Agriculture's Likely Role in Meeting Canada's Kyoto Commitments*

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Voluntary adoption of beneficial management practices will be the primary means by which farmers cut net greenhouse gas (GHG) emissions. The offset system will not be a major driver due to (a) the relatively low prices likely to be offered by large final emitters facing an emission cap, (b) discounts applied to those prices for temporary sequestration, (c) the transaction costs and risk premiums associated with signing carbon contracts, and (d) the low elasticity of supply of CO_2 *abatement. Although Canadian farmers are likely to participate to only a limited extent in the carbon-offset market, many will find it profitable to adopt one or more of the BMPs for reducing net GHG emissions. Canadian agriculture is likely to contribute significantly to net emission reductions by voluntarily sequestering carbon due to the adoption of zero till in the last decade, and possibly by cutting fertilizer levels in the next decade. The contribution will be mainly a response to meeting personal economic objectives rather than being induced by direct incentives through the offset program.*

L'adoption volontaire de pratiques de gestion bénéfiques (PGB) sera le principal moyen dont les producteurs disposeront pour diminuer les émissions de gaz à effet de serre (GES). Le système de compensation des GES ne constituera pas un facteur de motivation important pour les raisons suivantes: a) les faibles prix qu'offriront probablement les grands émetteurs finaux confrontés à un plafond d'émissions; b) les escomptes appliqués à ces prix pour la séquestration temporaire; c) les coûts de transaction et les primes de risque associés à la conclusion de contrats de réduction des émissions de carbone; d) la faible élasticité de l'offre de réduction du CO_2*. Bien que la participation des producteurs canadiens au marché de contrepartie de la fixation du carbone sera probablement limitée, de nombreux producteurs trouveront qu'il est rentable d'adopter une ou plusieurs PGB pour réduire l'émission nette de GES. L'apport de l'agriculture canadienne à la réduction nette des émissions sera probablement important compte tenu de la séquestration volontaire du carbone découlant de l'adoption du semis direct au cours de la dernière décennie et de la diminution probable des concentrations de fertilisants au cours de la prochaine décennie. L'apport sera principalement lié à l'atteinte d'objectifs économiques personnels plutôt qu'aux incitatifs directs du programme de contrepartie de la fixation du carbone.*

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INTRODUCTION

Agriculture could play a major role in meeting Canada's commitment to reduce greenhouse gases (GHGs) as specified under the Kyoto Protocol. The reductions could result from three potential avenues. One is a direct reduction in emissions, which from agriculture are primarily in the form of nitrous oxide and methane. A second avenue is through offset options associated with the production of biofuels and biomass energy that would replace traditional energy sources and consequently lower GHG emission levels. A third option is the sequestration of carbon through the use of management practices such as reduced tillage. The extent to which agriculture plays a role in meeting Kyoto commitments under the three avenues depends, to some extent, on the incentives created directly or indirectly by government policy.

Although Kyoto was not directly mentioned, it was addressed implicitly in the February 2005 budget by the Canadian federal government, which provided $5 billion for measures primarily focused on the development and adoption of environmental technologies (Department of Finance 2005). For example, the Clean Fund is designed to encourage cost-effective projects that reduce GHGs and the EnerGuide for Houses program provides grants to homeowners to improve the energy rating of their homes. Similar awareness and incentives to induce the voluntary adoption of GHG-reducing practices specifically for the agricultural sector were announced in 2000 under the Greenhouse Gas Mitigation Program for Canadian Agriculture. Other economic instruments such as subsidies to promote adoption of environmental friendly practices are used on a local basis in Canada while others, such as linking subsidies to support payments, are not presently used (Weersink et al 1998).

An alternative policy mechanism that will be forthcoming in the next year and will be applicable for all sectors of the Canadian economy is a carbon market. The government will establish acceptable levels of emission levels for large final emitters and those firms can then trade the right to emit GHGs. While not considered a large final emitter and consequently not facing GHG emission restrictions, agriculture could serve as a supplier of abatement to the market through its carbon sequestration and/or emission reduction activities.

The purpose of this paper is to assess the extent to which agriculture will likely be part of meeting Canada's Kyoto commitments through direct means induced by the carbon market or indirectly through the voluntary adoption of GHG-reducing practices. The paper begins by describing the three policy mechanisms that could affect the extent to which net GHG emissions are reduced: moral suasion, an offset market, and an inventory accounting system. The third section of the paper presents a conceptual model of a supply curve for carbon credits, which is kinked due to the transactions costs of an offset contract. The following section reviews the empirical evidence on the factors influencing this supply curve including the potential price of carbon, the costs of a contract, and the opportunity cost of sequestration and emission reduction activities relative to their net GHG emission reduction potential. On the basis of the data, we argue that involvement by farmers in the offset market will be limited but that there will be net GHG emission reductions from agriculture through voluntary adoption partially prompted by government extension efforts. The paper concludes with the implications for the role that agriculture will play in meeting Canada's Kyoto commitments. The paper does not canvas the merits of Canada's GHG policies, nor does it focus on the considerable technical uncertainties underlying the issue of climate change. Rather, we take the policies as given, and consider their likely influence on agriculture, as well as the likely contributions of agriculture to GHG targets.

GHG POLICIES FOR CANADIAN AGRICULTURE

A goal of the Canadian government is to reduce agricultural GHG emissions by approximately 10% or by 5.8 MT per year of CO_2-equivalent during the commitment period of 2008–12. The means to achieve these reductions primarily involve encouraging the development and adoption of beneficial management practices that could cut GHG emissions or sequester carbon. Another means not targeted specifically toward agriculture but that could possibly involve the sector is a carbon market that would pay farmers for sequestration or emission reduction activities. Both the voluntary adoption of BMPs and the adoption of BMPs induced by a carbon contract and their subsequent affect on net GHG emissions will be monitored as part of a national GHG inventory reporting system.

Development and Education Programs

The changes to Canadian agricultural policy for directly addressing Kyoto commitments are small and are focused on developing and encouraging the voluntary adoption of practices that either reduce GHG emissions or increase carbon sinks. Programs include the Model Farm Program, Enhanced Shelterbelts Program, and Biofuels Program. For example, $5 million was allocated under the Model Farm Program to develop methods for estimating net GHG emissions from farms and to evaluate GHG mitigation practices (Agriculture and Agri-Food Canada (AAFC) 2005a).

The Model Farm Program is linked to the Greenhouse Gas Mitigation Program for Canadian Agriculture, which is the major program for achieving the GHG reduction targets. It is composed of three elements (AAFC 2005a). The first is the identification of BMPs that reduce GHG emissions in comparison to current practices. Advisory committees of scientists and industry personnel are to identify the appropriate packages of BMPs to cut net GHG levels on the farm and to provide guidance for program delivery. The second element is to raise awareness of these BMPs among producers and to encourage their adoption through demonstrations and other communication activities. The demonstration sites are selected and promoted by industry groups. The final element is the measurement and verification of GHG emission coefficients on the demonstration sites. This component is linked to the Model Farm Program, as information on emissions levels will be used in the development of computer models for predicting of GHG levels under alternative management and biophysical conditions (AAFC 2005b).

Carbon Trading

The concept of trading pollutants has grown in popularity since the success of tradable permits for lowering sulphur dioxide emissions in the United States (Ellerman 2000). It is also a recognized policy mechanism under Kyoto that countries can use to create incentives for reducing GHG emissions. For example, the European Union has implemented a cap and trade system (Emission Trading Scheme) and Canada is finalizing its own trading program. The Canadian GHG offsets system will impose emissions targets on large final emitters that are concentrated in the electrical generation, oil and gas, mining, and manufacturing sectors. The large final emitters can purchase or sell the emission permits domestically among other large final emitters, purchase emission reductions from Appendix B countries, or purchase emission removals from projects that supply carbon sinks (Government of Canada 2005).

Agriculture in Canada will not face emissions restrictions that would force farmers to be potential purchasers of GHG permits, at least during the first commitment period. However, farmers could still be involved in a carbon market by supplying carbon credits through sequestration activities, such as reduced tillage, reduced summer fallow, and increased perennial forages and pasture. While these credits are temporary in nature, farmers could also supply permanent emission reductions through activities primarily related to animal waste and fertilizer. The potential role for agriculture to be involved in a carbon trading system is uniquely confined to Canada as agricultural sinks are not presently allowed in the EU Emission Trading Scheme and other regions with sink potentials have not ratified Kyoto (e.g., USA and Australia) or face institutional barriers (e.g., Russia).

GHG Inventory System

Whether through voluntary adoption of practices promoted in part through the awareness efforts of the GHG Mitigation Program in Agriculture or through the inducements provided by a carbon market, there is a need to track the extent of the changes and their resulting impact on net GHG emissions. Canada is obliged under the United Nations Framework Convention on Climate Change (UNFCCC) to provide an annual national inventory of GHG emissions and this has been produced by Environment Canada since 1992. However, the ratification of Kyoto requires the development of a mandatory, domestic GHG reporting system that is more detailed and disaggregated than the current inventory program. The goal is to have a single-window reporting system harmonized across all jurisdictions in place by the start of the first Kyoto commitment period. The initial implementation phase that will form the basis of the system has just begun and requires facilities emitting more than 100 Kt of CO_2-equivalent annually to report their 2004 emissions of six GHGs by June 1, 2005 (Environment Canada 2004).

The national inventory system has a subcomponent that is focused on agriculture. The National Carbon and Greenhouse Gas Emission Accounting and Verification System (NCGAVS) will estimate soil carbon stocks and nitrous oxide emissions for Canadian agricultural land. NCGAVS takes data on the land area allocated to agricultural activities and multiplies it by the level of net GHG emissions for that practice under local conditions. The estimates are derived at the Soil Landscapes of Canada polygon level and scaled up to provide regional, provincial, and national GHG measures. The coefficients for net emissions are based on scientific experiments, computer simulation models (such as developed under the Model Farm Program), and IPCC estimates. Information on the use of farm activities, such as tillage, changes in crop type and mix, fertilizer application levels, and animal numbers, will be gathered from a variety of sources including the Census of Agriculture, industry association data, and satellite imagery. The accounting system for soil carbon levels and CO_2 and N_2O emissions from agricultural land will be in place during 2005 while methane and N_2O emissions from enteric fermentation will be incorporated into NCGAVS at a later date (AAFC 2005c).

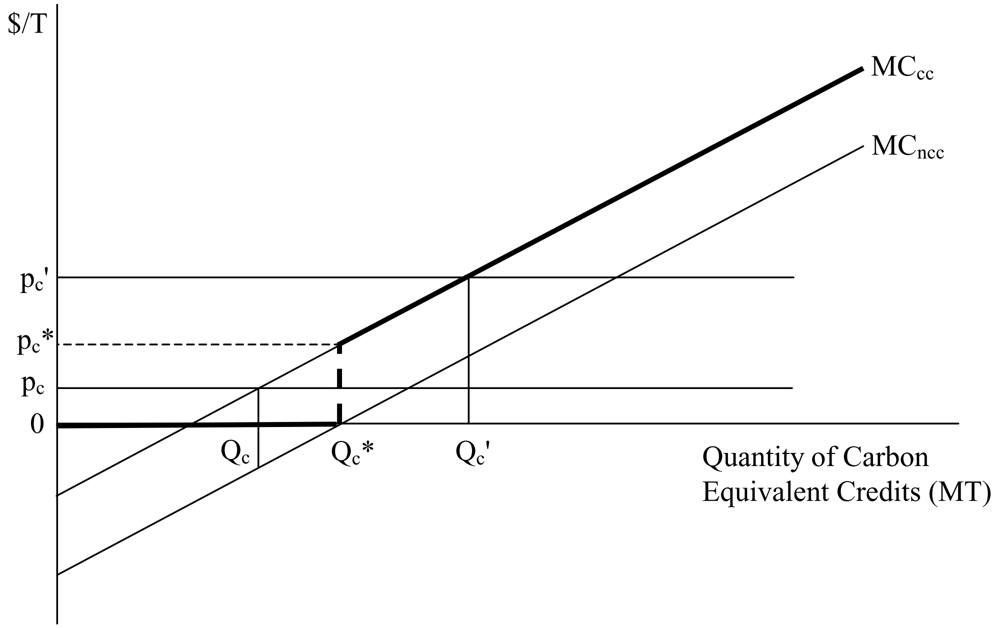

Figure 1. Determination of the supply curve of carbon for the offset market

THEORETICAL MODEL OF NET-GHG SUPPLY ACTIVITIES

The previous section highlighted the policy initiatives that could affect the role Canadian agriculture plays in meeting domestic GHG commitments under the Kyoto Protocol. Agriculture will either voluntarily adopt sequestration activities or practices that cut emissions or these will be induced by incentives created through a carbon market. Whether Canadian farmers supply carbon credits in an offset market depends on the market price for offsets relative to their marginal cost of supply.

The derivation of the supply curve of carbon from agriculture for the offset market is illustrated in Figure 1. The horizontal axis is measured in the amount of CO_2-equivalents that can be in the form of sequestered carbon or N_2O and/or CH_4 emissions reductions relative to a baseline year. For ease of exposition, we discuss the supply curve initially in terms of sequestered carbon rather than N_2O and CH_4 emission cuts but then refer the position of the resulting supply curve to the abatement activities of those gases.

The curve MC_{ncc} shows the marginal cost of sequestering another tonne of carbon when farmers adopt BMPs that sequester carbon but do not sign a carbon offset contract (ncc = no carbon contract). The supply curve without an offset market includes all costs (including opportunity costs) associated with adopting BMPs and will be upward sloping to reflect the fact that some farmers have lower marginal costs of sequestration than do other farmers, and that within a farm higher levels of sequestration come at a higher marginal cost. The distribution of costs among farmers for the BMPs results in farmers adopting the sequestration practices, to some extent, without any direct inducement from a carbon market or government. For farmers with a negative $\mathrm{MC}_{\mathrm{ncc}}$, the adoption of BMPs that sequester carbon will increase profits. Voluntary adoption results in sequestration of an amount CO_2 equal to Q_c^*. Increasing the profitability of BMPs (e.g., through R&D) will shift this MC curve downwards and subsequently increase voluntary adoption and the amount of carbon sequestered. If adoption increases over time, the change in Q_c^* will be documented by the national inventory system and help Canada meets its Kyoto commitments.

Rather than relying solely on voluntary adoption to increase net GHG emission reductions, the farmer could be induced to provide more of these activities through an offset market. The curve $\mathrm{MC}_{\mathrm{cc}}$ shows the marginal sequestration cost when farmers sign a carbon offset contract (cc = carbon contract). Note that in order to sign the offset contract, the farmer will have to adopt BMPs that sequester carbon. Thus, the $\mathrm{MC}_{\mathrm{cc}}$ curve lies on or above the $\mathrm{MC}_{\mathrm{ncc}}$ curve because of factors such as the transaction costs associated with signing a carbon offset contract, the option value that farmers attach to the potential to wait to sign the contract at a later date, and the risk premium that farmers require to take on the risk of signing a contract. Transaction costs refer to the time spent in search, negotiation, verification, and enforcement of a contract. These costs will be higher for a product such as sequestered carbon that is costly to observe and will vary across time and space. There are also significant adjustment costs to adopting the BMPs for sequestering carbon since the investments are large and require systematic changes to management systems rather than simple, incremental changes. There are also liability risks associated with the release of carbon that increase the cost of a carbon contract to both parties.

If a carbon offset market develops, farmers must decide whether to participate. We will assume initially that the producer can only offer new carbon contracts above Q_c^* to the market. This assumption captures the case where farmers who undertake BMPs, such as zero till, prior to the Kyoto commitment period cannot subsequently offer the sequestered carbon for trading on the carbon market. Since farmers can always adopt the BMPs and not sign the contract, they have to determine whether undertaking this action will generate higher returns sufficient to cover the incremental transaction costs. In Figure 1, farmers will prefer to simply adopt BMPs without signing the carbon offset contract as long as the carbon offset price is less than or equal to p_c^*, the transaction costs associated with the contract. For prices below p_c^*, the amount of carbon sequestered will be Q_c^* and this will captured through voluntary efforts; no additional carbon will be offered for trade in the offset market.

As the carbon offset price rises above the critical value of p_c^*, a shift occurs. Farmers that were previously not participating in the carbon market, but nevertheless sequestering carbon (i.e., the farmers that were sequestering the quantity Q_c^*), will continue to do so, but may increase their sequestration and offer the increase to the market. As well, some additional farmers will find it profitable to adopt BMPs and sign a carbon contract. The combined result is that the amount of carbon sequestered will rise above Q_c^*. For example, in Figure 1, when the carbon offset price is p_c', the quantity of carbon that will be sequestered under contract will be Q_c'. As a result of the costs of signing a carbon offset contract, the supply curve for carbon offsets is kinked (see the dark line in the Figure 1). The presence of this kink means that there is a range of prices (i.e., those below or equal to p_c^*) for which no carbon offsets will be generated. When the price moves above p_c^*, the quantity of carbon offsets supplied to the market can be expected to increase depending on the supply elasticity.

The situation is different if we assume that farmers can offer any amount of carbon credits rather than just those beyond what they are voluntarily providing as assumed previously (i.e., farmers can be paid for CO_2 abatement activities that they would have adopted even without payment). If marginal costs are only increased by transaction costs for those carbon abatement activities that are offered to the market, there is the potential for some positive credits offered on the market even if the carbon price is below the threshold. Indeed, the supply curve for CO_2 abatement credits would become the MC_{cc} line. For example, if the carbon price in Figure 1 is p_c ($p_c < p_c^*$), then the farmer can profitably offer Q_c credits to the carbon market. In addition, the farmer would voluntarily sequester $Q_c^* - Q_c$, so the total amount sequestered remains unchanged at Q_c^*. However, allowing credits to be paid for activities that would have been voluntarily adopted without the offset programs creates a potential adverse selection problem. Credits could be paid without making any actual difference to the level of carbon sequestration.

The above analysis provides important insights for the operation of the carbon market. As a result of the kink in the supply curve (assuming credits can only be paid on abatement beyond Q_c^*), there is no guarantee that the demand and supply curve will intersect. If the demand curve for carbon lies below the top section of the supply curve, then no market will exist for carbon offsets. No carbon offsets will be generated, even though large final emitters would be willing to purchase them at a positive price. A market for carbon offsets will only emerge if the demand for carbon offsets is sufficiently high—i.e., if the demand curve cuts the supply curve in the upward sloping portion.

EMPIRICAL EVIDENCE

The extent to which either sequestered carbon or emission reductions are offered for sale in the offset market depends critically on comparing the carbon price to the marginal costs of enrolling in a contract (the size of the vertical shift in the supply curve). While the offset price for sequestered carbon will be lower than the price for a permanent emission reduction due to the temporary nature of the stored carbon, the marginal costs of signing such a contract are also potentially lower. Another factor influencing the likelihood of involvement in the offset market is the slope of the supply curve. In this section we discuss the empirical evidence on the elements of the theoretical supply curve illustrated in Figure 1 and conclude with an approximation of a supply curve for sequestered carbon for Canadian agriculture.

Voluntary Adoption of BMPs (Q^*)

In this section we consider the extent to which carbon credits may make a difference to the adoption of BMPs for CO_2 abatement. The adoption of BMPs will continue to be primarily a voluntary process that involves more than just considering financial and risk-related factors. Without any direct incentives such as an offset market, the area of conservation tillage and permanent cover has increased and the area of summer fallow has fallen, resulting in Canadian agriculture changing from a net source of CO_2 in 1990 of 5.8 MT per year of CO_2-equivalent to a net sink in 2001 of 9.6 MT per year of CO_2-equivalent (Boehm et al 2004). To assess the likelihood of continued increases in sequestration along with the potential for emission reductions from voluntary adoption, we begin with an overview of factors necessary to spur adoption. These drivers, along with current profitability estimates, are then used to assess the potential adoption and emission reduction potential of major BMPs for each GHG.

Pannell et al (2005) conducted a detailed review of landholder adoption of conservation practices, considering three broad aspects of the issue: (a) adoption as a process of learning and skill development; (b) social, cultural, and personal influences on adoption decisions; and (c) characteristics of conservation practices that encourage their adoption. Here we will focus on the third of these categories and the two broad categories of characteristics of a technology that drive its adoption or nonadoption: the innovation's relative advantage and its trialability.

Relative advantage means "the degree to which an innovation is perceived as being better than the idea [or technology] it supersedes" (Rogers 2003, p. 229). Relative advantage depends on the landholder's unique set of goals and the biophysical, economic, and social context where the innovation will be used. Relative advantage depends on a range of economic, social, and environmental factors, such as the innovation's profitability, adjustment costs, complexity, and compatibility with existing technologies and beliefs. The crucial role of "relative advantage" as a driver of adoption, and the importance of profit as one of the key drivers for most farmers, has strong implications for conservation technologies. Among those farmers with a focus on profit, the farm-level economics of the conservation technologies will be most important. Those conservation technologies that are not profitable at the farm level will tend to be adopted only by farmers with stronger conservation goals. Conservation land uses that require adoption at large scale to generate conservation benefits will probably not be adopted sufficiently if they are perceived to be less profitable than the land uses they replace.

The trialability of an innovation refers to how easily the farmer can learn about its performance and optimal management. Trialability has been found to enhance adoption (e.g., Ohlmer et al 1998). Trialling an innovation provides information that reduces uncertainty about the relative advantage of the technology. Thus, trialling is important because it can increase the probability of the farmer making a correct decision about the technology. Trialling also provides an opportunity for the farmer to learn the skills needed to apply the innovation. The small-scale nature of a trial allows the farmer to avoid the risk of large financial costs if the technology turns out to be uneconomic or fails due to inexperience. The trialability of a technology is affected by a number of factors, including the divisibility of an innovation (Leathers and Smale 1992), the observability of results, the costs of a trial, and the complexity of the innovation.

Carbon Sequestration

The relative advantage and trialability of conservation tillage and reducing summer fallow resulted in Canadian agricultural soils becoming a net sink rather than a net source over the 1990s. Zero tillage is now practiced on 32% of Prairie cropland and Boehm et al (2004) estimate that the level of carbon sequestered could approximately triple to 30 MT per year of CO_2-equivalent by 2008 if the adoption rate of no-till doubles and if the area of summer fallow is reduced from 4.7 to 1.5 million hectares.

Profitability comparisons of conventional and reduced tillage are inconclusive, which is consistent with the common use of both tillage methods. In general, the likelihood of adoption in a region increases with the coarseness of the soil and decreases with the level of precipitation. The mixed adoption pattern is also consistent with several studies that have estimated a supply curve for sequestered carbon from agriculture. For example, Antle et al (2001, 2002) for Montana farmers, Pautsch et al (2001) for Iowa farmers, and Manley et al (2005) across many farm regions using meta-analysis, all found that initial carbon can be sequestered at very little cost to producers. Agricultural sinks would be supplied in some cases at costs of less than $10 per tonne of C but all three studies found that the carbon price required to induce significant adoption of BMPs for sinking carbon increases significantly with the increases in carbon required. This indicates that there is a limit to the voluntary level of adoption for conservation tillage and that the area under no-till may not increase substantially unless further technological advances increase its relative advantage in situations where it is currently not adopted.

Nitrous Oxide Reductions

Nitrous oxide emissions from manure, legumes, and fertilizer use are estimated to represent 70% of global nitrous oxide emissions and approximately 60% of total GHG emissions from Canadian agriculture (National Climate Change Process, Analysis and Modeling Group 1999). Direct emissions are primarily associated with fertilizer-induced emissions from the soil and emissions from organic fertilizer, while indirect emissions are from nitrous fractions of fertilizers that were translocated by leaching or volatilization and then emitted as N_2O. The IPCC (1997) estimates that 1.25% of the nitrogen applied will be released as N_2O so emission reductions exclusively involve reducing application levels.

While Adams et al (1992) estimated that costs equivalent to $50 per tonne of carbon would result from a restriction on fertilizer use, several other studies have found that reducing nitrogen fertilizer use outright or indirectly through improved crop management techniques, such as soil testing, can reduce both emissions and farm costs (Trachtenberg and Ogg 1994; AAFC 1999; Meyer-Aurich et al 2004). As with reduced tillage, this highlights the limited value of point estimates for marginal costs. In reality there is a wide range of costs, including within an individual farm, depending on the local conditions and the degree of abatement/adoption. The above point-estimates of costs or returns from reducing fertilizer use also do not account for possible influences of risk aversion on farmers' preferred fertilizer rates, or the possibility of applying extra fertilizer to take advantage of optimal weather conditions if they should occur (Babcock and Blackner 1994). In those conditions, the opportunity cost of reducing fertilizer use can be particularly high.

Overall, there appears to be significant potential to reduce N_2O emissions at the margin. Assessments of the relative advantages of cutting fertilizer application levels have not accounted for the flat response of yield to nitrogen around the economic optimum (Janovicek and Stewart 2004). The nature of the production function suggests that application rates could be reduced without significantly affecting profitability.

In addition to meeting the relative advantage criteria, it is also easy for the farmer to learn about performance and optimal management of a system for which he is already acquainted, as would be the case for variations in fertilizer rates. Application rates can be reduced partially and attempted on small plots so there is high degree of divisibility in the practice. In addition, the results of the trials are easily observable. New technologies that increase the ease of measuring soil fertility and potential regulations in many regions forcing farmers to assess fertilizer requirements through nutrient management plans will increase the care in which application rates are determined. Combining the characteristics of the technology along with the nature of the yield response function to nitrogen suggest that there is significant potential for fertilizer reductions by Canadian agriculture and subsequently cuts in nitrous oxide emissions.

Methane Reductions

The IPCC (2001) estimates that 50% of global methane emissions are from agriculture sources associated with rice, ruminants, and manure and 40% of Canadian GHG emissions are in the form of methane. The major sources of anthropogenic methane emissions from Canadian agriculture are farm animals (80%) and manure (20%) (Janzen et al 1998). The manure management systems for lowering GHG emissions are lumpy in nature and generally require significant capital investment or actual cuts in inventory numbers. Reducing protein levels in swine feed within Canada could reduce methane emissions at a relatively low cost but the total amount of reduction is small (AAFC 1999). Adding edible oils to livestock rations may also reduce CH_4 production by inhibiting the activity of CH_4-producing bacteria but the practice may not always be economical (AAFC 2003). Ionophores are feed additives that inhibit the formation of CH_4 by rumen bacteria but are already widely used in beef production (AAFC 2003), so there is limited scope for further abatement from this source. Manure management strategies could also reduce methane emissions but the costs are equivalent to approximately $200 per tonne of C for strategies such as digesters (Gibbs 1998) or alternative storage and application techniques (de Vos et al 2003). The range in estimates for methane abatement costs partially reflects the large degree of uncertainty in the amount of methane reduced with alternative practices. In most cases, the BMPs for reducing methane emissions are more likely to be profitable when a new livestock operation is established rather than refitting an existing facility (de Vos et al 2003). The relative disadvantage of methane-reducing techniques for existing livestock farms and the costs of trialling these technologies that tend to involve significant capital investments and are not divisible, suggest that voluntary adoption of BMPs to reduce methane emissions will be limited.

Slope of Supply Curve

As was illustrated in Figure 1, the total amount of carbon sequestered or emissions reduced may increase with the carbon offset price, provided that the price is above the transaction cost. The rate of change depends on the extent of the difference in profitability between the BMP and the present practice along with the amount of net emission reductions generated by the BMP. For individual farmers, the means to reduce net GHG emissions involve systematic changes in their operating systems rather than small, incremental changes. For example, increasing the amount of carbon sequestered involves reducing tillage or taking cropland out of production. Similarly, other than changes in ration, reductions in methane generally require abatement techniques that involve significant fixed investment costs, such as such as manure digesters.

The result is that the supply curve of net emission reductions for individual farmers is discontinuous with no changes in net emissions for a range of prices and with a change in BMP prompted by a sufficiently high carbon price. A further increase in price is then required to induce another systematic change in practice and subsequently net emission reductions. The result is that the aggregate supply curve is more likely to be inelastic than if reductions could be generated through small, continuous changes in management practices.

There is empirical support for a supply curve that is increasingly inelastic because of diminishing returns to carbon sequestration activities. Antle et al (2002), for instance, find that the supply elasticity of soil carbon sequestration associated with continuous cropping falls from the 0.65–0.70 range when marginal cost is approximately $US 7.00 per tonne CO_2, to the 0.20–0.30 range when marginal cost is approximately $US 35.00 per tonne CO_2.

Carbon Contract Costs ($MC_{cc} - MC_{cncc}$)

Even if the reservation prices for switching practices are less than the carbon prices offered by large final emitters, many farmers will be reluctant to sign a carbon contract for three major reasons: transaction costs, the temporary nature of the credit, and inflexibility (Fulton et al 2005). These three factors constitute the gap between MC_{cc} and MC_{ncc} and contribute to the kinked nature of the supply curve for sequestered carbon shown in Figure 1.

The transaction costs of exchanging credits supplied from the agricultural sector may be prohibitive in many cases. A report for the Canadian government estimated that monitoring and certifying credits across all sectors would cost between $0.4 and $2 per tonne of CO_2 (Marbeck Resource Consultants 2004). These costs will be shared, albeit not equally, between the contracting parties but may be above the price per unit of a temporary credit for sequestered carbon.

The transaction costs depend on the ability to measure and the size of the contract. The costs of measuring the annual amount of carbon accumulated could be relatively large since the actual level varies temporally and spatially with site and management characteristics. Rather than measure the amount of carbon sequestered annually on individual farms, an alternative will be to observe the practices employed by the farmer and generate an estimate of the carbon accumulated over the time period.[1] The estimates can be provided through computer simulation models such as those being developed under the Model Farm Program. Verification costs would be reduced since the measurement costs of observing management practices such as conservation tillage or cutting summer fallow area are less than having to monitor actual changes in carbon levels in the soil. As an example, the Saskatchewan Soil Crop Improvement Association (SSCA) has contracted with a number of existing no-till farmers to continue conservation tillage under Environment Canada's Pilot Emission Removals, Reductions and Learning Initiative (PERRL). The SSCA is paying farmers $2–6 per acre for farmers using zero tillage depending on the soil type and will attempt to sell the aggregated total credits in the future (McClinton 2005). The measurement costs are potentially higher for nitrous oxide and methane if actual measurements were conducted on each individual farm. However, as with sequestered carbon, it is likely that IPCC coefficients on emission reductions will be used to determine the size of the available credits from alternative abatement activities.

The problems of measurement costs are accentuated by the relatively small scale of the carbon involved. For example, assuming a Prairie farm of 1500 ha that can optimistically sequester 0.5 T of C per ha, the total amount of carbon available for sale is 750 T. Rosenzweig et al (2002) suggest that farmers are unlikely to be able to individually support contracts which have been traded in amounts larger than 1,000 T. Levels of nitrous oxide and methane generated at the individual farm level will also not meet this threshold with the exception of large, intensive livestock operations. The transaction costs of organizing the exchange of such amounts of carbon would offset the value to the larger emitters at predicted carbon prices. Aggregators, such as AgCert and producer organizations, are assembling smaller amounts of net emission reductions from a number of farmers and packaging them into contracts for sale to large emitters so as to reduce the transaction costs.

Finally, the threshold price does not consider the cost of being locked into a carbon contract. The loss of flexibility imposed on the farmer with the conditions of a carbon contract results in a cost that decreases the benefits of the contract. Vercammen (2002) estimated that the option value or premium to compensate for being restricted to undertake the sequestration activities could be in the range of \$2.75–4.00 per tonne CO_2. Other risks such as potential changes in policy that alter carbon prices (i.e., carbon prices would increase if the US ratified Kyoto) or risks associated with the potential release of stored carbon would further increase the risk premium required by a farmer before signing a carbon contract.

Carbon Price (p_c)

Although abatement costs for large industrial emitters have been estimated to be \$100 per tonne of C (Weyant and Hill 1999), forecast estimates for a carbon price are in the area of \$US 5–10 per tonne CO_2 (Springer 2003) for permanent abatement. The price would rise if the US ratified Kyoto and/or Russia was not allowed to include its so-called hot-air associated with the reduction in their GHG emissions from the 1990 baseline due primarily to the fall in economic activity. However, the carbon price paid by large final emitters cannot rise past \$Cdn 15 per tonne of CO_2-equivalent for permanent abatement under the Canadian offset system. Thus, the market price for carbon is relatively low and is likely to be insufficient to induce substantial farmer involvement.

The above carbon price is for a permanent emission reduction and is thus applicable for abatement activities such as alternative manure handling and application techniques. For example, AgCert has contracted with large swine operations in Canada to change their time of manure application from fall to spring and will in turn attempt to sell the accumulated emission reduction credits in the domestic offset market (Bolton 2005). In contrast, the carbon sequestered by agricultural sinks is only stored temporarily and will be released with a change in practices. The lack of permanence for a carbon credit from agricultural sequestration means that such credits sold are considered temporary and would only allow a purchasing large final emitter to delay its abatement activities. The result is that the price for a temporary carbon credit from sequestration activities is likely to be discounted significantly from the \$15 maximum in the Canadian system for permanent credit. The magnitude of this discount is not yet known, although conceptual analysis suggests discounting factors of between 0.5 and 0.05 (e.g., if a permanent credit was selling for \$10 per tonne of CO_2-equivalent, a temporary credit may sell for anywhere between \$0.50 per tonne and \$5.00 per tonne).

Potential Supply Curve of Carbon Sequestration

Overall, it appears that prices for carbon will be small relative to the range of opportunity costs of carbon abatement, so that the existence of carbon credits will make little to

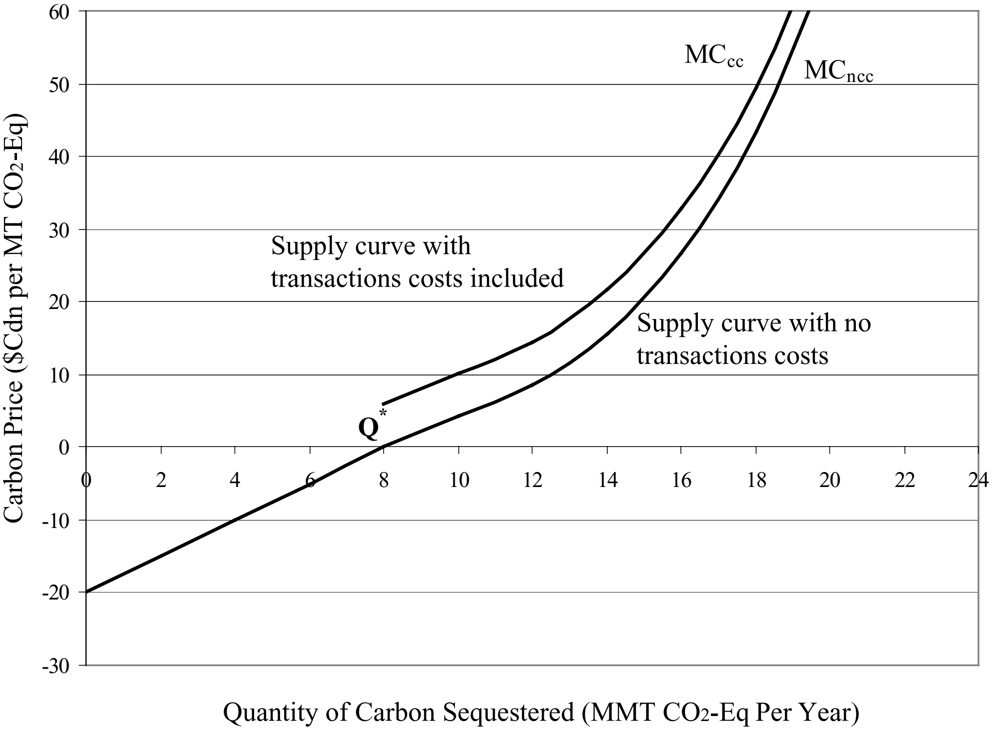

Figure 2. Potential supply curve for carbon sequestration from Canadian agriculture

the level of CO_2 abatement above the level that would have occurred voluntarily. The consequences of this are illustrated in Figure 2, which shows a version of Figure 1 drawn approximately to scale. Figure 2 shows our estimate of the supply curve for soil carbon sequestration for Canada, based on the evidence presented in the previous sections.

The level of carbon sequestered voluntarily of approximately 8 MT per year of CO_2 equivalents (quantity Q_c^* in Figure 1) is based on estimates from Boehm et al (2004). The curvature of the supply curve is based on an elasticity estimate of approximately 0.25 based on the work by Antle et al (2002) and the low, medium, and high adoption scenarios outlined in Boehm et al (2004). For carbon sequestration amounts less than Q_c^*, the supply elasticity is assumed to be approximately unitary. The solid black line indicates the projected level of carbon sequestered for alternative carbon prices assuming no transaction costs (MC_{ncc} in Figure 1). Transaction costs are estimated to be $6.00 per tonne CO_2 (Marbeck Resource Consultants 2004) and shifts up the supply curve to the dotted line in Figure 2 (MC_{cc} line in Figure 1). Given the maximum price offered under the Canadian offset system will be $15, the maximum amount of carbon offered by farmers under the offset system would be approximately 4 MT above the current 8 MT given the above assumptions and if the carbon was stored permanently. However, sequestered carbon is likely to be considered as a temporary credit that would allow purchasers of the credit to delay their reductions. Using a discount factor of 0.2, the resulting maximum price of approximately \$3 (0.2 × 15) will be less than the threshold price (p_c^* in Figure 1) of \$6. Thus, no carbon would be supplied by farmers to the offset market. Thus, the predicted impact of carbon credits on the supply of carbon offsets from agriculture is likely to be small, particularly when the discounting of temporary credits is included.

The combination of comparatively low potential carbon prices to the marginal cost of enrolling in an offset contract and the relative steepness of the supply curve indicates that the offset market will not make a significant difference to the level of CO_2 abatement in Canadian agriculture. Trades presently being arranged involve farmers who are already using the practice voluntarily, such as no-till, or for whom the cost of changing is negligible, such as moving manure application from fall to spring. These trades will result in only a small portion of targeted net emission reductions from agriculture.

SUMMARY

Canadian policy for reducing net GHG emissions from agriculture is focused primarily on moral suasion efforts. We consider that such efforts will probably have little effect on the ultimate level of CO_2 abatement, as voluntary farmer adoption of BMPs will be driven primarily by their economic attractiveness, rather than suasion. The GHG mitigation program for Canadian agriculture is intended to develop and promote the adoption of activities that reduce GHG emissions or increase the use of carbon sinks. Whether spurred by the extension efforts undertaken by this program or not, voluntary adoption of beneficial management practices will be the primary means by which farmers cut net GHG emissions. The offset system will not be a major driver due to (a) the relatively low prices likely to be offered by large final emitters facing an emission cap, (b) discounts applied to those prices for temporary sequestration, (c) the transaction costs and risk premiums associated with signing carbon contracts, and (d) the low elasticity of supply of CO_2 abatement.

Although Canadian farmers are likely to participate to only a limited extent in the carbon-offset market, many will find it profitable to adopt one or more of the BMPs for reducing net GHG emissions. For example, the significant increase in the adoption of no-till and the reduction of summer fallow has transformed Canadian agriculture from a net source of carbon to a net sink over the last decade. However, without additional technological advances the relative advantage of no-till has likely been largely taken advantage of by the present adopters. Similarly, net emission reductions for methane are unlikely to arise over the commitment period due to the low trialability of the large systematic changes required for abatement practices on existing livestock operations. However, Canadian agriculture may provide significant net emission reductions of nitrous oxide emissions through cuts in fertilizer application levels. Such cuts may be achievable at low cost due to the flat response function. These reductions will be aided by technologies and regulations that will encourage closer assessment of soil fertility needs and subsequent application levels, as well as higher energy prices. In addition, the reductions in nitrogen use involve systems that can be experimented with and observed easily. As a result, Canadian agriculture is likely to contribute significantly to net emission reductions by voluntarily sequestering carbon due to the adoption of zero till in the last decade, and possibly by cutting fertilizer levels in the next decade. The contribution will be mainly a response to meeting personal economic objectives rather than being induced by direct incentives through the offset program.

While acknowledging the importance of voluntary adoption of BMPs in reducing net emissions, we must be aware of the limitations on the likely extent of adoption and the influence of relative prices. The performances of BMPs are highly variable from place to place, and are only likely to have a positive relative advantage in a proportion of situations, possibly a minority. Their relative profitability may also vary over time depending on market prices. Even if they are profitable, there are other factors that may negatively influence their relative advantage, and factors that limit their trialability. Overall, history shows that expectations about adoption need to be tempered, for almost any sort of innovation. In addition, input and output prices can influence adoption and the impact on net emissions. For example, continued increases in fuel prices may increase the adoption rate of conservation tillage, which requires fewer field operations and thus less fuel consumption than conventional tillage. A reliance on voluntary adoption of BMPs to meet net emission targets requires an ongoing evaluation of the farm-level economics of BMPs. If BMPs are not sufficiently attractive, a role exists for technical R&D to create new BMPs that will be economically attractive to producers.

NOTE

[1] Mooney et al (2004) estimate the effect of regional heterogeneity in carbon values and its associated uncertainty on the costs of measuring carbon and suggest that it could be as low as 3% of the value of the credit.

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