Greenhouse Gas Mitigation on Diversified Farms

Elwin G. Smith and B. Mani Upadhyay

Agriculture and Agri-Food Canada. Lethbridge Research Centre, PO Box 3000, Lethbridge, AB, Canada. T1J 4B1.

Selected Paper presented at the Canadian Agricultural Economics Society - Western Agricultural Economics Association - Western Economics Association International joint annual meeting, San Francisco, CA, July 6-8, 2005

Greenhouse Gas Mitigation on Diversified Farms

ABSTRACT

Agriculture can potentially contribute to Canada meeting its commitment to reduce net greenhouse gas (GHG) emissions under the Kyoto protocol. A representative crop - livestock feeding farm on the Canadian prairies is used to estimate the cost of net GHG abatement, taking into account CO_2 equivalent emissions and carbon sequestration. Optimal cropping systems use direct seeding and continuous cropping, production systems that have lower net GHG emissions. Livestock feeding uses rations with high energy concentration (grain based) because they are more profitable and also produce less methane per animal than forage based diets. Reducing tillage is the least costly means of lowering net emissions ($20/t CO_2 eq.), followed by reducing cattle feeding ($32/t CO_2 eq.). If emission reductions are high or cattle numbers can not be reduced, cropping is altered to use very little nitrogen fertilizer ($272-567/t CO_2 eq.), and cattle feeding is switched to a higher forage diet (up to $1500/t CO_2 eq.). The high forage diet has lower emissions per capacity animal, but only because one-half the number of animals can be finished with the same facility capacity. A regional analyses of aggregate emissions will need to incorporate the heterogeneity of farms and soil carbon levels that exist.

INTRODUCTION

Canada ratified the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) in December, 2002 and the Protocol came into effect on February 16, 2005. The objective of the Kyoto Protocol is to reduce the rate of increase in greenhouse gas (GHG) emissions and lessen the adverse climate change impacts on the environment. Canada's commitment is to reduce net GHG emissions by 6% from 1990 levels over the period 2008-2012, a targeted decrease of 240 megatonnes. Despite this commitment, Canada's GHG emissions rose by 20.1% over the 1990-2002 period (UNFCCC 2005). The agricultural sector emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) account for roughly 14% of total Canadian GHG emissions (Gray, Harper, and Highmoore, 2001). Unlike other sectors, nitrous oxide and methane account for 76% of agriculture GHG emissions. In 2003, 72.0% of the nitrous oxide and 27.8% of methane emissions for the country were directly from agriculture (Environment Canada, 2005). In 2001, the Marakesh agreement included carbon sinks to credit countries for the reduction of GHG emissions resulting from land use, land-use change, and forestry (LULUCF). The primary sink for agriculture is the sequestration of carbon in soils as organic matter and the consequent improvements in soil, water and air quality. Mitigating activities also includes afforestation. These activities have the potential to provide a cost-effective method of reducing net GHG emissions in the short run.

Agriculture can contribute to Canada meeting its GHG emission commitments in two ways. First, producers can adopt production practices that decrease GHG emissions. Feed rations and feeding systems for livestock that reduce methane, reduced tillage practices for annual cropping, and employing legumes in cropping to reduce nitrogen fertilizer input requirements are possible options. For livestock, methane reduction activities from ruminants and manure management would be a major contribution to reducing GHG emissions, however, livestock does not offer any sequestration possibilities. Second, producers can sequester carbon in soils in the form of soil organic carbon (SOC) and biomass by adopting appropriate production practices. Reduced tillage and less summerfallow are two management practices that will result in higher SOC. However, some management practices (e.g., reduced tillage) can be complementary between activities that increase carbon sequestration and those that decrease GHG emissions, while others can result in trade-offs (e.g., reducing summerfallow increases nitrogen fertilizer requirements).

Information on the cost effectiveness of practices that reduce emissions or of carbon sequestration activities is limited. This information is central to determining whether incentive schemes could be used, and whether there is a potential for agricultural sinks to play a significant role in removing GHGs from the atmosphere. The marginal cost of sequestering SOC in the northern Great Plains has been estimated to range from $12/t to $500/t depending on soil characteristics, the amount of carbon sequestered, and policies (Antle et al. 2001). De Cara and Jayet (2000) determined the marginal abatement costs of CO_2 reduction depended on the amount of reduction and the characteristics of the farm. For French farms and at €69/t CO_2, 81% of farms met a 1% reduction in CO_2, 30% met a 10% reduction, but only 2% of farms met a 20% reduction in CO_2 emissions. Carbon sequestration in forests has been estimated to be costly (Sohngen and Mendelsohn 2003). Lee and McCarl (2003) estimated that in the near term the cost of carbon sequestration will be lower for agriculture than forestry, but that over time both will have higher costs because of declining sequestration as the systems reach new carbon equilibrium levels. Many of the projected carbon sequestration estimates are regional, such as areas of the United States or Europe, and have assumed no transaction costs for policies paying producers to sequester carbon. For soil carbon, although measurement costs of a policy based on a per carbon credit can be small, the policy can be more efficient than a per area basis payment (Mooney et al 2004).

The efficiency of soil carbon sequestration will depend on many site characteristics, including climate, soil physical properties, management, and the rate of soil organic matter decomposition in the soil. The costs of sequestration have been found to depend on site characteristics, current management practices, and farm structure and constraints (Antle et al 2001, De Cara and Jayet 2000). The annually cropped land of the Canadian prairies has the potential to sequester carbon in the soil, and reduce energy inputs by means of changes in tillage and cropping practices. Because of changes in a variety of economic and biophysical conditions, crop management practices on the prairies have changed since the 1990 Kyoto base period, with less tillage and less summerfallow practices being employed. Between 1991 and 2001, summerfallow land area declined by 41%, while chemical fallow increased from 4.2% to 18.0% of land fallowed (Statistics Canada 1991; 2001). Seeding practices have changed with no-till seeding increasing from 7.2% to 33.4% of seeded land, while conventional seeding and tillage declined from 67.1% to 36.1%. The reduction in fallow and tillage are both beneficial to sequestering carbon and mitigating emissions. These management production practices are being market driven with new innovations in equipment and weed control also being influenced by changes in relative prices of crops and inputs.

There are about one million cattle on feed in western Canada, with the number dropping into summer and fall until the new calf crop. Smaller feedlots of 1,000 to 5,000 hd capacity are about 61% of the total lots in western Canada and 20% of the total capacity. Feedlots with over 20,000 hd capacity have 37% of the region’s total capacity. The small feedlots are more likely to have commercial crop production. The larger lots use their land base to service the feedlot, producing silage and facilitating a location for manure application. There are about two million feeders animals finished for slaughter, nearly twice the one-time feeding capacity.

There is a potential to reduce carbon inputs into agriculture production processes on an integrated cattle feeding - cropping farm on the Canadian prairies, but the costs and impact on the integrated system are unknown. The objective of this study is to estimate the marginal abatement cost of reducing GHG emissions for an integrated cattle feeding - cropping farm on the Canadian prairies. The modelling method uses a representative farm approach with cattle feeding and crop production. The model has the flexibility to include crop substitution and technological possibilities that exist within the crop production system. Livestock alternatives are limited to alternative ration formulations of barley grain and barley silage, and their associated rates of gain and GHG emissions. Carbon sequestration is an option available within the crop sector to remove CO_2 from the atmosphere, provided soil carbon is not at a saturation level. The crops produced and tillage system determine GHG emissions and the long-run level of soil organic carbon. Livestock manure is used as a nutrient source for crops, barley silage must be produced on the farm, but barley grain can be purchased from off the farm.

MODEL AND APPLICATION

The model is a static linear programming (LP) model of a representative farm producing finished cattle and annual crops in the Brown soil zone of the Canadian prairies. Technology possibilities in the model provide technically feasible crops and tillage practices that increase carbon sequestration, and feeding and cropping systems that reduce emissions. The LP approach is selected because of the diversity of sources of GHG emissions, possible relationships among technologies, the specific technologies to evaluate, and the importance of the substitution possibilities among technologies. Greenhouse gas emissions are from three sources (CO_2, CH_4, and N_2O) and are converted to CO_2 equivalents (CO_2-eq.). The modelling approach facilitates a precise description of the different production possibilities. This is important because many trade-offs exist in the production systems. Reduced GHG emissions in one component could be partially off-set by increased GHG emissions elsewhere. Prices and yields are not the only factors determining optimal livestock production and land use, a GHG emission constraint will impact both livestock and crop production, and land use. The static nature of this LP model specification precludes temporal relationships. Technologies and prices are treated as a constant, and time paths for changes in soil carbon are annualized over a 20 year adjustment period. Thus, the results are valid for those technologies and prices included in the LP model.

The representative farm is for the Brown soil zone on the prairies. Livestock is linked to the crop sector in the model through the transfer of feed from the crop sector to livestock and the transfer of manure nutrients from the livestock sector to crops. The optimization model is

$$\max_x \sum_{c,d,f} p_c y_{c,d,f}(x_{c,d,f}) - \sum_{c,d,f} r_c x_{c,d,f} + \sum_h p_l y_{l,h}(y_{c,h}, x_h) - p_v y_v - \sum_h r_h x_h \qquad \textbf{(1)}$$

subject to:

$$\sum_{c,d,f,h} A x_{c,d,f,h} \le B \qquad \textbf{(2)}$$
$$x > 0$$

where x is a vector of production technologies, indices c, d, f, l, h, v are indices for crop, tillage system, fertilizer level, livestock sold, livestock feeding system, and feeder calves purchased, respectively, p is the price vector with the subscript defining the commodity, y is the yield vector and for animals the numbers bought and sold, r is the total input cost vector for production technology x, A is an input-output matrix of production technologies, and B is a vector of resource constraints. The objective function maximizes returns across the crop and livestock production. Crop production includes different crops, tillage technologies, and fertilizer rate. Livestock production includes different feeding systems. The model constraints include livestock capacity, land, rotational limits for oilseeds and annual legumes, equipment, labour, energy and carbon from inputs, soil carbon, and CO_2-eq. greenhouse gases. The energy, carbon, and GHG constraints are readily modified to impose an upper limit. Constraining the system to an upper level of GHG emissions, for example, is done by imposing an upper bound on the CO_2 equivalent output.

The crop production technologies include four tillage systems: conventional, minimum, direct seed, and zero tillage. Crops include wheat (hard red spring, durum, prairie spring and winter), barley (grain and silage), oats, canola, mustard, flax, lentil, field pea, hay, and summerfallow. There are four levels of fertility for each crop, mostly nitrogen differences but some differences in phosphate, including very low, low, low-to-typical, and typical which should approximate optimal rates. The rates for very low, low, and low-to-typical are about 25%, 45-50%, and 80%, respectively of the typical fertility rates. Yield declines were estimated from yield response equations (McKenzie et al 2004, 2005). Yield impacts from reduced nutrients are higher for canola. Yields for the very low, low, and low-to-typical fertilizer rates are, respectively, 30-48%, 50-78%, and 80-86% of the typical fertilizer rate yield. Machinery and herbicide requirements were determined by the crop and tillage practices. Livestock production is restricted to finishing beef cattle in a feedlot. Calves are brought in at 350 kg and sold at 625 kg. There are three feeding systems, from high concentrate diet with a high daily gain (1.6 kg/d), to a moderate concentrate diet with gain of 1.2 kg/d, to a low concentrate diet with gain of 0.8 kg/d. The lower concentrate diets utilize a higher proportion of forage in the diet in the form of barley silage. Rates of gain differ for these diets as well as the emissions of GHGs, primarily methane. Finished animals are replaced with calves to keep the facility at capacity.

Emissions

The modelling procedure includes three GHG emissions (CO_2, N_2O, and CH_4). Crop production is responsible for most of the N_2O, and livestock for all of the CH_4 emissions. Carbon dioxide sources include herbicides, fertilizers, fossil fuel used in machines, and an allocation to the energy used to produce and maintain machines, plus a reduction in SOC if a production practice results in lower SOC. Nitrous oxide emissions are from nitrogen fertilizer, crop residues, and livestock manure (IPCC 2000). Methane sources include the animals and the livestock manure. The N_2O emission is converted to a CO_2-eq. at the conversion factor of 296, CH_4 is converted at 23. Carbon sequestration will reduce the total CO_2-eq. emissions from the farm, but sequestration will depend on the initial SOC level, the crop or crops produced, the tillage system, and the region of production. A moderate level of SOC is for a rotation with some fallow and conventional tillage (32.4 t/ha). The maximum SOC for annual cropping is for no summerfallow with either direct seeding or zero tillage (33.4 t/ha). The adjustment in soil organic carbon is annualized assuming a 20 year period of adjustment. This linear adjustment is reasonable given yearly variation in carbon production (yield) coupled with the model having a short-run specification.

GHG emissions from the optimal solution are used as the baseline to determine the abatement costs of reducing GHGs. Net CO_2-eq. emission is constrained by defining an upper limit to the CO_2-eq. accounting variable. For a 5% reduction, the upper limit is set at (1-0.05) times the CO_2-eq. emitted in the baseline solution. The marginal abatement cost is the shadow value of CO_2-eq. The abatement cost function is simulated over a range of GHG reductions up to 90%, if feasible.

There will be differences in abatement costs depending on the initial SOC and production technologies. Two levels of initial SOC are used in the analysis. The moderate SOC level is that which would be typical of farms practising soil conservation in the region in the early 1990s, characterized by some minimum tillage and some summerfallow. The high level is the expected equilibrium level for production practices with no tillage and continuous annual cropping. Irrespective of the initial SOC level, increased abatement will increase the marginal abatement cost and reduce net returns.

RESULTS

The optimal cropping system is continuous cropping with land allocated to barley silage production for livestock feed, one-quarter of the land devoted to lentil, and the remaining to durum wheat. The silage and lentils are produced with minium tillage and durum with direct seeding. Historical cropping for the region of analysis has been about 40% fallow. In this analysis the yield difference between a crop after fallow and a crop following another crop was relatively small (SCI 2005), so there was no economic benefit from fallowing land. Fertilizer rates approximate the optimal rate for farms in this region. Livestock feeding is with a high concentrate ration. Feed barley is purchased, rather than grown on the farm. The optimal system emits 1505 t CO_2-eq., with most being CH_4 from the 1000 head of livestock. Dividing the emissions between crops and livestock is confounded by some of the interdependencies, however, estimates of emissions from crop and livestock production are in Table 1. The values reported in Table 1 are for high initial SOC, and livestock numbers could either vary or are fixed with GHG reduction levels. The pattern is similar for the moderate initial SOC, the marginal abatement cost (MAC) commences to increase at higher levels of GHG reduction.

The optimal cropping system emits 0.56 t CO_2-eq./ha, and livestock emits 0.94 t CO_2-

eq./hd of capacity. About 40% of the crop emissions were CO_2 from production activities and inputs, 40% from N_2O, and 20% from CO_2 emissions from the soil because barley silage and lentil are grown with minimum tillage. For livestock, about 90% of emissions are from methane. Emissions from manure are allocated to crop production because manure displaces inorganic fertilizer that would contribute to emissions.

Emission reductions in GHGs are for 5 to 80% of the base emission level. With the option to reduce livestock numbers to meet the targeted reduction. Reductions greater than 80% are not feasible. With livestock numbers fixed, reductions in GHG emissions greater than 25% are not feasible. The least costly reduction in GHG emissions is from the elimination of tillage for the barley silage and lentil. When livestock numbers are not fixed, the least costly means of reducing total emissions for the farm is to reduce the number of cattle fed. The MAC of reducing GHG emissions is \$32/t CO_2-eq. when livestock numbers are reduced. With very high reduction in GHG emissions, 70-80%, reductions are met by not feeding any cattle and by reducing fertilizer rates and altering crop mixes. At these high rates of reduction, an increasing proportion of land is allocated to hay production at very low rates of fertilization, and annual crop production also has low rates of fertilizer application. With a 70% reduction, the MAC is \$272/t CO_2-eq. and at 80% it is \$567/t (Figure 1).

When livestock numbers are fixed and GHG emissions are reduced, the flexibility for reducing emissions is limited. Total farm emissions can be reduced by switching to the low weight gaining ration. The emissions from the lower weight gaining ration are lower for the farm only because fewer animals are fed each year. Emission are lower on a per animal of capacity basis, but higher on a per animal finished basis. The optimal livestock system (high rate of gain) emits about 12% more methane than the low gain system, but finishes twice as many animals so the emissions per animal finished are 43% lower than for the low rate of gain. Emissions could be reduced by altering the livestock system, however the costs are high, so most of the adjustment to reduced GHGs is on the crop sector. A 5% reduction in farm GHG emissions is met primarily by switching from minimum to zero tillage for barley silage and lentil. A 10% reduction requires changes to the crops produced and fertilizer rates are reduced to low levels. The crop production system at the 10% reduction is similar to the 70% reduction when livestock numbers were not fixed. The MAC at the 10% level is \$273/t CO_2-eq. Reduction in GHG levels prior to being infeasible did result in a change to the lower gain feed ration, but this change combined with cropping system changes was costly (Figure 1).

The initial SOC level impacted the results by shifting the MAC (Figure 1). With a lower initial SOC level, the MAC is shifted down and the magnitude of the shift is in proportion to the difference in the initial SOC and the maximum level of SOC that can be attained. The MAC for a moderate level of SOC, when livestock numbers were not fixed is \$32/t CO_2-eq. up to the 90% reduction. When livestock numbers are fixed, the MAC is \$32/t CO_2-eq. for 15% reduction and increases up to the 40% GHG reduction (a 50% reduction is infeasible).

In summary, the optimal production system for both crops and livestock is very efficient in terms of GHG emissions. The production management options to further reduce net GHG emissions are limited, especially for cattle feeding. Reducing tillage is the least costly method of reductions on the farm. For the farm, reducing the number of cattle on feed is the next least costly means of reducing total farm emissions. Finally, cropping using low rates of fertilizer and crops requiring low rates of fertilization, and altering the cattle diet are very costly methods of reducing emissions.

The potential to reduce GHG emissions on an integrated crop-cattle finishing farm is primarily dependent on current SOC and the ability to use management to reduce the rate of organic matter decomposition in the soil. If a production system has been in place for several years and has increased SOC to its maximum level, there is very little potential to further reduce net GHG emissions because carbon can no longer be sequestered in the soil, and there is limited potential to reduce emissions from the livestock system used in this study. Under these conditions, further reductions in net GHG emissions will be costly and can only be attained by sub-optimal fertilizer application rates. Marginal abatement costs under these conditions easily exceed most other cost estimates from forestry and agriculture (Antle et al 2001, DeCara and Jayet 2000, Lee and McCarl 2003).

CONCLUSIONS

There is limited potential to reduce net GHG emissions from crop-cattle feeding integrated farms. Crop management practices including direct seeding or zero tillage and no summerfallow are optimal both in terms of the technical benefits of carbon sequestration and the economic feasibility to adopt these management practices. Generally, the least costly option to reduce net GHG emissions is to reduce tillage to direct seed or zero-till. Utilizing less fertilizer is costly in terms of foregone production. Cattle finishing offers few options to reduce emissions, and those that exist are costly.

Antle, J. M., S. M. Capalbo, S. Mooney, E. T. Elliott and K. H. Paustian. 2001. Economic analysis of agricultural soil carbon sequestration: An integrated assessment approach. *Journal of Agricultural and Resource Economics*. 26(2): 334-367.

De Cara, S. and P-A Jayet. 2000. Emissions of greenhouse gases from agriculture: the heterogeneity of abatement costs in France. *European Review of Agricultural Economics*. 27(3): 281-303.

Environment Canada.2005. Summary Canada's 2003 Greenhouse gas inventory. http://www.ec.gc.ca/pdb/ghg/2005summary/2005summary_e.cfm Accessed June 8, 2005.

Gray, R., D. Harper, and T. Highmoore. 2001. Greenhouse gas policies and the international competitiveness of the hog sector. A paper presented at the International Agricultural Trade Research Consortium Annual Meeting, Auckland, New Zealand.

IPCC.(Intergovernmental Panel on Climate Change) 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/gp/english/4_Agriculture.pdf

Lee, H-C. and B. A. McCarl. 2003. The dynamic competitiveness of U.S. agricultural and forest carbon sequestration. University of Western Ontario Working Paper. Available at http://www.ssc.uwo.ca/economics/econref/html/RRPaper.html.

McKenzie, R. H., A. B. Middleton, L. Hall, J. DeMulder and E. Bremer. 2004. Fertilizer response of barley grain in south and central Alberta. *Canadian Journal of Soil Science*. 84: 513-523.

McKenzie, E. Bremer, C. A. Grant, A. M. Johnson, J. DeMulder and A. B. Middleton. 2005. Yield and protein response of spring wheat to nitrogen fertilizer. *Canadian Journal of Soil Science*. (In review).

Mooney, S., J. Antle, S. Capalbo and K. Paustian. 2004. Design and costs of a measurement protocol for trades in soil carbon credits. *Canadian Journal of Agricultural Economics*. 52(3): 257-287.

Saskatchewan Crop Insurance (SCI). 2005. 2004 Insurance Cost Calculator. Available at: http://www.saskcropinsurance.com/ciinteractive/inscalc.shtml.

Sohngen, B. and R. Mendelsohn. 2003. An optimal control model of forest carbon sequestration. *American Journal of Agricultural Economics*. 85(2): 448-457.

Statistics Canada. 1991. 1991 Census of Agriculture. Ministry of Industry, Science and Technology. Various Issues.

Statistics Canada. 2001. 2001 Census of Agriculture. Available at: http://www.statcan.ca/english/freepub/95F0301XIE/tables.htm#use

UNFCCC (United Nations Framework Convention on Climate Change). 2005. Land-Use Land-Use Change and Forestry. Available at http://unfccc.int/methods_and_science/lulucf/items/1984.php

Table 1. Greenhouse gas emissions by enterprise and scenario, initial high soil organic carbon.

	Livestock not Fixed			Livestock Fixed		
Scenario	Crop	Livestock	MAC	Crop	Livestock	MAC
	t/ha	t/hd	$/t	t/ha	t/hd	$/t
Base	0.56	0.94	0	0.56	0.94	0
Reduce 5%	0.49	0.94	32	0.45	0.94	32
Reduce 10%	0.45	0.94	32	0.40	0.94	272
Reduce 15%				0.29	0.94	272
Reduce 20%	0.46	0.94	32	0.28	0.94	621
Reduce 25%				0.22	0.91	1500
Reduce 30%	0.46	0.94	32	infeasible		
Reduce 40%	0.47	0.94	32			
Reduce 50%	0.47	0.94	32			
Reduce 60%	0.48	0.94	32			
Reduce 70%	0.45	NL	272			
Reduce 80%	0.30	NL	567			
Reduce 90%	infeasible					

NL indicates no livestock in the solution.

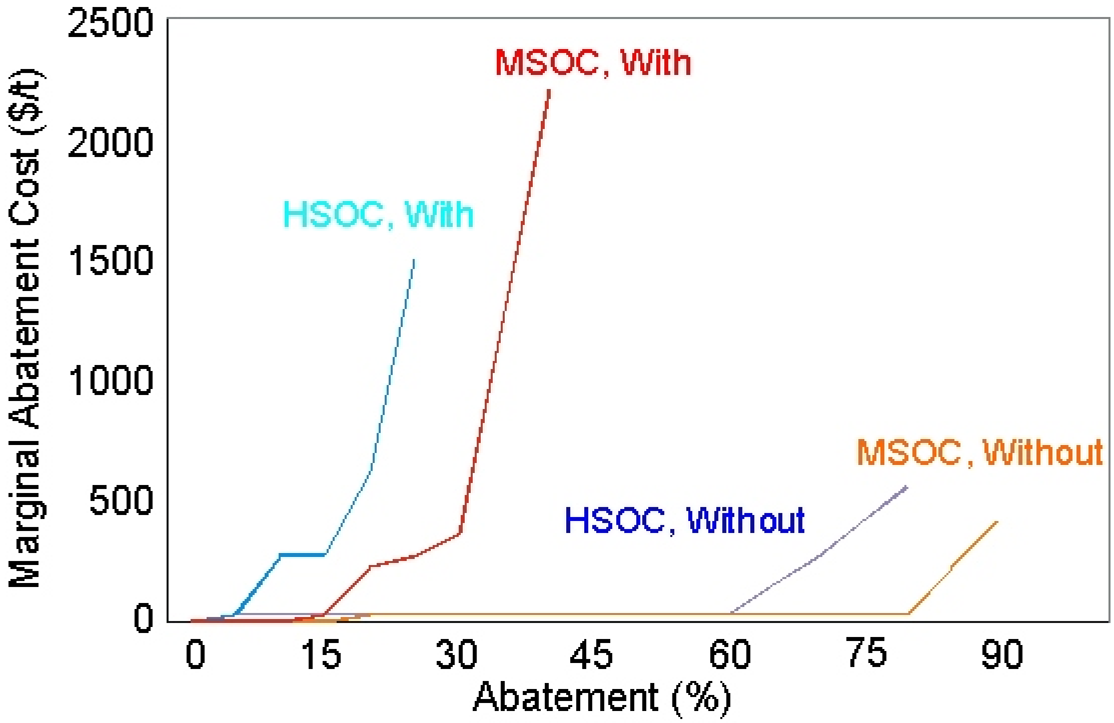

Figure 1. Marginal abatement cost of reducing net CO_2-eq. for an integrated crop and livestock feeding farm, for two initial soil organic carbon levels. (HSOC is initial high soil organic carbon, MSOC is initial moderate soil organic carbon, Without is allowing cattle numbers to be reduced, With keeps cattle numbers constant.)