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PRODUCER RESPONSES TO CARBON SEQUESTRATION INCENTIVES IN THE NORTHERN GREAT PLAINS

Dean A. Bangsund
North Dakota State University, dbangsund@ndsu.edu

F. Larry Leistritz
North Dakota State University - Main Campus

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Dean A. Bangsund

Department of Agribusiness and Applied Economics
Morrill Hall 213A
North Dakota State University
Fargo, ND 58105
d.bangsund@ndsu.edu

F. Larry Leistritz

Department of Agribusiness and Applied Economics
Morrill Hall 213B
North Dakota State University
Fargo, ND 58105

ABSTRACT–Agricultural lands can be used as a terrestrial sink for atmospheric CO_2 by changing their management and/or use. The goal of this study was to evaluate the economic potential of carbon sequestration on cropland in the spring wheat producing region of the northern Great Plains. In order to provide a more realistic assessment of the economic potential for agricultural carbon sequestration, this study reflects regional trends in land management practices, incorporates the value of co-products from the conversion of cropland to permanent grass, and considers producer differences in crop production profitability. The economic model compared the expected net present value of (1) maintaining current farm practices, (2) switching tillage practices, or (3) converting cropland to permanent grass over a 20-year time horizon. Six different carbon prices ($10, $25, $50, $75, $100, and $125 per metric ton) were used to gauge producer/landowner response to incentive payments. A carbon price of $25 per metric ton led to a 29% increase over the baseline level of C sequestration, representing 49% of the study area's technical storage capacity. The study area's technical capacity to store C was fully attained when the price of C was increased to $125 per metric ton.

Key Words: cropland management, Great Plains, greenhouse gas emissions (GHGE) mitigation, soil carbon sequestration

INTRODUCTION

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 sink of atmospheric carbon dioxide (CO_2) (Moulton and Richards 1990; Parks and Hardie 1995). Given the depleted level of soil carbon (C) in most agricultural 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 (McCarl and Schneider 2000). 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. The most common changes in land *use* that enhance soil C storage include 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).

Several studies on soil C sequestration have estimated the technical capacity for C sequestration (i.e., the amount of sequestration possible under "best case" situations for both land management and land use, without consideration of economic or social constraints). Current estimates

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of the technical potential of U.S. agricultural lands to sequester C through changes in management practices range from 89 to 318 million metric tons (MMT) per year (Lewandrowski et al. 2004). In addition, 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. In addition, shifting about 105 million acres of highly erodible cropland into permanent grasses represents a technical sequestration potential of 26 to 54 MMT of C annually over a 15-year period.

While agricultural lands currently are viewed as having substantial technical potential to sequester atmospheric CO_2 in the form of soil C, most agricultural lands are in private ownership, and changes in land management and/or land use are subject to market forces and profit motives 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 could play in mitigating greenhouse gas emissions. The goal of this study was to evaluate the economic potential of C sequestration on cropland in the spring wheat producing region of the northern Great Plains. Specific objectives included (1) evaluating economic incentives needed to influence changes in land management, (2) evaluating economic incentives needed to influence changes in land use, and (3) estimating the economic potential for soil C sequestration.

While a number of studies have addressed the response of agricultural landowners to economic incentives for carbon sequestration (e.g., Antle et al. 2001, 2003, 2007; Pautsch et al. 2001; Capalbo et al. 2004), these efforts have been limited in some important respects. When evaluating the potential for C sequestration associated with changes in land management, with respect to the northern spring wheat producing area of the United States, previous studies generally have not addressed recent trends in management practices (e.g., widespread adoption of reduced tillage, less use of summer fallow) (Antle et al. 2001; Pautsch et al. 2001). These trends influence the potential for producers to respond to future C incentives, and in some areas, these effects may be substantial. Similarly, in evaluating the potential for C incentives to stimulate changes in land use (e.g., conversion of cropland to grass), previous analyses often have not included the value of co-products (e.g., grazing, hay production) associated with the new land use (Antle et al. 2001, 2007; Lewandrowski et al. 2004). Failure to include the value of co-products clearly will affect the level of incentive payment required to stimulate a change in land use. Finally, previous analyses have generally assumed some degree of homogeneity with respect to production efficiency and producer profitability. As a result, most analyses of C sequestration have not differentiated C supply by producer profitability. However, empirical evidence indicates that substantial differences in profitability exist among crop producers in the northern Great Plains and that those differences are consistent over time and generally unaffected by short-term agronomic conditions (e.g., periodic drought) (Taylor et al. 2002). This study, however, reflects current trends in land management practices, incorporates the value of co-products, and incorporates differences in producer profitability in developing C supply response, thus addressing some of the shortcomings of previous studies.

The emergence of farmer participation in voluntary C markets, such as Chicago Climate Exchange (CCX), could provide insights on behavioral responses to financial incentives associated with the sale of C offsets. However, participation of farmers to date has provided few insights, due in part to the relatively low value per acre of C payments (about $2 per acre), the short period that C offsets from agricultural sources have been accepted on the CCX, and the fact that only no-till practices and grass seeding have met with CCX approval for registry of C offsets (Iowa Farm Bureau 2007; National Farmers Union 2007). If C prices increase in the future, or participation becomes more widespread, it may be possible to forecast C supply response from observable behavior. However, widespread changes in tillage practices and land use by producers, in direct response to C sequestration incentives, remains unknown.

METHODS

Estimating the response of agricultural producers to potential C sequestration incentives required a model that compared 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 or activities that yield the greatest net revenue. Production risk and 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 comparison of net present values was limited to a 20-year time horizon. Carbon

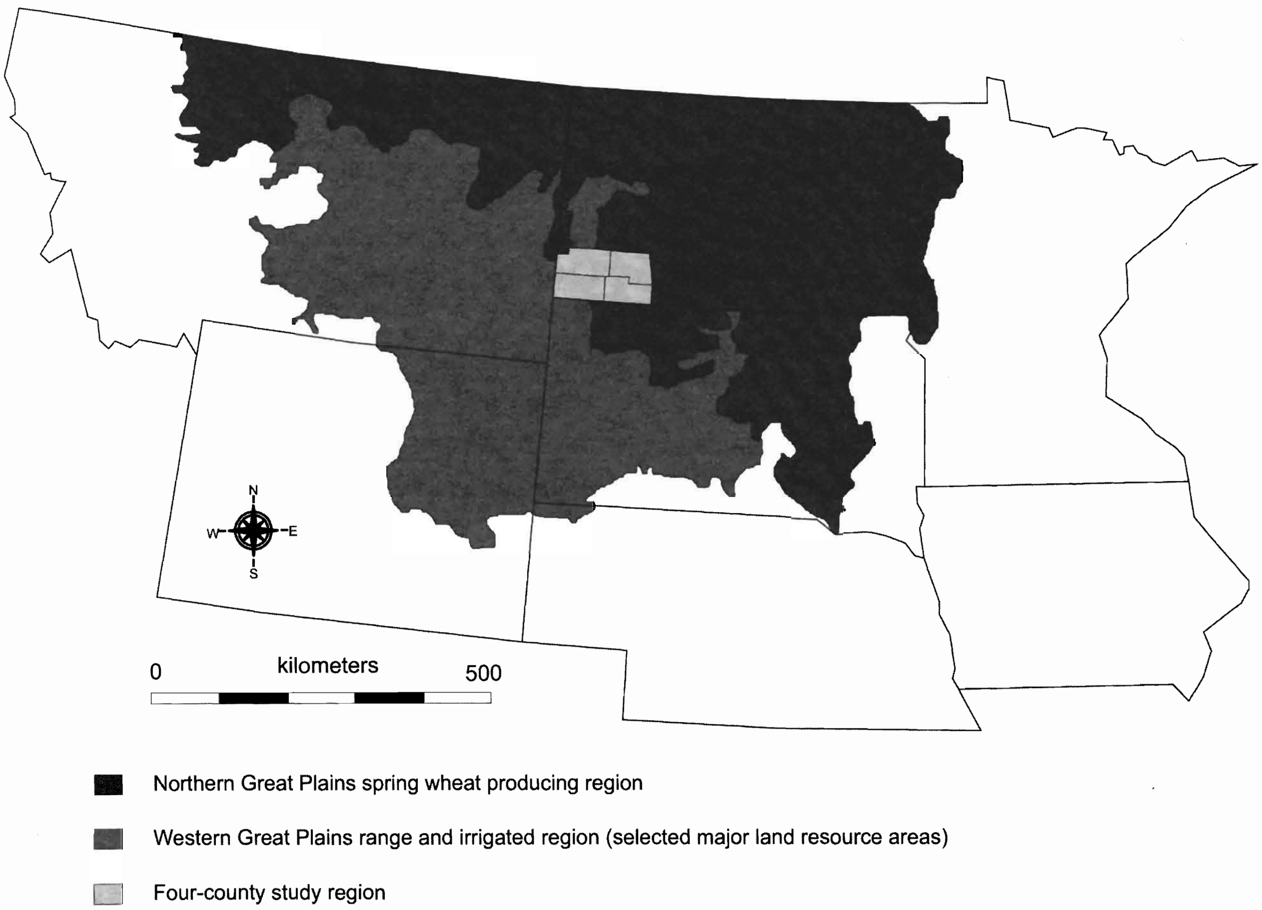

Figure 1. Northern Great Plains spring wheat producing regions.

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. Potential leakage (local and distant), as defined by Murray et al. (2007), was not included in the model.

The analytical framework can be summarized as follows:

$$\max \prod ij = \sum_{t=1}^{20} \frac{Pc \times R_i}{(1+r)^t} + \sum_{t=1}^{20} \frac{\pi_{ij}}{(1+r)^t} - \sum_{t=1}^{5} \frac{TC_{\Delta i,j}}{(1+r)^t}$$

Where:

Pc = price of carbon ($/metric ton),
R = rate of carbon sequestration (metric ton/acre),
r = discount rate,
TC = transition cost of switching tillage systems,
$\prod$ and π = producer net returns,
i = tillage system, and
j = profitability group.

This framework is consistent with previous static modeling analyses using one-time decision making (Lewandrowski et al. 2004).

STUDY DESIGN

The four-county study region is part of the northern Great Plains spring wheat region of the United States (USDA-NRCS 2006), which encompasses virtually all of North Dakota as well as portions of the adjacent states of Montana, Minnesota, and South Dakota (Fig. 1). The region is characterized by soils and topography favorable for agriculture, coupled with low average precipitation and a short growing season that limits the crops that can be grown (USDA-NRCS 2006). Average annual precipitation ranges from 250 to 550 mm. The average annual temperature is 4° to 9°C, with a frost-free period that ranges from 100 to 155 days (USDA-NRCS 2006). Spring wheat is the dominant crop. Because in most years precipitation is inadequate for maximum production potential, the crop-fallow production practice (i.e., the land is not cultivated for one growing season to store moisture, then a crop is grown the following year) has been widely used (Cihacek and Ulmer 1995). This has led to substantial depletion of soil C (approximately 6.5 metric tons [MT] per acre), compared to native grassland soil (Cihacek and Ulmer 1995). Similar crops and production practices are common on nonirrigated croplands of the adjacent western Great Plains range and irrigated region (Fig. 1).

Within the spring wheat region, a four-county area was selected for detailed study. This area (Adams, Bowman, Hettinger, and Slope counties in North Dakota) was selected because its soils and agricultural practices are representative of the larger spring wheat region while also allowing the study team to utilize data from field trials conducted at the Hettinger Research and Extension Center, located in Adams County.

Data requirements for the study included determining the extent of existing tillage practices in the four-county study area, crop rotations within the area, 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 can be categorized by the frequency, intensity, and sequence of field operations used to produce crops. Conventional tillage is characterized by intensive spring and fall tillage, and generally results in little crop residue (<15%) on the soil surface (USDA-ERS 2004). 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%) on the soil surface than in conventional tillage. 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%) on the soil surface than other tillage systems.

In the western North Dakota study area, *conventional* tillage was defined to encompass a single pass of a field cultivator or disk in the spring either prior to or in conjunction with a grain drill. Fall tillage encompassed the use of a heavy spring-tine harrow, used to primarily distribute crop residue with no incorporation into the soil, and results in only negligible disturbance of the soil profile. *Conservation* tillage was characterized as a one-pass tillage and planting operation in the spring with no fall tillage. *No-till* systems were defined as having no spring or fall tillage. Conventional tillage, conservation tillage, and no-till practices, as defined above, represented about 21%, 46%, and 33% of planted cropland in the four-county study area, respectively (Adams County Soil Conservation District 2004).

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	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.

Crop Production and Prices. Annual planted acreage and production for all major crops in the study region were compiled for 1978 to 2002 (North Dakota Agricultural Statistics Service various years). The 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 that averaged 3% 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. A limitation to the use of forecasted crop prices, rather than allowing for price adjustments caused by C sequestration activities in other regions, could result in some distortion of the C supply response at higher C prices. Price adjustments, resulting from C sequestration activity in other regions of the country, would likely reduce the expected C supply at higher C prices in the study region.

Crop Budgets. Three tillage systems were used (conventional tillage, conservation tillage, and no-till), which reflect the most common management practices employed by producers in the study area. Annual budgets (estimated costs and returns) 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 area. The budgets were based on average yields, prices, and production expenses. A second set of budgets was developed to reflect 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 extension educators and North Dakota State University extension personnel. Machinery and operating expenses were reflective of the change in tillage implements used in the different production systems. Input costs (e.g., price of fuel, cost per pound of fertilizer) prevailing in 2004 were used over the 2005 to 2009 period. Yields, prices, and costs estimated for 2009 were assumed to prevail through the period 2010 to 2024.

Production and marketing statistics of participants enrolled in the North Dakota Farm and Ranch Business Management program (NDFRBM) in the southwest region of North Dakota were used to modify the average farm-level profitability budgets to reflect typical revenues and costs associated with low and high profitability producers (North Dakota Farm and Ranch Business Management Education 2005). Average prices received, yields obtained, and costs incurred from 1993 through 2003 for the low 20% and high 20% 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 based on farm-level operational characteristics 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 producer raised 50% wheat, 25% barley, and 25% alfalfa, then the composite-acre budget for that producer would represent 50% of the per-acre net revenue from wheat production, plus 25% 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 from NDFRBM data; however, NDFRBM data 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 2).

Enterprise budgets for conversion of cropland to permanent grass were based on an average of native and exotic grass mixes (Sedivec, pers. comm. 2004). Co-products for grass enterprises were limited to hay production, although other co-products might arise from hunting leases, grazing, or biomass production. Co-benefits generally represent nonmarket goods (e.g., reduced erosion, improved water quality) that are not sold in markets, and were not included in the analysis. Establishment costs were based on a success rate of 90% (i.e., 1 year in 10 establishment fails) and were amortized over a 20-year period. The price for grass hay was assumed to be 30% less than the regional average for 1998-2002, as reported by the North Dakota Agricultural Statistics Service. A reduced hay price was used to account for price reductions that would accompany supply increases in the absence of demand changes, and to provide for a conservative assessment of the value of grass production.

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.

Carbon Sequestration Rates. Carbon sequestration rates were synthesized from secondary sources (North Dakota Farmers Union and U.S. Geological Survey 2003; Lewandrowski et al. 2004; Liebig et al. 2005), and

TABLE 2
PROJECTED NET RETURNS PER COMPOSITE ACRE, BY YEAR AND TILLAGE PRACTICE, SOUTHWEST NORTH DAKOTA, 2005 THROUGH 2009

Farm group/Tillage system	**2005**	**2006**	**2007**	**2008**	**2009**
	$ per composite acre				
Low profitability					
Conventional (re-crop)	-7.52	-6.93	-6.37	-5.20	-4.23
Conventional (fallow)	-18.77	-18.05	-17.39	-15.79	NA
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 (re-crop)	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 (re-crop)	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

Notes: Net returns exclude direct government payments, disaster payments, and federal crop insurance indemnities, but include loan deficiency payments. NA = not applicable.

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 3). It is recognized that C sequestration rates are likely to be nonlinear over time, despite the fact that the rates used represent average annual rates over the 20-year period.

Land under consistent management will eventually reach a point where C sequestration rates approach zero. Despite widespread adoption of some form of conservation tillage, changes from crop-fallow to continuous cropping systems and adoption of conservation and no-till systems are relatively recent. As a result of these recent adoptions, most land under continuous crop production was assumed to be in the early stages of soil carbon accretion. Considering the tonnage of soil carbon that has been depleted over the past several decades (i.e., estimated at about 6.5 MT per acre by Cihacek and Ulmer 1995), the assumption of constant average annual C sequestration rates used in this study does not violate a C saturation concern. Examining cumulative C sequestration rates over the 20-year period and comparing those to levels of C lost from soils in the region suggests that C equilibrium issues would not become a constraint to C payments.

TABLE 3
ESTIMATED CARBON SEQUESTRATION RATES, SOUTHWEST NORTH DAKOTA, 2005 THROUGH 2024

Tillage system	**Carbon storage rates[a] (metric tons of C/acre/year)**
Conventional tillage[b]	0.0400
Conservation tillage	0.0897
No-till	0.1495
Permanent grass	0.2835

Sources: North Dakota Farmers Union and U.S. Geological Survey (2003); Lewandrowski et al. (2004); Liebig et al. (2005).

[a] From 1998 through 2002, wheat represented about 70% of planted acreage when annual alfalfa production was adjusted to reflect only the portion planted each year. Thus, in any given year, 10% of planted cropland would have a crop rotation consisting of three consecutive years of wheat followed by another crop and 90% 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.

RESULTS

The economic analysis was conducted using several basic assumptions. First, total acreage of planted cropland, land enrolled in conservation programs, and grazing lands in the study region remained unchanged. The conversion of existing grass and grazing lands to cropland was not considered. 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 were modeled free of transactions 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, while using conventional tillage on other land). The influence of price responses associated with C sequestration activities (e.g., afforestation, biofuels) in other regions of the country were not considered. 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.

Baseline Analysis. The baseline scenario was designed to estimate changes in agricultural management practices and the level of C sequestration in the study area 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 area 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 (Fig. 2).

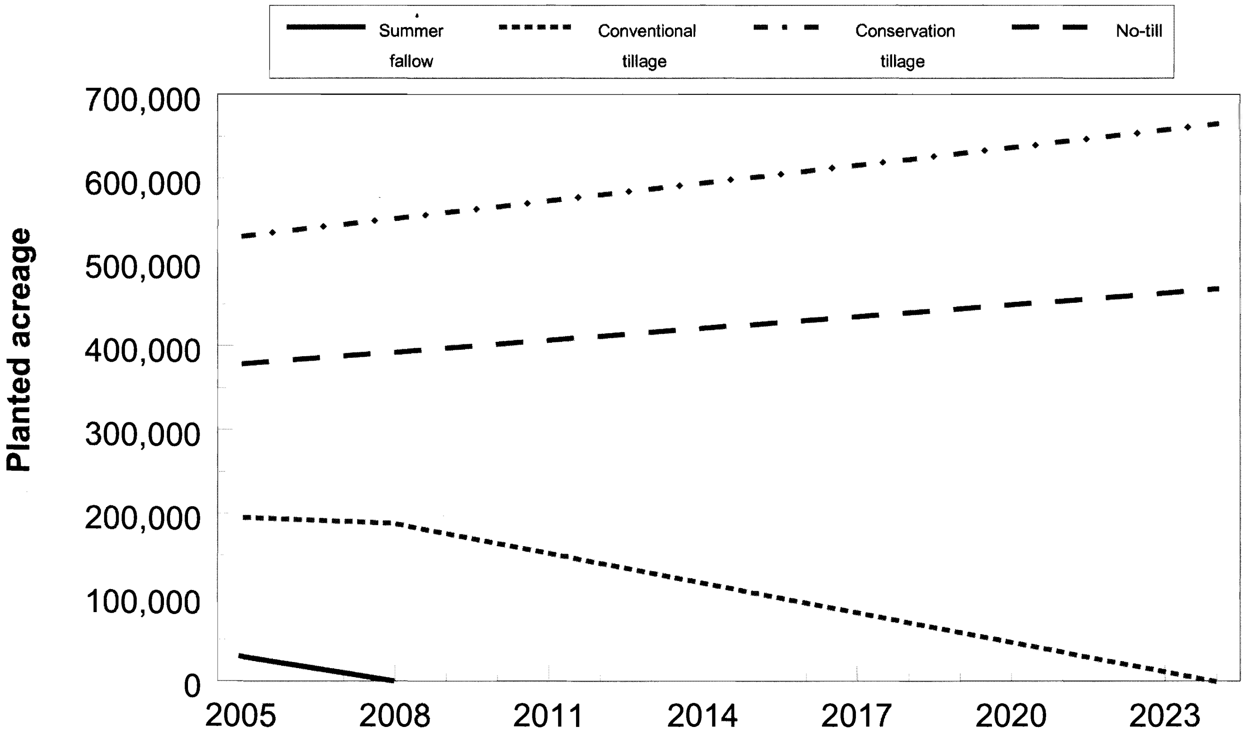

Figure 2. Projected tillage practices, southwest North Dakota, 2005 through 2024.

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

Changes in Management Practices and Land Use with Carbon Incentives. 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 producers switch from their 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.

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 (McCarl and Schneider 2001; Lewandrowski et al. 2004). In each scenario, the highest net present value for land management and land use alternatives were selected for low, average, and high profitability producers in each of the tillage practice groups. A discount rate of 5% was used in computing net present value.

With C priced at $10 per MT, permanent grass was the most economically advantageous option for low profitability producers with conventional tillage (summer fallow) and those with conventional tillage (re-crop); however, low profitability producers with conservation tillage and no-till would not switch practices (Table 4). The only change observed with average profitability producers would be a switch from summer fallow to continuous cropping with conventional tillage. No changes in

TABLE 4
TILLAGE AND LAND-USE CHANGES ASSOCIATED WITH VARIOUS CARBON INCENTIVES, BY PROFITABILITY AND TILLAGE GROUP, SOUTHWEST NORTH DAKOTA, 2005 THROUGH 2024

	Carbon price ($ per metric ton)					
Current practice	**10**	**25**	**50**	**75**	**100**	**125**
	Low profitability producers					
Summer fallow	G	G	G	G	G	G
Conventional tillage	G	G	G	G	G	G
Conservation tillage	NC	G	G	G	G	G
No-till	NC	NC	G	G	G	G
	Average profitability producers					
Summer fallow	CvT	CsT	G	G	G	G
Conventional tillage	NC	CsT	G	G	G	G
Conservation tillage	NC	NC	G	G	G	G
No-till	NC	NC	NC	G	G	G
	High profitability producers					
Conventional tillage	NC	CsT	CsT	G	G	G
Conservation tillage	NC	NC	NT	NT	G	G
No-till	NC	NC	NC	NC	NC	G

Notes: G = Grass; NC = No change; CvT = conventional tillage; CsT = conservation tillage; NT = No-till.

TABLE 5
CUMULATIVE SOIL CARBON ACCUMULATION ON CROPLAND, SOUTHWEST NORTH DAKOTA, 2005 THROUGH 2024

Payment rate ($ per 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

Notes: Results reflect constant carbon price over the 20-year period. Technical capacity was estimated at 6.4 million metric tons over the period based on converting 100% of roughly 1.1 million acres of planted cropland to perennial grass. Land in conservation programs was not included. NA = not applicable.

tillage practices were observed for the high profitability producers (Table 4).

When C was set at $25 per MT, the most economically advantageous option for low profitability producers with summer fallow, conventional tillage (re-crop), and conservation tillage was to switch to permanent grass (Table 4). Average profitability producers with summer fallow and conventional tillage would switch to conservation tillage. High profitability producers with conventional tillage would switch to conservation tillage. Tillage practices would not change for average profitability producers and high profitability producers with conservation and no-till practices.

As the C price was increased to $50 per MT and then to $75 per MT, a similar pattern of changes in tillage and land use occurred. At $50 per MT, low profitability producers switched their no-till acres to grass, completing the conversion of their cropland to permanent grass, while average profitability producers planted all but their no-till acres to grass, and high profitability producers switched conservation tillage acres to no-till. At $75 per MT, average profitability producers completed the conversion to grass while high profitability producers switched their conventionally tilled acres to grass.

When C price was $100 per metric ton, only one 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 metric ton. As a result, when carbon prices reached $125 per MT, the model indicated that all producers would switch to permanent grass.

Sequestration Levels with Carbon Incentives. With C priced at $10 per MT, the four-county study area was estimated to sequester about 2.5 MMT of C over the 20-year period (Table 5). Total C sequestered at a price of $10 per MT represented a 3.5% increase over baseline levels of C sequestration and represented about 39% of the study area's technical C storage capacity. Technical C storage capacity for the study region was based on placing all tilled cropland into permanent grass. 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% increase over the baseline level of C sequestration (Table 5). Total C sequestered at a price of $25 per MT represented about 49% of the study area's technical C storage capacity.

As C prices were increased to $50, $75, and $100 per MT, cumulative soil C storage increased, reaching levels of 4.9 MMT, 5.6 MMT, and 6.1 MMT, respectively, in 2024. At the $100 per MMT price, the amount of C stored represented a 151% increase over baseline storage levels and was equivalent to 95% of the area's technical storage capacity (Table 5). The study area's technical capacity to store C was fully attained 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% increase over baseline storage levels.

CONCLUSIONS AND IMPLICATIONS

Study findings indicated that, 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 that 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 that fewer options for land management and land use are available that would sequester additional C for those producers already practicing carbon-friendly tillage systems.

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 alterative to crop production but may be economically viable at C prices lower than those that have been previously suggested. These results are consistent with the degree of participation in the Conservation Reserve Program (CRP) 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 and the net returns from existing crops are not substantially influenced by external price responses to C sequestration activities in other regions.

The price of grass hay remained fixed across all C prices. In reality, it is highly unlikely that all tilled cropland in the study region would be converted to permanent grass, even at high C prices, and localized price adjustments to increased supply of grass hay in the short run are likely to occur in the absence of corresponding increases in the demand for grass hay. Similarly, it is also perhaps unrealistic to expect no crop price changes resulting from C sequestration activities in other regions of the country, which could influence the competitiveness of permanent grass. However, other price-related issues may perhaps be of equal importance. Widespread use of permanent grass could also provide reduced cost and/or greater availability of summer grazing, which in turn may stimulate expansion of the livestock sector (i.e., beef cattle). An expansion of the livestock sector would in turn increase the demand for winter forage (i.e., grass hay). Currently, long-run regional price adjustments to increased production of grass hay and corresponding effects on regional livestock enterprises are difficult to estimate, yet have implications for the conversion of cropland to permanent grass.

Recent changes in crop prices and input costs are having major effects on grain producers in the northern Great Plains. Economic assessments have yet to evaluate how these changes may affect C sequestration in the long run. What is understood is that as the level of net returns from crop production increases relative to other alternatives (e.g., grass production), the comparative value (i.e., difference between managed grass and no-till crop production) of carbon sequestration would also need to increase to trigger land-use changes. Therefore, grass production would require a bigger C payment to compete with combined revenues from crop production. The translation would mean that less grass production would occur at lower C prices, and reduced levels of C would be sequestered relative to the baseline for nearly all C prices modeled.

Interest in biofuels has increased substantially in recent years. Considering the agronomic conditions in the four-county study region and those in much of the greater spring wheat producing regions, the primary feedstocks for biofuels are likely to be herbaceous energy crops (e.g., perennial grasses). With respect to C sequestration, the managed grass enterprise modeled in this study would be similar in many respects to perennial grasses used for biofuels. Carbon sequestration rates would be similar. Establishment, management, production, and harvest would be similar. Co-products from those enterprises would provide similar revenue streams to producers. A key distinction is that C sequestration becomes the co-product from herbaceous energy crops, and that decisions to enter into long-term contracts to produce grass for biofuels could be made in the absence of revenue from C sequestration. In either case, the commercialization of cellulosic biofuels would likely increase C sequestration in the region relative to baseline estimates.

Rising input costs could influence the adoption rate for no-till production systems. Specifically, reduced inputs (e.g., fuel use) represent a substantial advantage for no-till systems over other tillage regimes. Recent increases in input costs should serve to broaden the financial advantages of no-till over other tillage systems. If a greater percentage of cropland falls under no-till management prior to the development of carbon markets, then baseline levels of C sequestration would increase, and the change in C sequestration at all C prices would be less than modeled.

An important issue in economic assessments is the treatment of farm profitability. Producers are not homogenous in their management skill, farm size, debt level, and profitability. Many studies have treated crop returns within large geographic regions in a homogenous manner, suggesting that average profitability is adequate to measure changes in land management and land use in response to C incentives. These assessments tend to exaggerate the amount of acreage shifts among various tillage systems that will occur with suggested C incentives. Producers who are achieving high profit levels 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. Likewise, 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 will be more variable than what has been depicted using only average profitability measures.

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