above. Note that equipment costs are based on custom rates, which implies that both systems are being evaluated on the same terms. Actual costs may vary significantly for individual farmers. For example, a farmer with an existing complement of conventional tillage equipment will likely have lower fixed costs for his machinery than those associated with purchasing a new no-till drill.

The impacts of the two different management systems on grain yield and the economic performance of the management systems over the four-year period are shown in table 3. No significant yield penalties due to no-till or substantially reduced fertilizer levels were found. Soybean yields were significantly higher in the BMP system compared with those in the conventional system; this difference may be attributable to the differences in soil moisture stress. BMP corn yields were 5 percent to 10 percent lower than yields for the conventional system for the two years corn was planted during the four-year period, but these differences were not statistically significant. Note the extremely low corn yield in 2000 due to wet and cold conditions. The results for comparative yield performance are consistent with findings from Vyn et al. (1994) who found there was little yield difference between no-till and conventional tillage for corn, soybeans and winter wheat in a long-term Ontario trial.

The economic analysis provides evidence that BMP resulted in significantly higher gross margins and net returns compared to the conventional practice.

GHG Emission Levels

An average reduction of 1.61 kg per hectare per year in nitrous oxide (N_2O) emissions over the three-year rotation is achieved by the BMP system when compared to the conventional system (figure 1). This reduction occurs during the corn and wheat years, while no significant differences are observed between systems during the soybean year, probably due to lack of difference in legume N input between systems. Reduction in the fertilizer rate and application during the rapid corn growth phase in the BMP system treatment directly affects the N_2O emissions early in the corn-growing season. However, differences in emissions during the wheat year occur due to lower N_2O spring thaw emissions under the red clover cover crop as suggested by Wagner-Riddle and Thurtell (1998), and not due to differences in the N application rate.

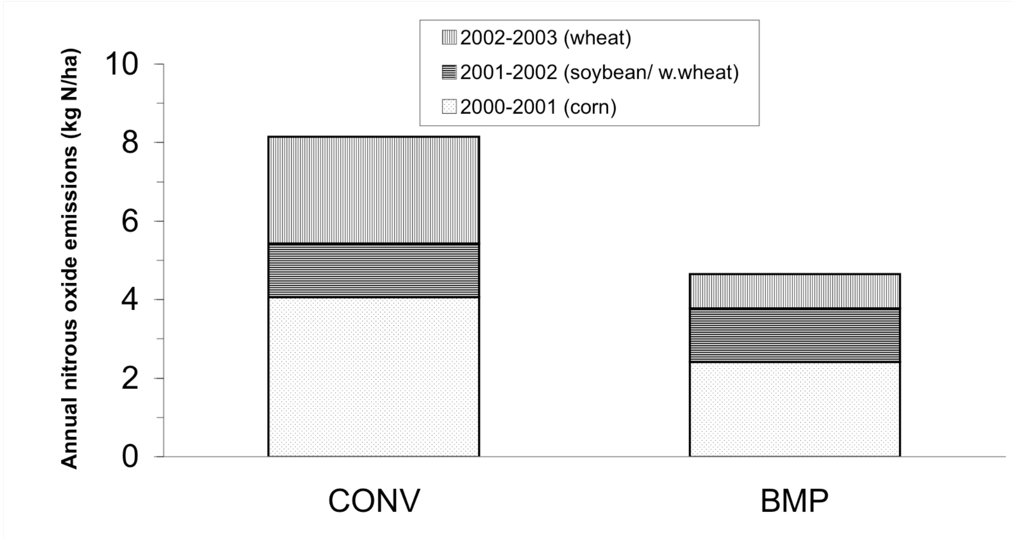

Figure 1 Annual nitrous oxide fluxes at the Elora Research Station, Ontario, for a corn–soybean–winter wheat rotation over May 2000 to April 2001, May 2001 to April 2002, and May 2002 to April 2003. Plots were subjected to two contrasting management practices: conventional (CONV) and best management practices (BMP).

In addition to reduced emission rates of N_2O, the BMP-system also contributes to GHG mitigation through reduced direct emissions of fuel exhausts and lower fertilizer processing requirements. Based on the calculations of this experiment, fuel consumption was reduced by 41 percent from 39 litres per hectare annually to 23 litres per hectare annually on average over one cropping sequence. Nitrogen fertilizer input was reduced by 38 percent, from 80 kg of N per hectare per year to 50 kg per hectare on average, over one three-year cropping sequence. Indirect emissions related to the manufacturing of the machinery and fertilizer and plant protection agents are also lowered. Since emissions from the manufacture of machinery and plant protection agents are comparably low in

Table 4 Contribution of BMP to the Mitigation of GHG Emissions

Source of mitigation	Magnitude (unit/ha and year)	C-equ/unit of reduction[1]	Mitigation of C (kg/ha and year)	Benefit with a C-market ($ per ha and year)	
				1 t C = $5	1 t C = $10
Reduced fuel consumption	16 l	0.85	14 kg	$0.07	$0.14
Reduced fertilizer consumption	40 N	1.61	64 kg	$0.32	$0.64
Reduced N_2O-emissions	1.61 kg N_2O	80.58	130 kg	$0.65	$1.30
C-sequestration	0–130 kg C	1	0–130 kg	0–0.65	$0–$1.30
Sum			208–338 kg	$1.04–$1.69	$2.08–$3.38

[1] C-equivalents calculated according to GEMIS 4.1(c) and Patyk and Reinhard (1997)

life-cycle assessments of agricultural production (Jungbluth, 2000), these are neglected in this study. It's worth noting also that the BMP system may contribute to the mitigation of GHG emissions through increased C-storage in the soil. Follett (2001) assumes C-sequestration rates for prairie conditions in Canada to be 100 to 300 kg C per hectare per year. For Ontario conditions, Weersink et al. (2003) assume 130 kg C per hectare per year. However, as stated above, C-sequestration in the soil from reduced tillage is strongly questioned in Eastern Canada. Table 4 shows the average GHG-mitigation potential of the BMP system from reductions in N_2O emissions, fuel consumption, fertilizer consumption and from a possible increase in C-sequestration. If the mitigation were remunerated by a carbon market, depending on the price for carbon and the accounting of C-sequestration the extra benefit associated with the BMP system would be in the range of $1.04 to $3.38 per hectare per year.

References

Angers, D. A., M. A. Bolinder, M. R. Carter, E. G. Gregorich, C. F. Drury, B. C. Liang, R. P. Voroney, R. R. Simard, R. G. Donald, R. P. Beyaert, and J. Martel. 1997. Impact of tillage practices on organic carbon and nitrogen storage in cool, humid soils of Eastern Canada. *Soil and Tillage Researc*h 41: 191-201.

Deen, W., and P. K. Kataki. 2003. Carbon sequestration in a long-term conventional versus conservation tillage experiment. *Soil and Tillage Research* 74: 143-150.

Desjardins, R. L., and R. Riznek. 2000. Agricultural greenhouse gas budget. In *Environmental sustainability of Canadian agriculture: Report of the Agri-Environmental Indicator Project,* ed. T. McRae, C. A. S. Smith, and L. G. Gregorich, 133-142. Catalogue No. A22-201/200. Ottawa: Agriculture and Agri-Food Canada.

Dumanski, J., R. L. Desjardins, C. Tarnocai, C. Monreal, E. G. Gregorich, V. Kirkwood, and C. A. Campbell. 1998. Possibilities for future carbon sequestration in Canadian agriculture in relation to land use change. *Climatic Change* 40: 81-103.

Follett, R. F. 2001. Soil management concepts and carbon sequestration in cropland soils. *Soil and Tillage Research* 61: 77-92.

GEMIS 4.1. (Globales-Emissions-Modell-Integrierter-Systeme) http://www.gemis.de.

Jungbluth, N. 2000. Umweltfolgen des Nahrungsmittelkonsums: Beurteilung von Produktmerkmalen auf Grundlage einer modularen Ökobilanz. PhD. Eidgenössische Technische Hochschule Zürich, Switzerland.

McCarl, B. A., and U. A. Schneider. 2000. U.S. agriculture's role in a greenhouse gas emission mitigation world: An economic perspective. *Review of Agricultural Economics* 22: 134-157.

Molenhuis, J. R. 2001. Budgeting farm machinery costs. Factsheet No. 8325, Ontario Ministry of Agriculture and Food. http://www.gov.on.ca/OMAFRA/english/busdev/facts/01-075.htmv

National Climate Change Process, Analysis and Modelling Group. 1999. Canada emissions outlook: An update. http://www.nrcan.gc.ca/es/ceo/outlook.pdf

OMAFRA (Ontario Ministry of Agriculture, Food and Rural Affairs). 2002. Agronomy guide to field crops. Publication 811, Ministry of Agriculture, Food and Rural Affairs.

———. 2003. Crop budgets. Publication 60, Ministry of Agriculture, Food and Rural Affairs.

Patyk, A., and G. A. Reinhardt. 1997. Düngemittel – Energie und Stoffstrombilanzen, Vieweg, Braunschweig/ Wiesbaden.

Sijtsma, C. H., A. J. Campbell, N. B. McLaughlin, and M. R. Carter. 1998. Comparative tillage costs for crop rotations utilizing minimum tillage on a farm scale. *Soil and Tillage Research* 49: 223-231.

Uri, N. D. 1999. The economic benefits and costs of conservation tillage. *Journal of Sustainable Agriculture* 15: 5-27.

Uri, N. D., J. D. Atwood, and J. Sanabria. 1999. The environmental benefits and costs of conservation tillage. *Environmental Geology* 38: 111-125.

Vyn, T. J., J. G. Faber, K. J. Janovicek, and E. G. Beauchamp. 2000. Cover crop effects on nitrogen availability to corn following wheat. *Agronomy Journal* 92: 915-924.

Vyn, T. J., J. Janovicek, and M. R. Carter. 1994. Tillage requirements for annual crop production in Eastern Canada. In *Conservation tillage in agroecosystems,* ed. M. R. Carter. Boca Raton, FL: CRC Press,

Wagner-Riddle, C., and G. W. Thurtell. 1998. Nitrous oxide emissions from agricultural fields during winter and spring thaw as affected by management practices. *Nutrient Cycling in Agroecosystems* 52: 151-163.

Weersink, A., M. Walker, C. Swanton, and J. E. Shaw. 1992. Costs of conventional and conservation tillage systems. *Journal of Soil and Water Conservation* 47: 328-334.

Weersink, A., S. Joseph, B. D. Kay, and C. G. Turvey. 2003. An economic analysis of the potential influence of carbon credits on farm management practices. *Current Agriculture, Food & Resource Issues* 4: 50-60.

Yang, X. M., and B. D. Kay. 2001. Rotation and tillage effects on soil organic carbon sequestration in a typic Hapludalf in Southern Ontario. *Soil and Tillage Research* 59: 107-114.