TERRESTRIAL CARBON SEQUESTRATION POTENTIAL IN SOUTHWEST NORTH DAKOTA

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EXECUTIVE SUMMARY

The primary goal of this study was to evaluate the economic potential for carbon (C) sequestration on cropland in Adams, Bowman, Hettinger, and Slope Counties in southwest North Dakota. Agriculture in the region is dominated by dryland small grain production and livestock grazing.

The methodological framework used is generally consistent with a static analysis using one-time decision making where the highest expected net present value of various alternatives is selected. The options considered in the study included
1) maintaining current farm practices,
2) switching tillage practices, or
3) converting cropland to permanent grass.

Crop production in the region was represented by 11 different combinations of profitability and tillage practices. Each combination was represented annually from 2005 through 2009 by a composite acre budget. Another set of composite acre budgets represented the projected net returns when a producer switches from his/her existing tillage system to an alternative tillage practice (e.g., conventional tillage operators could switch to conservation or no-till practices). The discounted present value of the stream of C payments plus discounted net returns from crop production associated with the existing tillage practice were compared to the present value of potential C payments plus discounted net returns associated with a switch in tillage practices. In addition, the value of converting cropland to perennial grass was evaluated for each profitability and tillage group.

A baseline analysis indicated that in the absence of external C incentives, by 2024, the 1.1 million acres of planted cropland in the region would sequester about 130,000 metric tons (MT) of C annually. Cumulatively, from 2005 to 2024, the region was estimated to sequester about 2.4 million metric tons (MMT) of soil C on cropland.

Six C prices, ranging from $10 to $125 per MT, were used to evaluate potential changes in land management and land use that could occur with C incentives. Total C sequestered at a price of $10 per MT represented a 3.5 percent increase over baseline levels. By contrast, with $100 per MT, cumulative soil C storage increased to nearly 6.1 MMT, a 151 percent increase over baseline levels.

Consistent with other economic studies of soil C sequestration, low C prices (≤$25 per MT) triggered some changes in land management and, to a lesser extent, changes in land use. However, substantial gains in C sequestration did not occur until C prices reached $50 or higher per MT. Greater amounts of C sequestration, relative to baseline projections, were not realized at low C prices because many of the changes in tillage systems shown to take place with similar C prices in other economic studies have already occurred in the study region. Two specific findings are noteworthy. First, the economic attractiveness of various C-sequestering activities varies by farm profitability. For example, with C priced at $25 per MT, the most economically advantageous option for low-profitability producers was to convert cropland to permanent grass, average profitability producers would switch tillage systems, and high-profitability producers would find no economic incentive to switch either land management or land use. Second, contrary to many economic studies suggesting that conversion of cropland to perennial grass in the upper Great Plains is not economically competitive with other C sequestration activities, results from this analysis suggest that, by including modest revenues from co-products, perennial grass is an economically viable alterative to crop production.

Despite the rather narrow focus of this study, it demonstrates that gains in C sequestration are likely to occur with relatively low C prices in the upper Great Plains portion of the Plains CO_2 Reduction (PCOR) Partnership region. Some changes in agricultural land management and use will occur with relatively low C prices, although the amount of C sequestration stimulated with low C payments is likely to be less than levels previously estimated in some economic assessments because of ongoing abandonment of summer fallow and adoption of conservation tillage practices. Thus agricultural soils can still serve as a low-cost option for C sequestration, albeit at levels substantially less than what have been suggested by technical assessments of soil C sequestration potential.

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BACKGROUND/INTRODUCTION

As one of seven Regional Carbon Sequestration Partnerships (RCSPs), the Plains CO_2 Reduction (PCOR) Partnership is working to identify cost-effective carbon dioxide (CO_2) sequestration systems for the PCOR Partnership region and, in future efforts, to facilitate and manage the demonstration and deployment of these technologies. In this phase of the project, the PCOR Partnership is characterizing the technical issues, enhancing the public's understanding of CO_2 sequestration, identifying the most promising opportunities for sequestration in the region, and detailing an action plan for the demonstration of regional CO_2 sequestration opportunities. This report focuses on the economic potential to sequester carbon in the cropland of southwest North Dakota.

Global debate on greenhouse gas emissions has led to recognition of the need to curtail or reduce greenhouse gas emissions to mitigate global climate change. Early in the debate on global warming and greenhouse gas emissions, agricultural soils were identified as a potential depository of atmospheric CO_2 (Moulton and Richards, 1990; Parks and Hardie, 1995). The interest in agricultural soils, within the framework of global warming, is important since soils can either be a source of greenhouse gas emissions or store atmospheric CO_2 through a variety of natural processes.

Given the depleted level of soil carbon (C) in most soils and the ability of soils to store atmospheric CO_2 in the form of organic matter, agricultural lands have been viewed as a means to mitigate greenhouse gas emissions (Lal et al., 1998, 1999). Agricultural lands can be used as a terrestrial sink for atmospheric CO_2 by changing the management and/or use of those lands, which has prompted soil scientists to place technical thresholds on the C sequestration capacity of soils.

Several studies on soil C sequestration have attempted to place a range on the technical potential or capacity for C sequestration that could occur through changes in land management and/or land use. While most studies estimating the technical capacity of agricultural lands to store C have been largely based on aggregated data, these studies have been widely used to illustrate the upper bounds of C sequestration potential on U.S. agricultural soils. Not accounting for changes in land use, current estimates of the technical potential of U.S. agricultural lands to sequester C range from 89 to 318 million metric tons (MMT) per year (Lewandrowski et al., 2004). In addition to changes in land management, Lewandrowski et al. (2004) estimated the technical potential of afforestation of U.S. cropland at 83 to 181 MMT of C annually over the first 15 years of tree growth. Also, Lewandrowski et al. (2004) estimated the technical sequestration potential of shifting about 105 million acres of highly erodible cropland into permanent grasses at 26 to 54 MMT of C annually over a 15-year period.

Agricultural lands currently are viewed as having substantial technical potential to sequester atmospheric CO_2 in the form of soil carbon. However, most agricultural lands in the United States are in private ownership, and changes in land management and/or land use are subject to market forces and profit-maximizing goals of individual landowners and producers. As a result, economic issues associated with terrestrial C sequestration are an important consideration when examining the role that agricultural lands will play in mitigating greenhouse gas emissions.

The changes in land *management* that enhance soil C storage include reducing tillage intensity and frequency, eliminating tillage, changing crop rotations, using winter cover crops, eliminating summer fallow, improving fertilizer management, adjusting irrigation methods, implementing buffer or conservation strips, and changing grazing regimes (Lal et al., 1999; Eve et al., 2000; Follet et al., 2001; Lewandrowski et al., 2004). The most common changes in land *use* that enhance soil C storage include participation in conservation programs, conversion of cropland to perennial grasses, afforestation, and restoring wetlands (Lal et al., 1999; Eve et al., 2000; Follet et al., 2001; Lewandrowski et al., 2004). To date, most economic assessments of land management and land use changes to increase C sequestration primarily have focused on switching tillage practices, changing crop rotations, eliminating summer fallow, shifting land to permanent grass, and afforestation.

Study Goals

The primary goal was to evaluate the economic potential of carbon sequestration activities on cropland in southwest North Dakota as part of a regional assessment performed under Phase I of the PCOR Partnership. Specific objectives included the following:

1) Evaluate economic incentives needed to influence changes in land management

2) Evaluate economic incentives needed to influence changes in land use

3) Estimate the economic potential for soil carbon sequestration

Scope

Soil type, crop rotations, precipitation rates, tillage practices, and economics of production agriculture vary throughout North Dakota and the Great Plains region. Given resource constraints and the diversity of conditions affecting soil C sequestration throughout North Dakota and the Great Plains region, it was necessary to limit the geographic scope of the study and limit the number of sequestration activities analyzed.

Economic assessments of soil C sequestration require some measurement of the rate of C accumulation in soils. Most economic studies have not used actual field data to measure changes in soil C storage, but rather have relied on a variety of secondary sources (e.g., ecological simulation models) to generate estimates of soil C storage. Data from field trials, specific to soil types, growing conditions, and production practices would be an improvement over using secondary sources or simulation results for purposes of economic modeling. As part of the PCOR Partnership, the effects of land management and land use on soil C are being evaluated at the Hettinger Research and Extension Center (HREC) in Hettinger, North Dakota. The geographic scope of this study was limited to a four-county region in the southwest corner of North Dakota to coincide with the same soil type, growing conditions, and production practices associated with ongoing research at the HREC (Figure 1). The study area is characterized as having a middle latitude steppe climate.

While a number of production-related activities have been identified that will increase C sequestration in cropland, this study limited the activities to changes in tillage practices and conversion of cropland to permanent grasses. Because of climate and soils within the study region, afforestation was not included in the analysis. Use of cover crops and conservation buffers, improved fertilizer management, changes in irrigation methods, and wetland restoration were also excluded.

Methodology

The approach used in this study was to estimate the expected net present value of three possible alternatives: 1) maintaining current farm practices, 2) switching tillage practices, or 3) converting cropland to permanent grass. A fundamental assumption in this study was that landowners/producers are willing and able to implement the activity(s) that yield the greatest net revenue. Production risk and

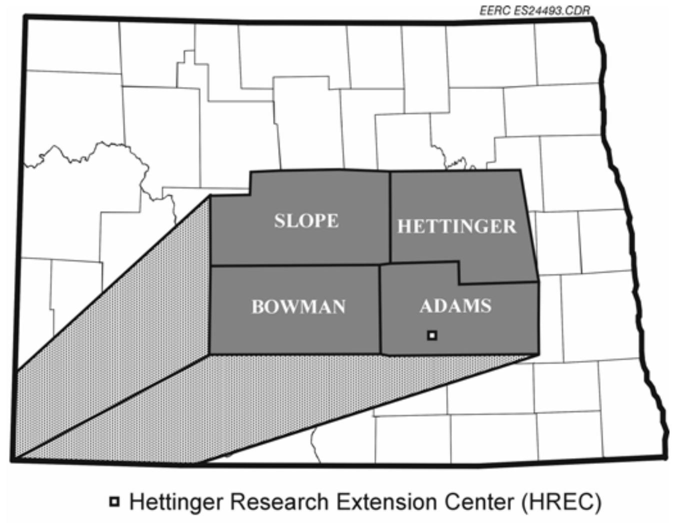

Figure 1. Study counties, North Dakota.

behavioral impediments to adoption of C-sequestering activities were not considered in the analysis.

Carbon payments were based on assuming permanent soil C sequestration, although the payment stream for producers was limited to a 20-year time horizon. Since a 20-year time frame was considered, issues pertaining to C stock equilibrium were not addressed. Carbon prices were modeled after a market-based system, and as a result, no restrictions were placed on the management of permanent grass. Carbon payments would be based on gross sequestration, and leakage associated with activities on other lands (e.g., rangeland) was not included in the model. Leakage on cropland was avoided by assuming all land under operator control would be included in C sequestration activities.

The above framework is generally consistent with other static modeling analyses using one-time decision making, and although the framework used in this study does not address all of the economic concerns associated with C sequestration, the general approach has been successful in providing insights on the initial economic feasibility of C sequestration activities on agricultural soils (Antle et al., 2001; Pautsch et al., 2001; McCarl and Schneider, 2001).

Data requirements for the study included determining the extent of existing tillage practices in the region, crop rotations within the region, expected future crop yields and anticipated prices, region-specific C sequestration rates, and discounted net returns from existing and alternative production practices. In addition, data were collected on yield, price, and cost factors associated with low-, average-, and high-profitability producers.

Tillage Practices

Tillage systems generally are categorized by the frequency, intensity, and sequence of field operations used to produce crops. Although specific tillage operations by individual producers rarely are consistent from year to year or from crop to crop, for any given geographic area, tillage practices can be placed into three broad classifications (Weston, 1994; Veseth and Karow, 1999; U.S. Department of Agriculture, 2004). Conventional tillage is characterized by intensive spring and fall tillage and generally results in little crop residue (<15 percent) on the soil surface. Conservation tillage is characterized by a reduction in tillage intensity and/or frequency when compared to conventional tillage and includes some level of soil disturbance in spring and fall, but results in more crop residue (15 to 30 percent) on the soil surface than conventional tillage. Some specialized tillage systems, such as ridge till and mulch till, are often grouped into the broad definition of conservation tillage. Also, conservation tillage, minimum tillage, and reduced tillage are terms often used interchangeably for the same basic set of production practices. No-till systems, sometimes included in the category of conservation tillage, have minimum soil disturbance in the spring and no soil disturbance in the fall and result in more crop residue (>30 percent) on the soil surface than other tillage systems. The difficulty in comparing actual field operations among the three practices is that the classification of tillage types (e.g., conservation tillage vs. conventional tillage) varies by region, crop, and year. As a result, the three generally accepted tillage systems were specifically defined by individual field operations.

In western North Dakota, *conventional* tillage was defined to include some spring tillage, a planting operation, and some level of reduced-intensity tillage in the fall. *Conservation* tillage was defined as one-pass tillage and planting in the spring with no fall tillage. *No-till* systems were defined as having no spring or fall tillage. Information on typical production practices was obtained from University Extension personnel.

Data collected in 2001 and 2003 by the Natural Resource Conservation Service (NRCS) in Adams County provided information on the type of tillage practices found in the region. NRCS collects information for the Conservation Tillage Information Center (CTIC) at Purdue University. Data collected for the CTIC represent physical inspections of a sample of fields in the spring to determine levels of crop residue and tillage practices. Based on data collected by NRCS, conventional tillage, conservation tillage, and no-till practices represented about 21 percent, 46 percent, and 33 percent of planted cropland in the region, respectively.

Crop Production

Annual planted acreage and production for all major crops in the study counties from 1978 to 2002 were compiled (North Dakota Agricultural Statistics Service, various years). A 25-year history of crop production was then used to estimate expected future yields from 2005 through 2009. Crop rotations from 2005 through 2009 were based on the crop mix from 1998 through 2002. However, only crops which averaged 3 percent or more of the region's total planted cropland were included in the analysis (Table 1).

Projected future national crop prices from 2005 through 2009 were obtained from the Food and Agriculture Policy Research Institute (FAPRI) (2004). FAPRI-forecasted prices were adjusted to reflect the historic relationship between national prices and actual prices received by producers in North Dakota based on methods developed by Taylor et al. (2004). Forecasted state-level prices were further adjusted to reflect anticipated prices received by producers within the study region.

Crop Budgets

Three tillage systems were used that reflect the most common set of production practices employed by producers in the study region. Conventional tillage comprised some spring tillage, planting, and minimal fall tillage. Conservation tillage comprised one-pass tillage application in the spring (i.e., seed bed preparation, pesticide and fertilizer application, and planting) and no fall tillage. No-till comprised one-pass planting

Table 1. Average Mix of Major Crops Produced, Southwest North Dakota, 1998 through 2002

Crop	Percentage of Planted Acreage[a]
Alfalfa	13.9
Barley	4.8
Canola	5.3
Sunflower	4.0
Durum Wheat	15.4
Spring Wheat	54.0
Summer Fallow	2.6

[a] Acreage in minor crops was reallocated to major crops for purposes of determining crop rotations.

in the spring (i.e., without soil disturbance) and no fall tillage.

Annual budgets were developed from 2005 through 2009 using projected yields and expected prices for each major crop and for each major tillage system in the study region. The budgets were based on average yields, prices, and production expenses. A second set of budgets was developed to reflect the adjustments in revenues and costs incurred when switching among tillage systems. Yield differences, and changes in herbicide and fertilizer requirements associated with a switch between tillage systems, were based on assessments obtained from county agents and University Extension personnel. Machinery and operating expenses were reflective of the change in tillage implements used in the different production systems. All budgets were developed using the North Dakota State University Extension Service Crop Budget Generator. Current (2004) input costs were used (e.g., price of fuel, cost per pound of fertilizer) over the 2005 to 2009 period.

Production and marketing statistics of participants enrolled in the North Dakota Farm and Ranch Business Management (NDFRBM) program were used to modify the average profitability budgets to reflect typical revenues and costs associated with low-profitability and high-profitability producers (NDFRBM Education, 2004). Individual producers tend to remain within various profitability groups over time, and relative ranking of long-term profitability (e.g., over 10 or more years) is not influenced by short-term agronomic conditions (e.g., periodic drought) (Taylor et al., 2002). Thus NDFRBM data were considered a reliable source of differentiating producers by profitability measures (Taylor et al., 2002).

Data from the NDFRBM program represent actual production statistics of producers in North Dakota. To be consistent with operating conditions in the study region, only information from producers in the southwest region of North Dakota was used. Average prices received, yields obtained, and costs incurred from 1993 through 2003 for the low 20 percent and high 20 percent profitability operators were estimated. The percentage difference in prices, yields, and costs between the low-profitability and average-profitability groups was used to modify the average-profitability crop enterprise budgets to reflect low-profitability producers. The average-profitability budgets were similarly modified to reflect high-profitability operators. As a result, crop enterprise budgets for 2005 through 2009 were developed which reflected low-profitability, average-profitability, and high-profitability producers in the study region. A composite acre approach was developed based on the percentage of land planted to major crops in the region (see Table 1). A composite acre budget is designed to represent the average net return per acre of cropland when all crops raised in a given area are included based on the percentage of cropland attributable to each crop. For example, if a hypothetical county raised 50 percent wheat, 25 percent barley, and 25 percent alfalfa, then the composite acre budget for that county would represent 50 percent of the per-acre net revenue from wheat production plus 25 percent of the per-acre net revenues from both barley and alfalfa.

The approximate cropland acreage under management by low-, average-, and high-profitability producers was estimated (Table 2); however, data from the NDFRBM program could not reveal the tillage systems used by producers in each profitability segment. As a result, conventional, conservation, and no-till production systems were assumed to be evenly distributed among the low-, average-, and high-profitability groups. Composite acre budgets were compiled for low-, average-, and high-profitability producers for each of the three tillage systems (Table 3).

Enterprise budgets for conversion of cropland to permanent grass were based on two possible grass mixes. The first mix was a combination of native grasses, and the second mix was a combination of exotic grasses (i.e., nonnative grass species) (Sedivec, 2004). When compared to the exotic grass mix, the native grass combination is more expensive to establish, has a lower yield, but has slightly higher C-storing potential. Alternatively, when compared to the native grass mix, the exotic grass combination would be less expensive to establish, has a relatively higher yield, but has slightly lower C-storing potential. Grass budgets represented an average of both the native and exotic grass mixes. Co-products

Table 2. Regional Cropland in Low-, Average-, and High-Profitability Farms, Southwest North Dakota, Average 1993 through 2003 (NDFRBM Education, 2004)

	Farm Profitability		
	Average	Low 20%	High 20%
Number of Farms[a]	231	46	47
Crop Acres per Farm	2062	1590	2932
Percentage of Total Acreage	55.7	15.4	28.9

[a] Represents number of farms with only crop enterprises and only farms enrolled in the NDFRBM.

Table 3. Projected Net Returns to Unpaid Labor, Management, and Equity, Composite Acre Budgets, by Year and Tillage Practice, Southwest North Dakota, 2005 through 2009, $ per composite acre[1]

Farm Group/Tillage System	2005	2006	2007	2008	2009
Low Profitability					
Conventional (recrop)	−7.52	−6.93	−6.37	−5.20	−4.23
Conventional (fallow)	−18.77	−18.05	−17.39	−15.79	NA[2]
Conservation Tillage	−2.80	−1.25	−0.75	0.29	1.31
No-Till	−2.90	−2.43	−1.91	−0.85	0.11
Average Profitability					
Conventional (recrop)	16.93	17.79	18.61	20.20	21.52
Conventional (fallow)	11.02	12.06	13.05	15.21	NA
Conservation Tillage	21.44	23.13	23.85	25.27	26.63
No-Till	21.34	22.04	22.78	24.22	25.53
High Profitability					
Conventional (recrop)	34.65	35.71	36.74	38.66	40.26
Conservation Tillage	39.00	40.81	41.70	43.42	45.06
No-Till	38.91	39.78	40.70	42.43	44.03

[1] Net returns exclude direct government payments, disaster payments, and Federal crop insurance indemnities, but include loan deficiency payments.
[2] Not applicable.

for grass enterprises were limited to hay production. Establishment costs were based on a success rate of 90 percent (i.e., 1 year in 10 establishment fails) and were amortized over a 20-year period.

Provisions in the current Federal farm program provide for two types of payments. Producers receive a direct payment regardless of crop raised or use of cropland. As a result, producers would receive the same direct payment if they placed cropland into permanent grasses (excluding enrollment in conservation programs) or raised crops. Other payments (i.e., loan program income) are tied to crop production. To account for differences in Federal farm program payments between crop production and permanent grass, loan deficiency payments were estimated for crop enterprises from 2005 through 2009 based on expected future commodity prices and loan deficiency rates. Including direct payments (i.e., those not tied to crop production) for both cropland and permanent grass would only raise revenues equally across both enterprises. Because Federal farm programs are subject to change, it is not certain that payments will remain constant over the 20-year planning period for either crop production or permanent grass.

Carbon Sequestration Rates

Since site-specific factors, such as soil type, climatic conditions, historical land use patterns, crop rotations, and existing management systems, have an influence on C sequestration rates, the goal at the onset of this study was to use HREC research data to determine C sequestration rates for the study region. However, the breadth of data currently available from field trials was deemed insufficient for economic modeling. As a result, despite limiting the geographic scope of the study to directly coincide with HREC research, secondary sources had to be used to develop C sequestration rates. Unfortunately, secondary data are usually aggregated to be representative of larger geographic regions and are likely to be less precise than data obtained from field experiments when applied to a specific set of local conditions.

Carbon sequestration rates were synthesized from secondary sources (Lewandrowski et al., 2004; North Dakota Farmers Union and U.S. Geological Survey, 2003; Liebig et al., 2004) and included adjustments for crop rotations and soil disturbance in each tillage system in the study region. Carbon sequestration rates ranged from 0.04 MT per acre per year for conventional tillage to about 0.28 MT per acre for permanent grass (Table 4).

RESULTS

The economic analysis was conducted using several basic assumptions. First, total acreage of planted cropland in the study region remained unchanged and the amount of land enrolled in conservation programs remained constant over the period. Second, Federal farm legislation was assumed to remain relatively unchanged over the period and would not alter the economics of C sequestration. The net present value of current and alternative C sequestration activities was modeled free of transaction costs. Producers were assumed to practice the same tillage system on all land operated (i.e., they did not use conservation tillage on some land tracts while using conventional tillage on other tracts). Finally, producers were assumed to be willing and able to switch to the tillage practice or land use that offered the highest net present value.

Since conservation and no-till production practices are already widely used in the study region, a baseline analysis was conducted to provide estimates of C sequestration in the absence of external C incentives, given anticipated C sequestration rates and current trends in tillage practices. Several scenarios, each using a different C price, were then used to evaluate potential changes in land management and land use that could occur with C incentives. Sequestration levels for each C price scenario were then compared to C sequestration in the baseline scenario.

Table 4. Estimated Carbon Sequestration Rates, Southwest North Dakota, 2005 through 2024 (North Dakota Farmers Union and U.S. Geological Survey, 2003; Lewandrowski et al., 2004; Liebig et al., 2004)

Tillage System	Carbon Storage Rates,[a] MT/acre/year
Conventional Tillage[b]	0.0400
Conservation Tillage	0.0897
No-Till	0.1495
Permanent Grass	0.2835

[a] From 1998 through 2002, wheat represented about 70 percent of planted acreage when annual alfalfa production was adjusted to reflect only the portion planted each year. Thus, in any given year, 10 percent of planted cropland would have a crop rotation consisting of three consecutive years of wheat followed by another crop and 90 percent of the land would have a crop rotation consisting of two consecutive years of wheat followed by another crop. Carbon storage rates were adjusted to accommodate the percentage of land in each rotation.
[b] Excludes summer fallow practices.

Baseline

The baseline scenario was designed to estimate the level of C sequestration in the study region from 2005 through 2024 in the absence of external C incentives, given current trends in tillage practices and anticipated C sequestration rates. Market forces, technological factors, and agricultural policies are encouraging the abandonment of summer fallow and conventional tillage practices and the adoption of conservation tillage practices. Summer fallow practices within the region were estimated to essentially end by 2009; conventional tillage, as defined in this study, would be discontinued within 20 years; and the adoption of conservation and no-till practices would continue throughout the 20-year period (Figure 2).

In 2005, C sequestration on planted cropland within the study region was estimated at 112,000 MT annually. By 2024, C sequestration was estimated at 130,000 MT annually because of increases in conservation and no-till production systems. Cumulatively, over the 2005 to 2024 period, the four-county study region was estimated to sequester about 2.4 MMT of soil C (Table 5). On average, each acre of tilled cropland was estimated to sequester about 2.1 MT of C over the period.

Sequestration with Carbon Incentives

Six different C prices were used to track changes in land management and land use associated with sequestration incentives. Carbon prices used were $10, $25, $50, $75, $100, and $125 per MT of permanent C sequestration. The prices were consistent with values used in other studies (Lewandrowski et al., 2004; McCarl and Schneider, 2001). In each scenario, the highest net present value for land management and land use alternatives was selected for low-, average-, and high-profitability producers in each of the tillage practice groups. A discount rate of 5 percent was used.

The four-county study region was estimated to sequester about 2.5 MMT of C over the

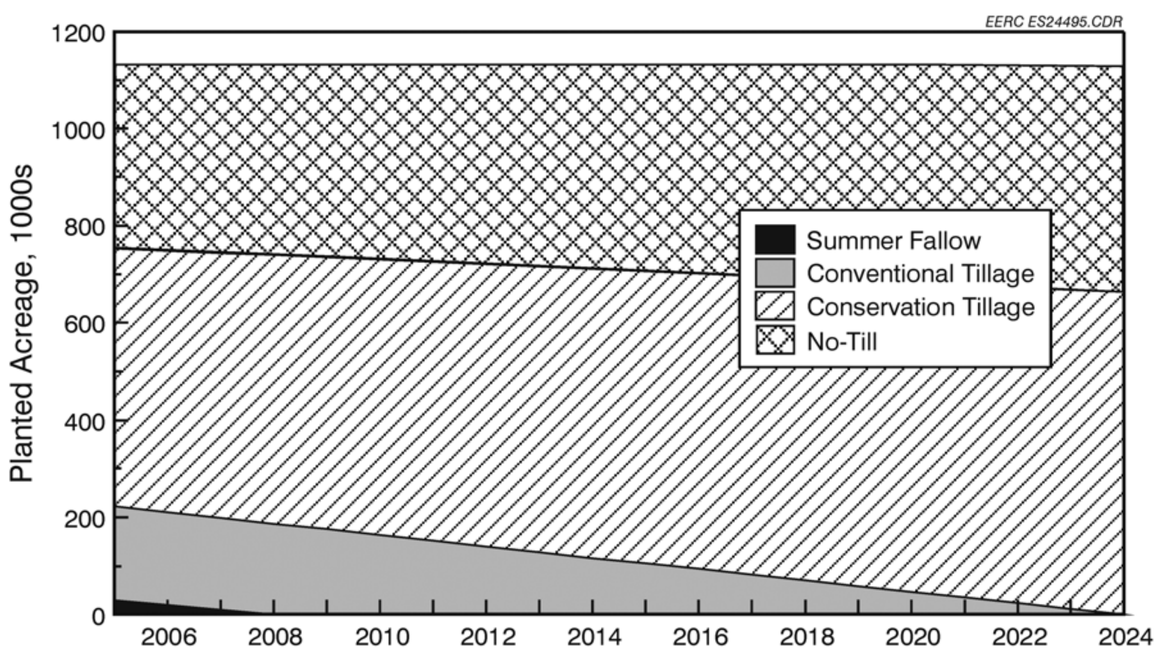

Figure 2. Projected tillage practices, southwest North Dakota, 2005 through 2024.

20-year period, with C priced at $10 per MT (Table 5). Total C sequestered at a price of $10 per MT represented a 3.5 percent increase over baseline levels of C sequestration and represented about 39 percent of the study area's technical C storage capacity (Figure 3).

When C prices were increased to $25 per MT, cumulative soil C storage over the period increased to 3.1 MMT, which represented a 29 percent increase over the baseline level of C sequestration (Table 5). Total C sequestered at a price of $25 per MT represented about 49 percent of the study area's technical C storage capacity.

At $50 per MT, cumulative soil C storage in the study area increased to nearly 4.9 MMT (Figure 3). The level of C storage achieved with a price of $50 per MT represented a 101 percent increase over baseline storage levels and would be equivalent to 76 percent of the region's technical storage capacity.

When C was set at $75 per MT, cumulative soil C storage in the region increased to 5.6 MMT, which represented a 132 percent increase over storage in the baseline scenario. The level of C storage achieved with a price of $75 per MT would be equivalent to 88 percent of the region's technical storage capacity.

At $100 per MT, cumulative soil C storage in the study area over the 20-year period increased to nearly 6.1 MMT. The amount of C stored at a price of $100 per MT represented a 151 percent increase over baseline storage levels and was equivalent to 95 percent of the area's technical storage capacity.

The region's technical capacity to store C was met when the price of C was increased to $125 per MT. Cumulative C sequestered at $125 per MT was estimated at 6.4 MMT, which represented a 165 percent increase over baseline storage levels (Table 5).

Changes in Carbon Sequestration Activities

The analysis started with 11 different combinations of profitability and tillage practices. Each combination of tillage practice and profitability was represented annually from 2005 through 2009 by a composite acre budget. Another set of annual composite acre budgets represented the projected net returns when a producer switches from his/her existing tillage system to an alternative tillage practice (e.g., conventional tillage operators could switch to conservation or no-till practices). The present value of the stream of C payments plus discounted net returns from crop production associated with the existing tillage practice were compared to the present value of potential C payments plus discounted net returns associated with a switch in tillage practices. In addition to comparing tillage options, the value of converting cropland to permanent grass was evaluated for each profitability and tillage group.

Even without C incentives, crop budgets indicated that for low- and average-profitability producers, summer fallow practices were less profitable than continuous cropping. As a result, even with no C payments, a switch out of summer fallow and into continuous cropping occurred in the model. This situation is consistent with the continued decline of summer fallow acreage observed in the study region. With C priced at $10 per MT, permanent grass was the most economically advantageous option for low-profitability producers with summer fallow and those with conventional tillage (recrop) (Table 6). No change in tillage practices was observed for the high-profitability producers or average-profitability producers using conservation or no-till production systems.

When C was set at $25 per MT, the most economically advantageous option for low-profitability producers with summer fallow,

Table 5. Cumulative Soil Carbon Accumulation on Cropland, Southwest North Dakota, 2005 through 2024[1]

Payment Rate, $/MT	Soil Carbon Sequestered, MMT	Percentage Increase over Baseline	Percentage of Technical Capacity
0 (baseline)	2.42	NA	37.8
10	2.51	3.5	39.1
25	3.13	29.3	48.8
50	4.87	101.0	75.9
75	5.63	132.2	87.7
100	6.09	151.3	94.9
125	6.42	164.9	100.0

[1] Results reflect constant carbon price over the 20-year period. Technical capacity was estimated at 6.4 MMT over the period based on converting 100

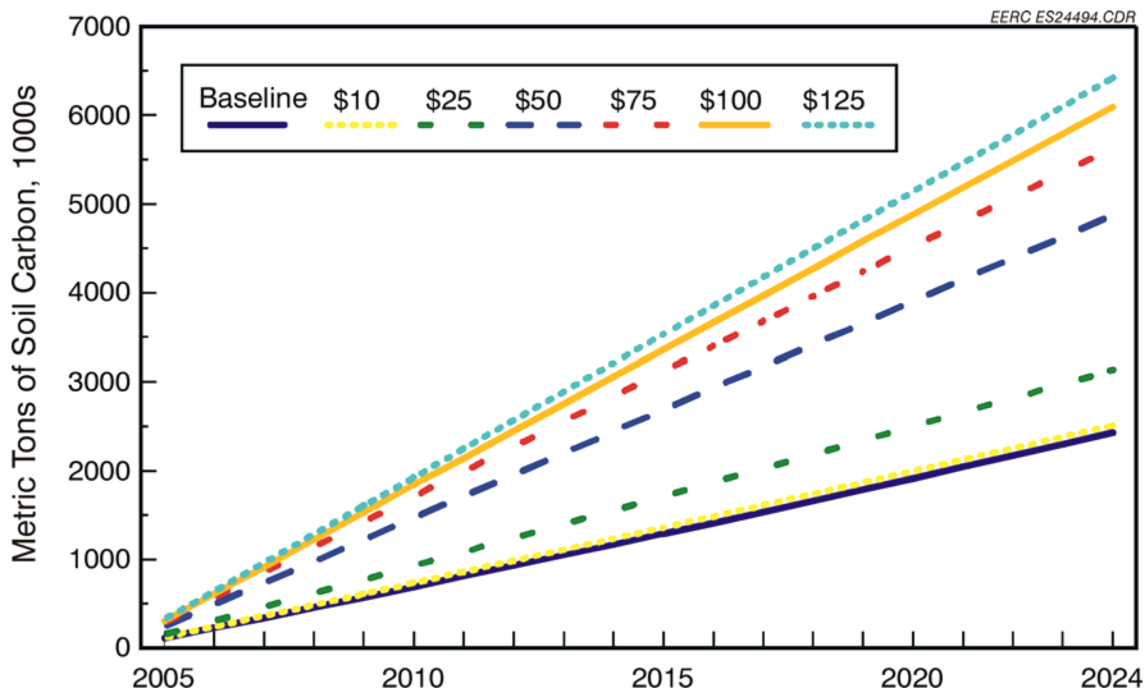

Figure 3. Cumulative soil carbon sequestration, southwest North Dakota, 2005 through 2024.

Table 6. Tillage and Land Use Changes Associated with Various Carbon Incentives, by Profitability and Tillage Group, Southwest North Dakota, 2005 through 2024

	Carbon Price, $/MT					
Current Practice	10	25	50	75	100	125
	Low-Profitability Producers					
Summer Fallow	Grass	Grass	Grass	Grass	Grass	Grass
Conventional Tillage	Grass	Grass	Grass	Grass	Grass	Grass
Conservation Tillage	No Change	Grass	Grass	Grass	Grass	Grass
No-Till	No Change	No Change	Grass	Grass	Grass	Grass
	Average-Profitability Producers					
Summer Fallow	Cons. Till	Cons. Till	Grass	Grass	Grass	Grass
Conventional Tillage	No Change	Cons. Till	Grass	Grass	Grass	Grass
Conservation Tillage	No Change	No Change	Grass	Grass	Grass	Grass
No-Till	No Change	No Change	No Change	Grass	Grass	Grass
	High-Profitability Producers					
Conventional Tillage	No Change	Cons. Till	Cons. Till	Grass	Grass	Grass
Conservation Tillage	No Change	No Change	No-Till	No-Till	Grass	Grass
No-Till	No Change	No Change	No Change	No Change	No Change	Grass

conventional tillage, and conservation tillage was to switch to permanent grass (Table 6). Average-profitability producers with summer fallow and conventional tillage would switch to conservation tillage. No change in tillage practices occurred with high-profitability producers or average-profitability producers with no-till practices.

When C price was $50 per MT, low-profitability producers, regardless of tillage practices, would switch to permanent grass. Average-profitability producers, with the exception of those with no-till practices, also would switch to permanent grass (Table 6). High-profitability producers with conventional tillage would switch to conservation tillage, while those with conservation tillage would switch to no-till practices.

When C was set at $75 per MT, all low- and average-profitability producers, regardless of tillage system, would switch to permanent grass. High-profitability producers using conventional tillage would switch to permanent grass, while those with conservation tillage would switch to no-till systems.

When C price was $100 per metric ton, only one additional change was noted. High-profitability producers with conservation tillage would switch to permanent grass. High-profitability producers with no-till practices would not switch to permanent grass until the price of C was raised to $106 per MT. As a result, when carbon prices reached $125 per MT, the model indicated that all producers would switch to permanent grass.

Influence of Key Parameters

As with any economic study, assumptions and generalized values for some parameters were incorporated into the analysis. Sensitivity analysis of all factors that might influence C sequestration levels in the study region was not performed; however, some insights were gained during the study.

Study results were sensitive to C sequestration rates. Reducing C sequestration rates by 25 percent decreased the economic incentives for producers to switch land management practices or adopt land use alternatives. Carbon prices needed to reach $25 per MT to trigger any meaningful changes in land management, whereas a number of land management changes occurred with lower prices using baseline rates for C sequestration. When C sequestration rates were reduced by 25 percent, a C payment of $50 per MT only generated a 39 percent increase over baseline levels of C storage in the region. However, default C sequestration rates at the same C price (i.e., $50 per MT) resulted in a 101 percent increase over baseline levels of C storage. Increasing C sequestration rates resulted in the opposite effect—the economic incentives to switch land management or land use increased, and those changes occurred at lower C prices relative to default rates.

The discount rate used in the analysis was consistent with rates used in other C sequestration studies. However, discount rates will influence the net present value of an income stream over time. On a relative basis, lower rates place greater value on payments further out in a time line, whereas higher discount rates reduce the relative value of long-term payments. In the case of this analysis, transition costs (i.e., reduction in net returns) associated with switching among tillage systems were assumed to occur in the first five years of the period, thereby making the analysis somewhat more sensitive to relatively higher discount rates than if the transition costs of switching from one tillage system to another were spread out over a longer period. Essentially, if a lower discount rate was used, ceteris paribus, the model would suggest changes in land management or land use would likely occur at lower C prices.

The baseline analysis used a 20-year period for conventional tillage to be discontinued within the study region. If conventional tillage in the region disappears more quickly (e.g., 10 years), the baseline level of C sequestration would increase, and the amount of C sequestered because of external incentives would decrease. Essentially, fewer land management changes could occur, as all producers would be using either conservation or no-till systems.

The price of grass hay, the only co-product from permanent grass included in the analysis, had an effect on the level of C sequestered. A 25 percent reduction in the price of grass hay substantially increased the C price required for permanent grass to compete with crop production. Without co-product revenues, permanent grass would not be economically competitive for average- and high-profitability producers using no-till systems.

Currently, producers in the study region are finding economic advantages in adopting conservation and no-till systems in the absence of external incentives. Despite the long-term advantages, transition costs (i.e., initially lower yields and elevated herbicide and fertilization costs) still exist when producers switch from conventional to conservation tillage systems. If short-term yield loss and production costs associated with switching to conservation and no-till systems are less than modeled, then less economic incentive would be required to switch practices. Under those conditions, greater amounts of C would be sequestered at low C prices. However, if transition costs are greater than modeled, less C would be sequestered at low C prices, or alternatively, similar levels of C sequestration would require greater incentives.

DISCUSSION

Consistent with other economic studies of soil C sequestration, low C prices (≤$25 per MT) would trigger some changes in land management and, to a lesser extent, changes in land use. However, substantial gains in C sequestration did not occur until C prices reached $50 or higher per MT. One reason that greater amounts of C sequestration, relative to baseline projections, were not realized at low C prices is because many of the changes shown to take place with similar C prices in other economic studies have already occurred in the study region. Also, by segregating producers by profitability, large acreage shifts based on average profitability trade-offs did not occur. When those two factors are examined in detail, the model showed that farm profitability is likely to influence adoption rates and fewer land management and land use options are available to sequester additional C for those producers who already are practicing carbon-friendly tillage systems.

Since the approach used in this study for providing C sequestration incentives was based on a private market system and not a government-based program, producers were allowed to capture co-products from the conversion of cropland into permanent grass. As a result, depending upon producer profitability, permanent grass was economically competitive with crop production over a reasonable range of C prices. This finding has substantial implications for assessing the economic potential for cropland to sequester C. In many regions of the Great Plains, converting cropland to permanent grass has the greatest technical potential to sequester C. Yet, most economic studies have placed substantial restrictions on the management of that land use option. As such, most studies have suggested that converting cropland to permanent grass is not economically competitive with other C sequestration activities. The treatment of co-products has broad implications for whether or not that land use alternative is economically attractive to producers.

A drawback to the modeling approach used in this study is that the price of grass hay (co-product from permanent grass) remained constant, even as acreage of permanent grass in the region increased. Localized price adjustments to increased supply of grass hay are likely to occur in the absence of corresponding increases in the demand for grass hay. It is likely that demand would not increase sufficiently, at least in the short run, to offset the increase in supply. As such, the price of grass hay could be expected to decrease as the supply increased, affecting the economic attractiveness of that land use option, even as C prices increased. However, the treatment of permanent grass was an oversimplification of reality. Permanent grass could also be used to provide grazing, which, in turn, may affect the regional supply of summer forage for beef cattle. Reduced cost and/or greater availability of summer grazing may stimulate expansion of the livestock sector, which could in turn increase the demand for winter forage. A much more comprehensive modeling approach would be required to fully evaluate the demand and supply relationships associated with conversion of cropland to permanent grass. The implication is that as price adjustments occur because of changes in supply, the economic attractiveness of land use alternatives will also change, and a more accurate measure of the economic potential of C sequestration will likely require more rigorous modeling.

The modeling approach used in this study largely sidestepped demand and supply relationships and those effects on grass hay prices. However, a conservative price for grass hay (price used was 30 percent lower than the 1998 to 2002 regional average) was used in the model, not as much to predict price responses to increased supply, but to demonstrate that valuing co-products from permanent grass, even at reduced levels, has substantial implications for whether or not that land use option is economically attractive to producers. Granted, regardless of revenues from co-products, it is unlikely that all tilled cropland in the study region would be converted to permanent grass, even at high C prices. However, as was demonstrated, co-product revenues and C payments from permanent grass do not need to be excessive for that land use alternative to compete with crop production in western North Dakota. Other nonagricultural co-products, such as recreational revenues, are likely to further complicate the economic potential for changes in land use. Even if the hay prices used in the analysis were cut in half, with C prices ranging from $25 to $50 per MT, modest revenues from recreational activities would be sufficient to keep permanent grass competitive with crop production. However, the economic attractiveness of permanent grass is likely to differ in other production regions in the state.

One issue with many economic assessments is the treatment of farm profitability. Producers are not homogeneous in their management skill, size, debt, and profitability. Many studies have treated crop returns within large geographic regions in a homogeneous manner, suggesting that average profitability is adequate to measure land management and land use changes in response to C incentives. These assessments tend to exaggerate the amount of acreage shifts under various tillage systems that will occur with suggested C incentives. Producers who are highly profitable with their current practices are likely to require a greater incentive to change their operations. Alternatively, lower economic incentives associated with C sequestration may be more economically attractive to producers who are struggling to make adequate returns from their existing operations. As a result, the economic attractiveness of various C-sequestrating activities varies by farm profitability. For example, given the prices and default values used in this analysis, with C priced at $25 per MT, the most economically advantageous option for low-profitability producers in the region was to convert cropland to permanent grass, average-profitability producers would switch tillage systems, and high-profitability producers would find no economic incentive to switch either land management or land use. The implication is that, ultimately, in a private-market system for carbon sequestration, actual acreage of C-sequestrating activities is going to be more variable than what has been depicted using only average profitability measures.

As would be expected, the overall level of C sequestration in the study region was dependent upon the annual per-acre rate for C accumulation. A wide range in possible C sequestration rates found with secondary data reduces the confidence that can be placed on the economic potential of C sequestration. For example, the North Dakota Farmers Union and U.S. Geological Survey (2003) list the possible C storage rate for rotation wheat using no-till practices at 0.30 MT per acre, ± 0.21 MT per acre. Those figures represent about 70 percent variance in the mean rate. Those figures suggest the actual rate could fall between 0.09 and 0.51 MT per acre. Liebig et al. (2004) also indicated that dry land cropping under no-till management in the northwestern United States and western Canada could expect a 70 percent range in actual C sequestration rates. With such wide ranges in the potential C storage rate, it becomes problematic to analyze the economics of C sequestration at the producer level. As was discussed earlier, the model showed that even a 25 percent change in the rate of C sequestration was sufficient to have substantial influences on the economics of C sequestration. A probability distribution associated with C sequestration rates would assist economic assessments of C sequestration in placing greater confidence in adoption rates and producer responses to C incentives.

Potential for Improvements in Data and Methods

A more comprehensive assessment of the potential for soil C sequestration in western North Dakota would require changes in methodology and improvements in data. The following suggestions would improve the confidence in the economic potential of soil C sequestration in the study region:

- Cropland was treated as being homogeneous with respect to productivity, topography, past tillage practices, crop rotations, and C sequestration rates. Accounting for more physical variation in cropland and differentiating land by factors that are likely to affect C sequestration would improve study results.

- While the approximate percentage of land under conventional, conservation, and no-till practices was known, the amount of time that land has been in those tillage practices was not known. Issues associated with C-stock equilibrium and future C sequestration rates should be assessed.

- Over the time period used in this study (20 years), the long-term improvement in soil health resulting from conservation and no-till systems could influence crop yields. Quantification of long-term agronomic advantages of adopting conservation tillage would improve the analysis by allowing the model to value any yield differential between tillage systems.

- Crop yields and C sequestration rates are likely to vary annually because of climatic conditions. An improvement in the model would be to incorporate stochastic elements to account for yield volatility and fluctuations in C sequestration rates.

- Carbon sequestration rates in the published literature remain fairly generic to broad geographic areas and are not easily differentiated based on site-specific attributes, such as past cropping history, fertilization rates, topography, or local climatic conditions. At present, ecological simulation models are one of the methods used to account for site-specific conditions; however, greater resources (time and data) are required to implement those techniques in the economic analysis.

- Little is known about the distribution of tillage practices among low-, average-, and high-profitability producers. If the most profitable producers are not using carbon-friendly tillage practices, then C sequestration achieved with low C prices would be overstated. Likewise, if the percentage of low-profitability producers using no-till or conservation practices was overstated, then the level of C sequestration identified in the study would be underestimated.

- Most producers rent a substantial portion of the land they operate. A number of issues arise pertaining to how long-term C sequestration arrangements would be structured or administered between producers and landowners.

- Commodity price adjustments resulting from changes in domestic supply and demand will affect the economics of land use alternatives. Future analyses should attempt to account for potential changes in commodity prices and co-product values resulting from changes in land use.

- The co-product associated with permanent grass in this analysis was limited to hay production. Accounting for all possible co-products associated with permanent grass production would improve the understanding of the economic trade-offs between land use alternatives.

- Transaction costs, to the extent shared by producers, would reduce the effective price of C. Since terrestrial C sequestration is viewed as a low-cost opportunity to mitigate CO_2, high transaction costs associated with low C prices would potentially reduce the attractiveness of C sequestration activities.

Little is known regarding the type and extent of transaction costs that would be incurred between buyers and sellers of C credits/offsets in a market-based system.

CONCLUSIONS

Although the geographic scope and extent of C sequestration activities examined in this study were limited, several findings are noteworthy. Some findings were consistent with previous economic assessments of C sequestration, while other results differed from previous studies.

Profitability of producers is a factor influencing the economics of adopting C sequestration activities. Producers who are highly profitable with existing practices are likely to require a greater incentive to change their operations. Alternatively, financial incentives associated with C sequestration may be more economically attractive to producers who are struggling to make adequate returns from their existing operations. Using only average profitability (i.e., treating all cropland as being economically homogeneous) to measure changes in land management and land use results in overestimation and/or underestimation of the changes that may occur at any given C price. Just as soil type, crop rotations, and tillage practices are used to differentiate C sequestration potential within a given area, profitability and farm-level economics should also be used to further differentiate the response of producers/landowners to C incentives.

Both within North Dakota and in other regions of the country, farming practices that sequester C are currently being implemented and adopted without external C incentives. Much of the gains in C sequestration purported to be economically viable with relatively low C values in some economic studies have come from the elimination of summer fallow and the change from conventional to conservation tillage. However, some of the gains suggested that would occur with low C payments in those studies are likely overstated. The use of summer fallow is quickly disappearing, even in regions where the use of summer fallow has been extensively practiced in the past. Also, as reported by the Conservation Tillage Information Center, conservation tillage practices are increasing throughout the United States. As a result, less cropland is available to switch to more C friendly practices, and it is possible that relatively higher C prices would be needed to entice producers to switch to more intensive C sequestration activities.

Many economic assessments of C sequestration have been conducted using aggregated data for much larger geographic regions. The drawback of using broad averages for crop yields, C storage rates, crop rotations, and net returns from crop enterprises is that study results tend to be overgeneralized. When examining the issue of soil C sequestration, farm-level economics require more specific data to make definitive assessments on producer responses to C incentives. As was demonstrated in this study, even within a relatively small four-county region of North Dakota, anticipated producer responses to C incentives varied considerably to changes in site-specific factors. In order to achieve more accurate assessments of the economic potential of agricultural soils to sequester C, economic assessments should account for localized economic and agronomic factors. A more accurate portrayal of the economic potential for C sequestration would be to combine results from numerous, geographically specific studies into larger regional assessments.

Contrary to many economic studies suggesting that conversion of cropland to permanent grass is not economically competitive with other C sequestration activities, results from this analysis suggest that by including modest revenues from co-products, perennial grass is not only an economically viable alternative to crop production, but may be economically viable at C prices lower than have been previously suggested. These results are consistent with the degree of participation in the Conservation Reserve Program within the study counties and, to a greater extent, much of western North Dakota. The conversion of cropland to permanent grass is likely to be an economically viable option to sequester C, especially to the extent that marginally productive cropland remains unenrolled in future Federal conservation programs.

Despite the rather narrow focus of this study, it demonstrates that gains in C sequestration are likely to occur with relatively low C prices. Some changes in agricultural land management and use will occur with relatively low C prices, although the amount of C sequestration stimulated with low C payments is likely to be less than levels previously estimated in some economic assessments because of ongoing adoption of conservation tillage practices. Thus agricultural soils can still serve as a low-cost option for C sequestration, albeit at levels substantially less than what have been suggested by technical assessments of soil C sequestration potential.

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