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# An Economic Analysis of the Potential Influence of Carbon Credits on Farm Management Practices[1]

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## The Issue

The objective of the 1997 Kyoto agreement was to limit greenhouse gas (GHG) emissions among signatory countries and thereby slow global warming. Under the agreement, Canada has committed itself to reduce GHGs over the next decade by 6 percent from estimated 1990 levels. Debate has now begun on the appropriate government policies that will induce the desired GHG reductions. Regulations could be in the form of direct controls or economic incentives, such as a subsidy/tax system or an emission trading system. The success of the U.S. emission market for $SO_2$ (Schmalensee et al., 1998) has generated growing interest in the use of a similar market mechanism for carbon (Holmes and Friedman, 2000).

The existence of a carbon credit market presents the agricultural sector with another potential revenue source (Sandor and Skees, 1999). While agriculture contributes approximately 10 percent of Canada's greenhouse gas emissions, it also has the potential to sequester carbon through strategies such as zero tillage, reduced summer fallow and improved grazing. These sequestration activities could be incorporated into an emission trading system and create a "carbon credit" for each unit of $CO_2$ that is removed from the atmosphere. Firms with high emission reduction costs could then buy these credits rather than bear the large abatement costs associated with reducing their GHG emission levels. The perception is that the marginal cost of abatement for agriculture is less than that for other sectors (McCarl and Schneider, 2000). Thus, farmers may be able to profit by selling credits for activities that sequester carbon. An example of such a transaction was the purchase of carbon credits from Iowa farmers who adopted no-till by a consortium of Canadian energy companies (GEMCO) (Lessiter, 1999). Whether the development of a carbon credit market will affect the management decisions of an Ontario crop farmer is the focus of this study.

## Implications and Conclusions

The profit maximizing situation for the representative Ontario crop farmer involved growing 200 acres of corn, 100 acres of soybeans and 100 acres of winter wheat under conventional tillage. The net farm return was $54,239 under this base scenario for a 400 acre farm and 59 tons of carbon was sequestered. The presence of a carbon market and the subsequent ability to sell carbon credits will increase revenues but by less than $1.50 per acre at optimistic carbon prices of $10 per ton. When the market price of carbon reaches $191 per ton, the farmer is willing to switch from conventional tillage to no-till since the value of the carbon credit is sufficient to cover the loss in income. Increasing all crop prices will increase the difference in relative profitability between tillage systems and will therefore increase the threshold price. Changes in the mix of crops grown within a rotation with fixed crop prices will only occur with carbon prices in excess of $1,000 per ton given the small relative differences in carbon sequestration ability between crops considered. Using alternative carbon sequestration coefficients generated from the Century biophysical simulation model rather than from local experimental data, the threshold carbon price inducing a change in tillage system falls to $151 per ton. In addition, forage would be the best option with a carbon price of $51 per ton. Given that present market prices for carbon are less than $5 per ton, Ontario crop farmers could possibly increase revenues with their existing practices but are unlikely to change practices in the near future.

## Background

The agricultural sector generates approximately 9.5 percent of Canadian GHG emissions not including the use of fossil fuels or the indirect emissions from fertilizer production (Desjardins and Riznek, 2000). Of the 67 Mt of $CO_2$ equivalents generated annually by agriculture, less than 2 percent is through $CO_2$ emissions, 35 percent is from methane and the remainder is in the form of nitrous oxide (National Climate Change Process, Analysis and Modelling Group, 1999). Although agriculture generates GHGs, it also has the potential to sequester significant amounts of carbon. When soils are first put into agricultural production, up to 50 percent of the carbon tied up in the soil is released

(Rasmussen and Parton, 1994). This stock can be recaptured through practices such as conversion of marginal land back to native pasture, adoption of conservation tillage, reduction of summer fallow and use of cover crops (Lal et al., 1998).

Several studies have looked at the economics of sequestering carbon in agricultural soils. Antle et al. (2001) estimated the marginal costs of sequestering carbon for three million hectares in Montana if farmers switched from a rotation using summer fallow to continuous cropping. Pautsch et al. (2001) conducted a similar analysis but their study focused on the costs of moving from conventional to conservation tillage for farmers in Iowa (nine million hectares). The marginal costs ranged from zero to $700 per tonne of carbon depending on the level of carbon sequestered. In a comparison of the two studies, Antle et al. (2002) found that initially higher carbon levels could be sequestered more cheaply in Montana due to the difference in opportunity costs. However, more carbon could be sequestered in total by Iowa producers as the price of carbon rose due to the larger amount of farmland and the higher sequestration levels associated with the switch in tillage system versus a rotational switch. Similar estimates for switching tillage practices have been found for prairie agriculture in Canada by Kulshreshtha, Jenkins and Desjardins (2000). Adams et al. (1999) estimated the average costs of carbon sequestration associated with planting trees on agricultural lands to be approximately $25 per tonne of carbon.

These previous studies suggest carbon could be sequestered by agriculture at a cost of $10 to $35 per tonne of carbon. Non-agricultural firms with abatement costs higher than these estimated average costs of carbon sequestration will be willing to pay farmers to change practices. McCarl and Schneider (2000) conclude in their review that the costs of carbon emission reductions in other sectors exceed $100 per tonne of carbon. Thus, if the costs of reducing greenhouse gases in the farm sector are less than the abatement costs in other sectors of the economy, non-agricultural firms will want to purchase emission reduction credits from farms in order to reduce their total costs of abatement.

Although there is not a formal carbon market in place, nor have allowable standards on individual firm emission levels of carbon been established, contracts have been negotiated. Energy companies in particular have approached farm groups about selling credits for the carbon sequestered by practices such as no-till, suggesting that there is a demand for emission reduction credits that farmers may be able to supply. The relative demand and supply pressures will establish the price for the good as in any market and that price will determine the decisions of the market participants. This study examines the price levels for carbon that will alter the production decisions of a crop farmer in southwestern Ontario.

# Empirical Model

The optimal choice of management activities for carbon sequestration can be readily determined within a linear programming (LP) model that considers the technical possibilities of substitution between activities, the levels of GHG emissions from these activities, and their prices/costs. In the LP model developed for this study, the farmer is assumed to maximize net farm returns subject to constraints on available land (400 acres) and crop rotation restrictions. The farmer can choose between three different crops (corn, soybeans and winter wheat), although at least 25 percent of the available land must be planted to each crop. The farmer can also choose to plant these rotations using one of three tillage systems: conventional, chisel and no-till. The farmer may also decide to plant all farmland into permanent pasture and sell the hay crop. The management choice is influenced not only by the yields, prices and costs for each alternative but also by the possibility of selling carbon credits associated with the sequestration levels of each activity.

The returns and expenses associated with each of the crop rotation and tillage practice choice variables are summarized in table 1. Yield data for corn, soybeans, and winter wheat under each of the three tillage systems are from studies by Weersink et al. (1992) on the basis of experiments conducted in southern Ontario. Sales of crop production are based on respective average market prices from 1987 to 1997 as obtained from OMAFRA (2000a). Costs associated with each crop for the year 2000 are based on a survey of custom rates and variable expenses conducted by OMAFRA (OMAFRA, 2000b). Further details on the differences in individual expenses between crops for alternative tillage systems are provided in Joseph (2002).

The annual amount of carbon sequestered per acre varies with each activity. Conventional practices involve more frequent and higher disturbance tillage than minimum or zero tillage. By reducing soil disturbance and the rate of soil organic matter decomposition, conservation tillage practices enhance soil carbon sequestration (Janzen et al., 1998). While there is some consensus on the relative differences in sequestration levels between tillage practices, a range of values have been estimated. For example, the Canadian Economic and Emission Model for Agriculture (CEEMA) used by Agriculture Canada, has two sets of coefficients on practices for alternative prairie soil zones and tillage practices: one set of expert opinion coefficients and another derived by Smith et al. (1997) from the Century model (Kulshreshtha et al., 1999). The range in carbon sequestration coefficients may be due to the variability in the period of measurement in carbon change or to differences in climatic and environmental factors. For example, Lal et al. (1998) suggest that soil carbon will increase slowly over the first two to five years of improvements in soil management with larger increases between five to ten years, flattening off thereafter, and reaching a finite limit after about fifty years.

**Table 1** Net Returns for Alternative Choice Variables ($ / acre)

| | | Tillage system | | |
|---|---|---|---|---|
| **Crop** | | **Conventional** | **Chisel** | **No-till** |
| Corn | Yield (ton/acre) | 3.65 | 3.46 | 3.43 |
| | Revenue | $478.15 | $453.26 | $449.33 |
| | Expenses | 312.17 | 308.37 | 296.95 |
| | Net returns | $165.97 | $144.89 | $152.37 |
| Soybeans | Yield (ton/acre) | 1.24 | 1.25 | 1.09 |
| | Revenue | $354.64 | $357.50 | $311.74 |
| | Expenses | 214.39 | 211.62 | 197.46 |
| | Net returns | $140.25 | $145.88 | $114.27 |
| Winter wheat | Yield (ton/acre) | 2.13 | 2.16 | 2.10 |
| | Revenue | $302.46 | $306.72 | $298.20 |
| | Expenses | 232.28 | 229.65 | 216.87 |
| | Net returns | $70.17 | $77.05 | $81.32 |
| Forage | Yield (ton/acre) | | 2.75 | |
| | Revenue | | $214.50 | |
| | Expenses | | $130.41 | |
| | Net returns | | $84.09 | |

For the purpose of our model, carbon sequestration coefficients are based largely on a study by Yang and Kay (2000). A research trial with a crop rotation and tillage experiment on a Woolwich silt loam soil was conducted at the Elora Research Station of the University of Guelph. The estimated average organic carbon contents after twenty years and the annual rates of accumulation are listed in table 2 (columns 2 and 3, respectively). The annual rate of change in carbon was calculated by subtracting the base amount of carbon in the barley-barley-corn-corn rotation and annualizing it. For example, the annual rate of carbon sequestration of 0.34 $\mathrm{MgCha^{-1}}$ for continuous corn was found by taking the difference between its organic carbon content and the base (66.55 – 59.70 = 6.85) and dividing by 20 (6.85/20 = 0.34). The barley-corn rotation was considered the base practice, as it had the lowest carbon content and was common in southern Ontario twenty years ago.

Yang and Kay (2000) found no interactions between crop rotations and tillage systems. Thus, the amount of carbon sequestered by a given crop under a given tillage system was calculated by adding the annual amount sequestered by conversion from conventional tillage to no-till of 0.13 $\mathrm{MgCha^{-1}}$ from Smith et al. (1997) to the crop estimates obtained by Yang and Kay (2000) summarized in table 2. For example, the annual carbon sequestration coefficient for conventionally tilled corn was simply the value of 0.34 $\mathrm{MgCha^{-1}}$ (see table 2) estimated by Yang and Kay (2000) whereas the

**Table 2** Rotation and Tillage Effects on Soil Organic Carbon (MgCha$^{-1}$)

| Crop rotation / Tillage | Organic C content after 20 years | Annual accumulation |
|---|---|---|
| Continuous corn | 66.55 | 0.34 |
| Soy-soy-corn-corn | 65.15 | 0.27 |
| Soy-wheat-corn-corn | 66.82 | 0.36 |
| Barley-barley-corn-corn | 59.70 | 0.00 |
| Forage | 70.13 | 0.52 |
| Chisel plowing | 64.59 | 0.24 |
| Mouldboard plowing | 64.87 | 0.26 |

Source: Yang and Kay (2000)

amount sequestered by no-till corn adds 0.13 to this amount to result in 0.47 MgCha$^{-1}$ (or 0.19 ton ac$^{-1}$). The amount of carbon sequestered annually by each choice variable is summarized in table 3. The carbon sequestration coefficient for soybeans under conventional tillage of 0.20 MgCha$^{-1}$ was determined by taking the annual accumulation for the soy-corn rotation of 0.27 MgCha$^{-1}$ (see table 2) and subtracting off half of the amount that is sequestered by corn. The amount sequestered by soybeans under no-till adds 0.13 MgCha$^{-1}$ to the value for conventionally tilled soybeans, to result in 0.33 MgCha$^{-1}$yr$^{-1}$ (0.20+0.13) or 0.14 ton ac$^{-1}$yr$^{-1}$. The values for wheat were calculated in a similar manner and are summarized in table 3.

Given the uncertainty surrounding the appropriate carbon sequestration coefficients, an alternative set was also used in this study. Table 3 contains estimates provided by the Century model from Smith et al. (1997). In general, the Century model predicts lower sequestration values, but the relative differences between crops and tillage systems are similar to those estimated through the process described above with Yang and Kay estimates as the base. Conventional tillage is assumed to sequester little carbon while wheat does not sequester as much as in the Yang and Kay forecasts. The major difference is that forage production is predicted to sequester five times more carbon under the Century model than under the base model estimates.

## Results

The base model assumes there is no carbon market. Net farm returns generated from the 400 acres are maximized at $54,239, obtained from growing 200 acres of corn and 100 acres each of soybeans and winter wheat using a conventional tillage system. This rotation also maximizes profits under a no-till system. The total amount of carbon sequestered with the optimal solution is 59 tons and this cannot be sold under the base model scenario.

**Table 3** Annual Carbon Sequestration Coefficients (tons $ac^{-1}$ $yr^{-1}$)

| | Yang and Kay | | | Century model | | |
|---|---|---|---|---|---|---|
| | Conventional | No-till | Chisel | Conventional | No-till | Chisel |
| Corn | 0.14 | 0.19 | 0.13 | 0.00 | 0.07 | 0.02 |
| Soybeans | 0.08 | 0.14 | 0.08 | 0.04 | 0.12 | 0.06 |
| Wheat | 0.23 | 0.29 | 0.23 | 0.00 | 0.06 | 0.04 |
| Forage | | 0.22 | | | 1.02 | |

The presence of a carbon market will increase net returns to producers but the impact will not be significant. For example, assuming a carbon price of \$10 per ton, which is significantly greater than the current market price, the farmer under the base model solution would generate approximately \$1.50 per acre by being able to sell carbon credits (\$10/ton ∗ 0.1475 ton/acre), or \$600 at the farm level. It is questionable whether these returns would be sufficient to offset the transaction costs associated with the exchange. In order to determine the carbon prices that would induce a switch in management practices, we first examine tillage choice and then crop rotation.

Since a chisel plow system sequesters slightly less carbon than conventional tillage and is not as profitable, a carbon market will never induce a change from conventional to chisel plow under the base model carbon sequestration coefficients. However, a no-till system under the optimal rotation sequesters 0.2025 tons of carbon per acre [0.2025 = 0.19 ∗ .5 (corn) + 0.14 ∗ .25 (soybeans) + 0.29 ∗ .25 (wheat)]. Over the 400 acres, no-till sequesters 22 tons [(0.2025 ∗ 400) – 59] of carbon more than a conventional tillage system. Net farm returns for no-till are \$50,037, or \$4,202 lower than the conventional system with the same rotation. Thus, the price of carbon that will cause a shift in tillage system is \$191 (\$4190/22) per ton of carbon (see table 4).

If all crop prices increase by 10 percent, total revenues for both tillage systems rise but the difference in net returns between conventional and no-till increases to \$5,240 from \$4,202. Thus, higher crop prices increase the carbon price at which the farmer will switch tillage systems from \$191 to approximately \$238 (\$5240/22). Similarly, a 10 percent decrease in all crop prices reduces the farm returns generated by crop production and increases the attractiveness of revenue from a carbon market. The threshold price for carbon inducing the shift to no-till consequently drops to \$142 per ton.

Carbon prices will have to be even higher than the threshold necessary to cause a change in tillage system if a farmer with a set tillage system is to change crop rotations. For example, the price of wheat will have to increase by \$44.19 per ton to \$186.19 before wheat becomes the dominant crop in the rotation and is planted to half of the available cropland.[2] The price change will increase total revenue by \$94.12 per acre (\$44.19/ton ∗

**Table 4** Carbon Prices Required to Induce a Shift in Management Practices ($ per ton)

| **Practice switched from base results* to** | **Assumed carbon sequestration coefficients**** | |
|---|---|---|
| | **Yang and Kay** | **Century model** |
| No-till | 191 | 151 |
| Wheat grown<br>on 0.5 of rotation | 1,046 | n/a |
| Forage production | 284,179 | 51 |

* Base model has 200 acres corn, 100 acres soybeans and 100 acres of winter wheat planted using conventional tillage.

** Sequestration coefficients for alternative practices and crops with each method given in table 3.

2.13 ton/acre). With crop prices remaining constant as in table 1, the carbon price to induce the same change in rotation will have to be large enough to generate returns equal to this increase in revenue. Given that wheat sequesters 0.09 more tons of carbon per acre than corn (see table 3), the carbon price necessary to induce wheat rather than corn as the primary crop in the rotation must be $1046 per ton (= 94.12/.09) (see table 4). While wheat prices have increased recently to above this threshold level, it is unlikely that carbon prices would increase to the point that they have an effect on crop choices within a given tillage system.

The impact of a carbon market may be larger if alternative carbon sequestration coefficients are used. The results of using the sequestration estimates from the Century model are in column 3 of table 4. A carbon price of $151 per ton induces a switch to no-till. The difference in revenue between the two systems remains the same but no-till sequesters 28 more tons of carbon. Note that at carbon prices lower than this value a farmer using conventional tillage will generate small amounts of additional revenue, since only 4.0 tons of carbon are sequestered on the 400 acres. In addition, a carbon market based on the Century model sequestration coefficients will not affect the choice of wheat versus corn in the rotation since there is no or little difference in the amount of carbon taken up by these two crops under the Century model estimates.

The major difference in the carbon sequestration coefficients is in terms of the amount taken up by forage production. The Century model values predict that a hay crop sequesters over 100 times the amount sequesterd with the optimal crop rotation under conventional tillage. The difference in revenue between the two systems is $20,603 over the 400 acres. Thus, the price of carbon that will cause a shift from the base solution to a forage system is $51 ($20,603/404) per ton of carbon. In contrast, approximately 0.08 more tons of carbon per acre were sequestered with forage than the base system using coefficients generated with the Young and Kay estimates. The threshold carbon price was then close to $300,000 per ton.

## Concluding Remarks

The results of this study suggest the potential of a carbon credit market would not be a windfall gain for crop farmers in southwestern Ontario; these results contrast with the findings of previous studies for prairie agriculture. The opportunity costs are too high for Ontario farmers to change their management decisions at anticipated carbon prices, since there are relatively small differences in the amount of carbon sequestered between alternative practices and the land base available to sequester is much smaller than for western farmers. Carbon prices could be enhanced by government, since carbon-sequestering land-management practices may provide additional environmental benefits such as a reduction in erosion and chemical use, and could well increase the quality of wildlife habitats (Subak, 2000). However, even if the additional value of these benefits were included in the carbon price, it would not likely change the present practices of Ontario crop farmers.

The optimism surrounding the benefits to agriculture of a carbon credit market regardless of location must be tempered for several reasons. First, accurate measurements are necessary to quantify the carbon sequestration coefficients for any mitigation strategy. Since there are large spatial variations in carbon across a given field (VandenBygaart et al., 2002), there are unanswered questions surrounding which sequestration values to use and who should pay for sampling. Secondly, there is a temporal variation in addition to the spatial variation that will affect the value of the carbon. An initial switch in practices may sequester carbon but the rate of increase declines over time so that the practice eventually serves to store carbon rather than sequester new levels. Potential means for designing a mechanism to account for the temporary nature of carbon sinks are discussed by Feng et al. (2001). Third, carbon credit agreements may bring short-term revenue but also a long term obligation that increases costs in terms of reduced management flexibility. Finally, farmers may find themselves as buyers rather than sellers of credits if the emission market is extended to other greenhouse gases. GHG emission levels from agriculture are primarily associated with nitrous oxide and methane, and the impact of these emissions on radiation balances may prove to be much greater than the impact associated with the amount of carbon that is sequestered.

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# Endnotes

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[2] Details on the results of the sensitivity analysis for other model parameters are available from the authors upon request.