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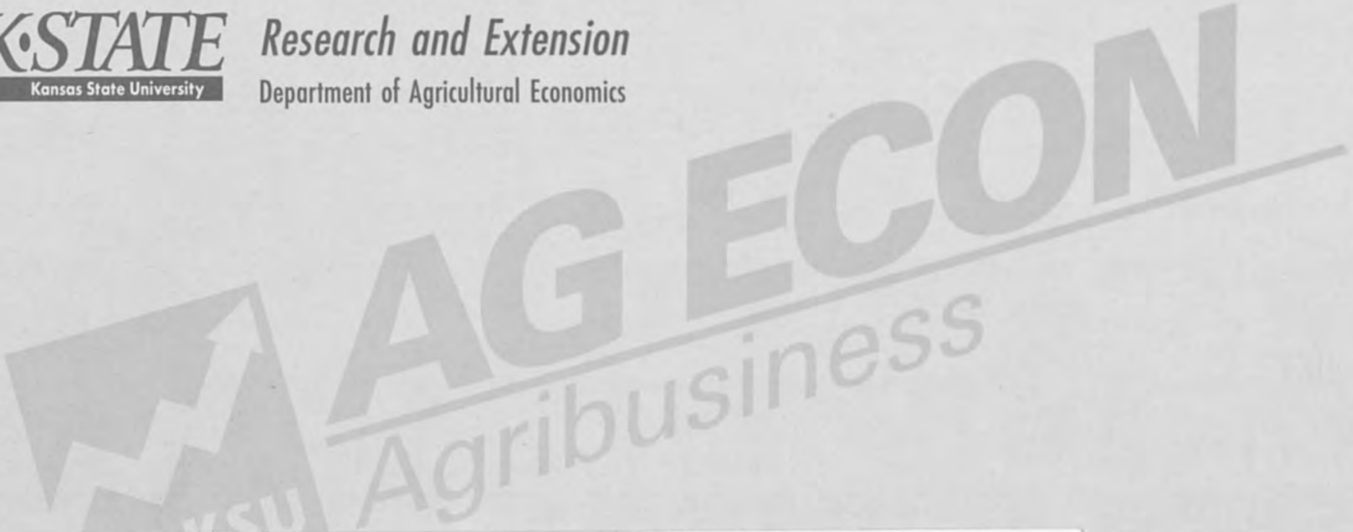

AN ECONOMIC ANALYSIS OF CARBON SEQUESTRATION FOR WHEAT AND GRAIN SORGHUM PRODUCTION IN KANSAS

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Abstract

This study examined the economic potential with and without carbon credit payments of two crop and tillage systems in South Central Kansas that could reduce carbon dioxide emissions and sequester carbon in the soil. Experiment station cropping practices, yield data, and soil carbon data for continuously cropped wheat and grain sorghum produced with conventional tillage and no-tillage from1986 to1995 were used to determine soil carbon changes and to develop enterprise budgets to determine expected net returns for a typical dryland farm in South Central Kansas. No-till had lower net returns because of lower yields and higher overall costs. Both crops produced under no-till had higher annual soil C gains than under conventional tillage. Carbon credit payments may be critical to induce farm managers to use cropping practices, such as no-till, that sequester soil carbon. The carbon credit payments needed will be highly dependent on cropping system production costs, especially herbicide costs, which substitute for tillage as a means of weed control. The C values estimated in this study that would provide an incentive to adopt no-tillage range from $0 to $95.99/ton/year, depending upon the assumption about herbicide costs. In addition, if producers were compensated for other environmental benefits associated with no-till, carbon credits could be reduced.

Key words: carbon credit value, carbon sequestration, grain sorghum, no-tillage, wheat.

Introduction

Technological advances have enhanced agricultural productivity, which benefits society. However, some of these advancements have created external costs for society that contribute to degradation of the environment. Improved productivity has resulted from substitution of machinery and chemicals for labor, tillage, and animal power. However, machines use fossil fuels, which release CO_2 into the atmosphere, which in turn may directly and indirectly contribute to climatic changes. Some of these changes, which vary geographically, include more volatile weather patterns. Records indicate that seven of the 10 hottest years in history have occurred in the past 10 years (Drennen and Kaiser 1994). Several authors report that environmental changes can be linked to increasing levels of specific greenhouse gases, the most critical being carbon dioxide (USDA 2000; Hurley 1999; Sandor and Skees 1999).

Agricultural activities contribute about 3% to annual total U.S. CO_2 emissions (42.9 of 1442 MMTC, million metric tons of carbon). Agriculture, though, has the potential to decrease atmospheric carbon (C) concentrations via storage in soils, plant material, and trees, as well as reducing CO_2 emissions (Hurley 1999; Lal et al. 1999). Some scientists have estimated that agriculture's annual potential C storage is 80 to 100 MMTC, while others estimated a potential of 300 MMTC (Richter 2000; McMahon 2000). Lal et. al (1998) estimated that potential sequestration on cropland soils over the next 50 years could be as high as 5,000 MMTC. Lal et al. (1998) and Rice (2000) reported estimates of 0.5 MT/ha/yr, which is equivalent to sequestering C at the rate of 0.22 ton/acre/yr.

Sequestering C in agricultural soils or plant material is accomplished by higher intensity cropping rotations and reduced or no-tillage strategies to maintain or increase soil organic matter (Havlin et al. 1990). According to Doering, a crop producer can control soil properties in the top layer, up to 15 inches, as very little C is stored or released to the atmosphere below that level (Rounding Up Carbon 2001). Reduced soil disturbance will lessen oxidation of soil C by microbes, thereby leading to retention of the C. In addition, studies have shown that a C boost may help plants yield more with less nitrogen, increasing production efficiency of applied inputs and food production capacity (Comis 1997; Hurley 1999; Paudel and Lohr 2000). Sequestering C will improve soil quality, as organic C influences many chemical and physical attributes including water holding capacity, nutrient retention, pH, structure and stability, and bulk density and penetration (Peterson et al. 1998; Smith et al. 2000).

Firms or industries may choose to purchase C "offset" credits from agricultural producers as a cost-effective approach to reducing (offsetting) their own emissions. If C sequestration in soils is to be economically feasible, it must cost less than reduction of greenhouse gases at their source (Williams and Aller 2000). Most C sequestration techniques in agriculture involve reducing tillage intensity. Carbon sequestration in soils is not free. For the agricultural producer, using less tillage means lower fuel costs, less equipment repair and depreciation, and decreased labor expense. However, with reduced tillage, the farm manager often must use more herbicides and pesticides, and their costs may offset other operating and ownership cost reductions.

Basic research has been conducted on the C cycle, but more research is needed on understanding the C sequestration process in agricultural soils and the economic feasibility of adopting cropping and tillage systems to enhance C sequestration in soil. This is important not only from a scientific perspective, but from an environmental and economic policy perspective.

Firms concerned about CO_2 emissions because of potential regulatory measures are exploring the potential of purchasing C credits (offsets) from those who can generate a credit by reduced use of fossil fuels or C sequestration. For example, the Greenhouse Emission Management Consortium (GEMCo), which is a group of Canadian energy companies, has tentatively arranged for Iowa farmers to sequester 2.8 MMTC. These preliminary commitments were brokered by Cantor Fitzgerald, CQuest, Ltd., and IGF Insurance in 1999. The producers agree to implement land management strategies known to improve agronomic productivity of cropland, reduce soil erosion, and improve water quality and wildlife habitat (Donnelly 2000; McConkey et al. 2000; Williams et al. 2000). These producers would be paid per ton of C sequestered. In another agricultural C sequestration project, Project Salicornia, Econergy International Corporation and a U.S. utility company are paying producers to produce the halophyte crop "salicornia" in Bahia Kino, Mexico (Silva-Chavez 2000). Implementation of sustainable production strategies and a C credit market have the potential to increase farm income and the value of the most productive farmland by 10% or more in the U.S. alone (Sandor and Skees 1999).

Further research into the economics of C sequestration is needed because legislative measures have recently been introduced in Congress that would provide monetary incentives to agricultural producers to adopt 'agricultural best practices' to enhance C sequestration in soils <thomas.loc.gov>. As Antle et. al (2000) found, land use and management changes in non-forested land in Montana respond to both market and policy incentives. They indicated that payments to induce producers from crop/fallow to continuous cropping begin at $5/ton/yr and increase to $70/ton/yr as more acres in continuous cropping are desired.

Estimated sequestration costs will vary widely due to location, soil type, estimated C uptake, land rental rate, management techniques, and resulting crop yields. McCarl and Schneider (1999), Miller (2000), and Caspers-Simmett (1999) estimated that the marginal costs of U.S. agriculture to sequester C was in the range of \$10 to \$25/ton/yr. Spatial heterogeneity in soil makes specific quantification and verification of C per acre much more difficult and expensive. Marginal costs of C sequestration rise as forest or agricultural establishment moves from land with low productivity and/or low opportunity costs to areas of higher productivity and/or opportunity costs (Silva-Chavez 2000; Richards 2001). The net effect of C storage from tillage reduction and C release from production inputs is vital to understand the potential benefits to agriculture.

Research on the economic feasibility of agricultural practices that sequester C are quite limited. There are few, if any, studies that consider the CO_2 release and change in atmospheric C due to input substitution in soil sequestration practices. This study presents an economic analysis with and without carbon credit payments of no-tillage continuously-cropped wheat and grain sorghum in South Central Kansas, as a means to sequester C in soils. The analysis uses actual yields and soil C sequestration rates and estimates of atmospheric C loading resulting from tillage, crop, and input use.

Objectives of the Study

Specific objectives included determining the tillage and field operations for each of the cropping systems based on experiment station practices from 1986 to 1995. Enterprise budgets for each system were developed based on a representative case farm for the South Central region of Kansas. Carbon sequestration rates and the amount of CO_2 not released due to decreased tillage and substitute input use, including direct, indirect (embodied), and feedstock energy use, was determined. From this, the market value of a C credit in \$/ton/year and \$/acre that was needed to make the returns from no-tillage systems equivalent to or greater than conventional tillage systems was found.

Methodology

Study region and cropping systems

The Harvey County Experiment Field, from which the yield and soils data was obtained, is located in the Central Outwash Plains of the Central Great Plains winter wheat and range resource region in South Central Kansas. This landscape is nearly level to rolling or sloping plains. Thirty-year average annual precipitation in Harvey County is 30.8 inches. The region receives about twice the annual precipitation as western Kansas, where fallow is included in wheat and grain sorghum rotations (Williams, Roth, and Claassen 2000).

The crop production systems studied include:

(1) CTSS, conventional tillage continuous sorghum;

(2) NTSS, no-till continuous sorghum;

(3) CTWW, conventional tillage continuous wheat; and

(4) NTWW, no-till continuous wheat.

The major difference between cropping systems is the type of weed control, either mechanical or chemical. The number of annual field operations and total acres covered in each are presented in Table 1.

Although producers in this area do not always produce these crops in continuous sequences, the experimental data does provide an opportunity for some useful comparison of the impact of crop and tillage systems on yields, C sequestration, and net returns. A producer would most likely find that bromus weed species, as well as diseases, would invade continuous no-till wheat, thereby requiring additional chemical inputs for pest control not accounted for in this study.

In the CTWW system, wheat stubble is moldboard plowed after the wheat is harvested in late June and early July. The field is disked in July to break apart any clods formed by plowing. The soil is then field cultivated to control weeds and to prepare the seedbed in August, September, and October. Wheat is drilled in October and harvested in late June or early July. An average of 4% crop residue remained on the surface under this system.

The NTWW system has no field operations in which soil is tilled. During the interval between crops, herbicides are applied for control of weeds and volunteer wheat. Wheat seed is planted directly into the remaining residue of the previous wheat crop. An average of 95% of the crop residue remained on the soil surface under this cropping system.

The CTSS system includes a chisel operation typically followed by disking and field cultivation operations. Shortly after planting, herbicides are applied for preemergence control. Under this system, 18% of the crop residue remained on the soil surface.

The NTSS system also has no operations that disturb the soil. Application of herbicides typically occurs in late April and in mid-June. Preemergence herbicides are applied shortly after planting in mid-June. After planting, this system maintained an average of 55% of the sorghum residue on the soil surface.

Net returns and yields

Net returns for two tillage systems for each crop were determined with regard to farm size for a representative farm. Net returns compared in this study are equal to gross income minus all variable and fixed costs, excluding a cost for owned land and managerial expertise. Net returns were equivalent to net return to land and management. These costs included opportunity costs (ie, operator labor and interest expense on inputs and equipment). Variable inputs and general equipment requirements for each cropping system based on experiment station practices were determined, and specific costs for the individual field operations were estimated. These specific costs were aggregated into enterprise budgets. Gross returns were determined by using the five-year average annual prices from South Central Kansas crop reporting districts for wheat and grain sorghum from 1995-2000. Annual yield data was collected from the Harvey County Experiment Field in South Central Kansas for the years 1986-1995. The average government payment (Production Flexibility Contract Payments) per acre for wheat and grain sorghum for 1995-2000 was also included in the net return calculation.

Establishing farm size

Weighted average data in 1995 from 137 cash crop, dryland farms in seven counties in the South Central Kansas Farm Management Association were used to establish typical size and to estimate costs and returns for each enterprise budget. On an annual average, harvested acres were 949 of 1031 crop acres (Langemeier 2000). On a per farm basis, 540 acres were planted to wheat and 260 acres to sorghum and those acres were cropped continuously. Thus, wheat comprised 62% of the total land planted to wheat, sorghum, soybean, and corn. Continuous wheat cropping strategies (CTWW and NTWW) used 540 acres, while continuous sorghum (CTSS and NTSS) used 260 acres. Remaining acres were typically planted to soybean and hay crops. The equipment complement for the case farm was developed for these acre averages and the required field operations.

Input and tillage requirements

Labor, fuel, and specific machinery requirements were determined for each cropping strategy for the representative farm. Specific tillage methods and input requirements used (ie, fertilizer and chemical application rates to estimate costs) were gathered from the actual field operations at Harvey County Experiment Field. Required tillage implement sizes and tractor horsepower were estimated using an engineering equation (Schrock 1976). These equipment estimates accounted for acres, equipment efficiency, daily hours available for field work, and available work days (Buller et al. 1976).

Requirements for tractor horsepower were estimated based on draft requirements of tillage implements, available work days, and the average annual probability of completing the field work 75% of the time within the available or suggested work period. Fuel requirements were taken from a study that estimated average fuel use per acre for certain tillage operations on actual farms (Schrock, Kramer, and Clark 1985). Labor requirements were based on acres covered in an hour with the appropriate equipment complement and on the acres involved per field operation.

Equipment values for calculating depreciation were based on 82% of list price, a discount of 18%. All equipment ages were assumed to be half of the listed depreciable life: tractors, 10 years; planters, 12 years; and tillage implements, 14 years. Equipment list prices were adjusted to the appropriate year the machine was purchased and used to figure the original value for depreciation purposes.

Input costs for herbicides, fungicides, insecticides, and fertilizers were based on actual application rates used in the experiment. Average prices were obtained from local agricultural input suppliers. All inputs applied either before or after planting were custom hired. This study assumed the operator paid for all inputs including custom application expenses.

Price and yield data

Crop prices were the annual averages from the Central, South Central, East Central, and South East districts of the Kansas Crop and Livestock Reporting Service for 1995-2000. Specific yield data for wheat and grain sorghum were obtained from the Harvey County Experiment Field for 1986-1995. Average yield data were used in the enterprise budgets. Yield results are reported in Table 2. No-till wheat and sorghum both resulted in lower yields (about four to five bushels per acre less) than the same crop under conventional tillage. Claassen (1996) reports additional details concerning the field experiments.

Soil carbon data

Carbon data for the experiment were obtained by soil tests of organic matter content pre-experiment in 1984, again in 1990, and post-experiment in 1995. Changes in soil organic matter by soil depth over the 10-year period were determined for each crop and tillage system. This experiment focused on the top six inches of the soil because this layer is where the producer has the greatest potential land management influence. The mean percentage of soil organic matter for each system was converted to percent total soil C, and then into tons C/acre/yr. Tons C/acre/yr (in the top six inches) was used to determine the economic value to the farm manager.

Net carbon sequestration data

While a particular cropping system may be sequestering C in the soil, C in the form of CO_2 is also released into the atmosphere from the combustion of diesel and other fossil fuels (gasoline, natural gas, propane, coal for electricity, etc.) used in field operations such as tillage, fertilizer and herbicide application, planting, and harvest. In addition, the energy used in the production (manufacture/processing) of farm equipment, fertilizers, and herbicides, also have C releases associated with them. Carbon release values (pounds of C per Btu expended) from direct, embodied or indirect, and feedstock energy for the fertilizers and chemicals applied were estimated (Nelson and Schrock 2001). Carbon release estimates from direct energy use in field operations (planting, tillage, and harvest) were also included. The result was an estimate of the amount of C released to the atmosphere from field operations and application of fertilizers, herbicides, fungicides, and insecticides.

From soil C sequestered and estimates of C emissions, the net change in C resulting from a cropping system was determined. The net change of C for each crop and tillage system was equal to sequestered soil C less atmospheric loading of C in tons/acre.

Results and Analysis

Average annual net return to land and management using 2001 cost-of-production estimates were positive for all cropping systems (Table 3). The highest expected net return was for CTSS. The next highest expected net return was from NTSS, followed by CTWW and NTWW, respectively. The gross return per acre indicates the value of the crop plus the government commodity program payments without accounting for costs. CTSS had the highest gross, followed by NTSS, CTWW, and NTWW, respectively.

Conventional tillage systems had higher gross returns and net returns to land and management than the no-tillage systems. Herbicide costs were higher for no-tillage production strategies, but labor, fuel, fertilizer, and repair costs were less than under conventional systems (Table 3). In addition, machinery ownership costs were less under no-tillage. However, the savings in these costs were not enough to offset the higher chemical and custom application costs. Lower yields and accompanying higher overall costs for no-tillage resulted in lower net returns for these tillage systems. Because of these net results, carbon credit payments may be critical to induce farm managers to use cropping practices that may sequester more soil C.

Sorghum is relatively more profitable than wheat, whether in conventional or no-tillage. Because of this and the cropping flexibility allowed by the current government commodity program, an overall increase has occurred in acres planted to sorghum relative to wheat in South Central Kansas from 1996 to 2000 compared to 1995.

Sensitivity analysis

Sensitivity analysis was performed to determine how much variable costs or gross returns would need to change to make conventional and no-till systems equal in net returns.

The cropping systems were examined independently in the first analysis to indicate how much costs would have to decrease or yields increase for the no-tillage systems to generate the same returns (Table 4). Wheat yields over the study period were 32.6 bu/acre for NTWW and 37.5 bu/acre for CTWW, while sorghum yields were 73.8 bu/acre for NTSS and 77.8 bu/acre for CTSS. Average wheat prices were $3.29/bu, and average sorghum prices were $2.14/bu for the 5-year period from 1996-2000. In order for NTWW to be equally preferred to CTWW, net returns for NTWW would have to be $22.44/acre more. This is equivalent to an increase of 6.82 bu/acre in NTWW. In order for NTSS to be equally preferred to CTSS, net returns of NTSS have to increase $11.66/acre, which is equivalent to an increase of 5.44 bu/acre in NTSS.

Alternatively, no-till systems' costs would need to be less. Herbicide costs would have to be reduced by 63.9% for NTWW to be equally-preferred to CTWW, using net return as the decision rule. In the sorghum systems, a 23.9% herbicide cost reduction would be needed for NTSS to be equally-preferred to CTSS (Table 5).

Kansas Farm Management Association enterprise records from 24 farms producing no-till wheat and 23 farms producing no-till sorghum in North Central Kansas in 2000 indicated that herbicide and insecticide costs totaled $5.66/acre for wheat and $30.61/acre for grain sorghum (Kansas Farm Management Association 2001). These costs are $3.00/acre greater in wheat and $8.95/acre more in grain sorghum than for crops produced with tillage. Similar data were not available for South Central Kansas. If herbicide costs in no-till systems could be reduced in South Central Kansas to these levels, the net return for NTWW would be $7.02/acre greater than CTWW. With the herbicide cost reduction in NTSS, net returns would be $6.57/acre greater for NTSS compared to CTSS. If herbicide and insecticide costs in NTWW were only $3.00/acre more than in CTWW, the NTWW system would earn $8.29/acre more than CTWW. If herbicide and insecticide costs in NTSS were only $8.95/acre more than in CTSS, the NTSS system would earn $6.22/acre more than CTSS.

This sensitivity analysis indicates that the amount of herbicides used could have an important impact on the outcome of the economic analysis of the no-tillage systems' carbon sequestration potential.

Soil carbon changes over 10 years

Total tons C/acre/yr sequestered in the top six inches of the soil is an important factor influencing the economic feasibility of C sequestration practices. Depending on the land management and cropping strategies, the producer will either gain or lose C on a given acre of land.

As expected, both no-till systems had higher annual soil C gains than conventional tillage (Table 6). The highest C gain was in the NTWW system at 0.52 tons C/acre/yr. CTWW had slightly more than half of that at 0.30 tons C/acre/yr, with NTSS and CTSS following at 0.28 and 0.12, respectively. However, these soil C gains did not account for C released to the atmosphere in conjunction with field operations (CO_2 from fuel emissions) or chemical and fertilizer applications (CO_2 released from energy used in production of the inputs). These releases would affect the total net C sequestered in a cropping system. Emissions of CO_2 for inputs were converted to C equivalents of tons C/acre/yr (Table 7). Comprised in the C loss were feedstock energies used to make the input (ie, herbicides processed from petroleum and fertilizers from natural gas), embodied energies utilized in manufacturing the input, and direct energies (ie, diesel fuel) used in applying the input or tilling a field.

In this study, CO_2 emissions from direct energy use were highest for the conventional systems (wheat and sorghum) due to greater tillage, while embodied emissions were highest for the no-till systems due to the use of more manufactured inputs (Table 7). The conventional tillage systems had greater overall C release to the atmosphere than did the no-till systems. Both sorghum cropping systems had higher total emissions than the wheat cropping systems. This is due to greater use of energy-intensive inputs like fertilizers and chemicals in sorghum than in wheat. The system emitting the most emissions overall was CTSS, and lowest was NTWW.

In determining net C gain or loss resulting from a cropping system, the total C emissions (into the atmosphere) resulting from field operations in a system were subtracted from C sequestered (or lost) in the soil. The sorghum cropping systems had lower net results in C than the wheat cropping systems counterparts (Table 6). The no-tillage systems had greater sequestration rates than did their conventional tillage counterparts. One result worth noting is that CTSS resulted in a slight overall net C loss due to losses by atmospheric C emissions from produced inputs. The highest level sequestered was NTWW at 0.48 ton C/acre/yr.

A high value for C credits could make the net returns of no-tillage systems equivalent to conventional tillage systems (Table 8). Under the original herbicide costs used in the field study, a $95.99/ton value for C would make the net returns of NTWW equal to CTWW. A C value of $57.62/ton would make net returns of NTSS equal to CTSS. This translates to a per acre/year C value needed of $22.44 and $11.66, respectively. The C ton values were determined by dividing the difference in net returns between the wheat or sorghum tillage systems by the difference in soil C sequestered for the respective systems. The C acre values were determined by the difference in net returns between tillage systems of the same crop.

Greater differentials exist between the net returns and the net C sequestered of CTWW and NTWW versus that between CTSS and NTSS. In this study, a higher C price is required for a no-till wheat system than is required for a no-till sorghum system to yield equivalent returns. If the C credit or monetary incentive is lower than the required value, the producer would realize greater financial benefit by continuing production under conventional tillage. A producer of CTSS would be much more sensitive to the C credit value or incentive. The difference in net returns of sorghum systems was much lower, so equivalent net returns between tillage systems would be achieved by a lower carbon value. Thus, a sorghum producer may be more inclined to change production strategies to no-tillage at a lower carbon incentive value than the incentive required under wheat systems based on this experiment.

If the NTWW and NTSS herbicide costs are 50% lower than in the original analysis, it becomes economically feasible for the producer to switch tillage strategies from CTSS to NTSS without a C credit incentive in place (Table 9). However, a net C price of $20.85/ton is required for the farm manager to switch to NTWW from CTWW under these conditions. This translates to a soil C sequestration incentive of $4.88/acre or $21.35/ton of C sequestered. A lower net C price of $20.85/ton results because the soil C value of $21.35/ton did not account for CO_2 emissions resulting from field operations.

Summary and Implications

The CTSS cropping system had the highest net return per acre among the four continuous cropping systems. The next most profitable cropping system was NTSS, but it would take an additional return of $11.66/acre for NTSS to have the same return as CTSS. CTWW achieved net returns $22.44/acre higher than that of NTWW. The system that sequestered the most soil C was NTWW, both before and after C emissions from field operations and production inputs were included in the analysis. NTSS sequestered more C than CTSS. In addition, CTSS, the system with the highest net returns, produced a net loss of C due to atmospheric releases greater than soil sequestration. A high enough C credit value will provide incentive for the farm manager to change land management strategies, such as tillage or input substitution, to build soil C despite yield differences. The initial analysis indicated that a minimum C incentive payment of $95.99/ton/year for NTWW and a payment of $57.62/ton/year for C sequestered in NTSS would be required. However, if the differentials in herbicide costs obtained from actual farm enterprise records could be maintained and similar yields received as in this field experiment, a much lower C incentive value would be needed for farm managers to undertake no-tillage practices to sequester soil C. Further, C sequestration practices may also create external benefits that society may be willing to pay for, such as improved water quality and wildlife habitat, reduced sedimentation, and less wind erosion of soil (Williams and Aller 2000). Producers may benefit from obtaining monetary rewards for their C and from payments for other environmental quality improvements associated with C sequestration.

The results of the sensitivity analyses indicated that the NTWW and NTSS systems could provide a farm manager additional economic benefits, particularly if they were paid for soil C sequestered. The economic gain (or loss) from C sequestration in agricultural soils depends on the costs of a number of inputs, especially herbicides, the cost savings associated with their efficient use, and the monetary value of C sequestered. The cost for owned land may also vary depending on the land's ability to sequester C. A farm manager must consider net returns from both conventional and no-till cropping systems and the opportunity for additional revenue from C credits. The C values estimated in this study that would provide an incentive to adopt no-tillage range from $0 to $95.99/ton/year, depending upon the assumption about herbicide costs.

An important limitation to this study was that only continuous wheat and sorghum cropping systems were analyzed, and continuous wheat is typically not produced due to weed and pest problems. Other crops are produced in South Central Kansas, and rotations of these crops are often implemented. Also, this research was performed at an experiment station, so more tillage may have been used in the conventional system and more inputs may have been applied than used in a typical farm field, where time between operations is more limited. Further research using this experimental data will include crop rotations of wheat and sorghum and reduced tillage. Therefore, future research will involve equipment efficiency and cost related to farm size. A no-tillage system requires fewer pieces of equipment and has fewer field operations than conventional tillage, which makes the fixed costs lower. As a result, a producer may be able to farm more acres, spread labor, and lower fixed costs even more with a no-tillage system.

References

Antle, J., S. Capalbo, S. Mooney, E. Elliot, and K. Paustian. 2000. "Economics of Agricultural Carbon Sequestration in the Northern Plains." Research Discussion Paper No. 38 Department of Agricultural Economics and Economics, Montana State University: Bozeman, MT.

Buller, O.H., L.N. Langemeier, J.L. Kasper, and L.R. Stone. 1976. *Field Workdays in Kansas.* Bulletin 596. Kansas Agricultural Experiment Station: Manhattan, KS.

Caspers-Simmet, J. 1999. Carbon Credits a New Crop for Grain Producer. *Agri-Marketing.* December 2.

Claassen, M.M. 1996. "Effects of Reduced Tillage and Crop Rotation on Wheat and Grain Sorghum." In the *Field Research 1996.* Report of Progress 762. Kansas Agricultural Experiment Station: Manhattan, KS. 26-29.

Comis, D. 1997. "Rising CO_2 Could Affect Fertilizer Needs." Agricultural Research Service. <www.ars.usda.gov/is/pr/1997/970109.htm>

Donnelly, A. 2000. "Background on Carbon Emission Reduction Valuation Considerations in the GEMCo/Iowa Farm." <www.il.nrcs.usda.gov/news/donnelly.htm>

Drennen, T.E., and H.M. Kaiser. 1994. Global Warming and Agriculture: The Basics. *Choices*. Second Quarter: 38-40.

Havlin, J.L., D.E. Kissel, L.D. Maddux, M.M. Claassen, and J.H. Long. 1990. Crop Rotation and Tillage Effects on Soil Organic Carbon and Nitrogen. *Soil Science Society of America Journal.* (54): 448-452.

Hurley, E.G. 1999. "A Carbon Sequestration Budget for a 640 Acre Farm in Central Iowa." July. <www.public.iastate.edu/~ehurley/carbon42.pdf>

Kansas Farm Management Association. 2001. *Enterprise Profit Center Summary, Analysis and Management Information 2000.* Department of Agricultural Economics, Kansas State University: Manhattan, KS.

Lal, R., J.M. Kimble, R.F. Follett, and C.V. Cole. 1998. *The Potential of U.S. Cropland to Sequester Carbon and Mitigate the Greenhouse Effect.* Sleeping Bear Press, Ann Arbor, MI.

Lal, R., R.F. Follett, J. Kimble, and C.V. Cole. 1999. Managing U.S. Cropland to Sequester Carbon in Soil. *Journal of Soil and Water Conservation* 54 (1): 374-381.

Langemeier, L.N. 2000. *Farm Management Data Bank Documentation*. Staff Paper No. 01-05. Department of Agricultural Economics, Kansas State University: Manhattan, KS.

McCarl, B.A., and U. Schneider. 1999. Curbing Greenhouse Gases: Agriculture's Role. *Choices*. First Quarter:9-12.

McConkey, B., B. Chang Liang, G. Padbury, and W. Lindwall. 2000. "Carbon Sequestration and Direct Seeding." Semiarid Prairie Agricultural Research Centre, Agriculture and Agri-Food Canada. <ssca.usask.ca/2000proceedings/McConkey.htm>

McMahon, K. 2000. Saving Carbon for Cash. *Farm Industry News*. January: 70.

Miller, D. 2000. Selling Your Carbon. *Progressive Farmer*. September: 20.

Nelson, R.G., and M.D. Schrock. 2001. *Direct and Embodied Energy and CO_2 Emission Analysis of Selected Kansas Agricultural Cropping Rotations*. Kansas State University: Manhattan, KS. Unpublished data.

Paudel, K.P., and L. Lohr. 2000. "Meeting the Kyoto Target Through Conservation Tillage and Its Implication for Natural Capital Maintenance, Production Efficiency, and Sustainability." Paper Series 2-2000 from Department of Agricultural Economics and Rural Sociology, Auburn University: AL.

Peterson, G.A., A.D. Halvorson, J.L. Havlin, O.R. Jones, D.J. Lyon, and D.L. Tanaka. 1998. Reduced Tillage and Increasing Cropping Intensity in the Great Plains Conserves Soil C. *Soil & Tillage Research*. (47): 207-218.

Rice, C.W. 2000. "Agricultural Practices to Sequester Atmospheric CO_2 in Soils." Paper presented at the Carbon Sequestration in Kansas Planning Meeting. Kansas State University, Manhattan, KS. June 27.

Richards, K.R. 2001. "Current Studies Costing Carbon Sequestration." School of Public and Environmental Affairs, Indiana University: Bloomington, IN. <www.indiana.edu/~lawecon/group10.html>

Richter, S. 2000. Carbon Catching. *Cooperative Partners*. September: 4-6.

Rounding Up Carbon - Sequestration Has Its Ties. Agronomy Notes No. 267. 2001. Montana State University, Bozeman, MT. <scarab.msu.montana.edu/Agnotesold/agnotes21b_145.htm>

Sandor, R.L., and J.R. Skees. 1999. Creating a Market for Carbon Emissions: Opportunities for U.S. Farmers. *Choices*. First Quarter: 13-17.

Schrock, M.D. 1976. *Avoiding Machinery Bottlenecks*. Publication C-563. Kansas Cooperative Extension Service: Manhattan, KS.

Schrock, M.D. J.A. Kramer, and S.J. Clark. 1985. Fuel Requirements for Field Operations in Kansas. *Transactions of the American Society of Agricultural Engineers*. 28(3):669-674.

Silva-Chavez, G. 2000. "Economic and Social Costs and Benefits of Carbon Sequestration Projects in Mexico: Policy Recommendations For Future Projects." Project course. School of Public Affairs, University of Maryland: College Park, MD. <www.geocities.com/RainForest/Canopy/8169/thesis.html>

Smith, R.G., M. Lerohl, T. Messele, and H.H. Janzen. 2000. Soil Quality Attribute Time Paths: Optimal Levels and Values. *Journal of Agricultural and Resource Economics*. 25 (1): 307-324.

USDA. 2000. "*Growing Carbon: A New Crop that Helps Agricultural Producers and the Climate Too.*" Washington, D.C.: U.S. Department of Agriculture.

Williams, J.R., and T.D. Aller. 2000. "Economic Issues of Carbon Sequestration and Trading." Paper presented at the Carbon Sequestration in Agriculture: Challenges and Opportunities Conference. Kansas State University: Manhattan, KS. December 2.

Williams, J.R., T.D. Aller, and R.G. Nelson. 2000. "Carbon Sequestration: An Overview of the Issues." Paper presented at the Risk and Profit Conference. Department of Agricultural Economics, Kansas State University: Manhattan, KS. August 17-18.

Williams, J.R., T.W. Roth, and M.M. Claassen. 2000. Profitability of Alternative Production and Tillage Strategies For Dryland Wheat and Grain Sorghum in the Central Great Plains. *Journal of Soil and Water Conservation* 55(1): 49-56.

Table 1. Annual number of acres and number of field operations by cropping system.

	Individual Crop Systems *			
Operations	CTWW	NTWW	CTSS	NTSS
Acres planted				
Wheat	540	540	0	0
Sorghum	0	0	260	260
Preplant tillage				
Wheat	5	0	0	0
Sorghum	0	0	4.1	0
Chemical (Custom Application)				
Wheat	0.4	2.6	0	0
Sorghum	0	0	1.2	3.2
Fertilizer				
Wheat	1	1	0	0
Sorghum	0	0	1	1
Plant				
Wheat	1	1	0	0
Sorghum	0	0	1	1
Harvest				
Wheat	1	1	0	0
Sorghum	0	0	1	1
Total operations	8.4	5.6	8.3	6.2
Acres covered †	4536	3024	2158	1612

* CTWW - Conventional-tillage continuous wheat
NTWW - No-till continuous wheat
CTSS - Conventional-tillage continuous sorghum
NTSS - No-till continuous sorghum

† Total number of acres covered with field operations per year.

Table 2. Average yields 1986-1995 (Bu/acre) by cropping system.

	Individual Crop Systems *			
Crop	CTWW	NTWW	CTSS	NTSS
Wheat	37.46	32.55	-	-
Sorghum	-	-	77.82	73.84

* Refer to Table 1 for an explanation of cropping system codes.

Table 3. Returns and selected costs ($/acre) by cropping system.

	Individual Crop Systems *			
Cost & Returns †	CTWW	NTWW	CTSS	NTSS
Variable costs	$67.40	$89.78	$90.87	$109.42
Fixed costs ‡	52.77	36.68	55.14	39.73
Total costs	120.17	126.46	146.01	149.15
Gross crop return	123.24	107.09	166.53	158.02
Government payments	31.84	31.84	43.00	43.00
Gross return §	155.08	138.93	209.53	201.02
Average net return ¶	34.91	12.47	63.52	51.87
Selected costs				
Labor	7.99	2.60	7.58	3.07
Fuel/Oil	7.04	1.67	5.72	1.78
Repairs	12.95	5.91	12.35	6.78
Subtotal	27.98	10.18	25.65	11.63
Herbicide	1.39	35.12	22.01	48.83
Insecticide/Fungicide	0.97	0.97	4.85	4.85
Fertilizer	20.14	18.61	21.91	20.27
Custom Hire	4.97	11.88	7.46	13.96
Subtotal	27.47	66.58	56.23	87.91
Depreciation	26.30	18.32	27.28	19.58
Interest on machinery	25.49	17.69	26.83	19.41
Subtotal	51.79	36.01	54.11	38.99

* Refer to Table 1 for an explanation of cropping system codes.

† Costs and returns to the operator.

‡ Excludes charges on land values which could change depending upon the land's ability to sequester carbon.

§ Equal to gross crop return plus government payments.

¶ Average net return to land and management (including government payments).

Table 4. Sensitivity analysis of net returns and yield which changes tillage preference.

	Individual Crop Systems [*]			
	CTWW	NTWW	CTSS	NTSS
Average yield [†]	37.46	32.55	77.82	73.84
Average Price [‡]	$3.29	$3.29	$2.14	$2.14
Orig. net return to land/mgmt [§]	$34.91	$12.47	$63.52	$51.87
To change tillage preference to no-till:				
Difference in net returns [§]	NA	$22.44	NA	$11.66
Equivalent yield difference [†]	NA	6.82	NA	5.44

[*] Refer to Table 1 for an explanation of cropping system codes.

[†] In Bu/acre.

[‡] In $/bushel.

[§] In $/acre.

Table 5. Sensitivity analysis of herbicides that changes tillage preference.

	Individual Crop Systems *			
	CTWW	NTWW	CTSS	NTSS
Orig. herbicide cost †	$1.39	$35.12	$22.01	$48.83
Orig. variable cost †	$67.40	$89.78	$90.87	$109.42
Orig. net return to land/mgmt †	$34.91	$12.47	$63.52	$51.87
Herbicide cost reduction necessary for equivalent returns:		-63.90%		-23.86%
New herbicide cost †	NA	$12.68	NA	$37.18
New variable cost †	NA	$67.34	NA	$97.77
Net return to land/mgmt †	NA	$34.91	NA	$63.52

* Refer to Table 1 for an explanation of cropping system codes.

† In $/acre.

Table 6. Total carbon assessment, bushels, and returns.

	Individual Crop Systems *			
	CTWW	NTWW	CTSS	NTSS
6" Total Soil Carbon †‡	0.295	0.524	0.118	0.276
Decade % Chg. Carbon	31.65%	56.82%	11.11%	27.03%
Total carbon emissions †‡	0.049	0.044	0.135	0.091
Net carbon gain/loss ‡	0.246	0.480	-0.017	0.185
Average yield §	37.46	32.55	77.82	73.84
Gross return ¶	$123.24	$107.09	$166.53	$158.02
Net return to land/mgmt ¶	$34.91	$12.47	$63.52	$51.87

* Refer to Table 1 for an explanation of cropping system codes.

† Refer to Table 7 for detail.

‡ In Tons/ac/yr.

§ In Bu/acre.

¶ In $/acre.

Table 7. Carbon equivalent emissions from field operations (Tons/ac/yr)

System *	Direct energy	Embodied/Indirect energy	Feedstock energy	Total emissions
CTWW	0.021	0.015	0.014	0.049
NTWW	0.008	0.030	0.006	0.044
CTSS	0.019	0.021	0.096	0.135
NTSS	0.010	0.052	0.029	0.091

From: Nelson, R.G., and M.D. Schrock. 2001. Direct and Embodied Energy and CO_2 Emission Analysis of Selected Kansas Agricultural Cropping Rotations. Kansas State University. Unpublished data.

* Refer to Table 1 for an explanation of cropping system codes.

Table 8. Carbon value analysis to change tillage preference.

	Individual Crop Systems *			
	CTWW	NTWW	CTSS	NTSS
Net return to land/mgmt †	$34.91	$12.47	$63.52	$51.87
Net carbon gain/loss ‡	0.246	0.480	-0.017	0.185
Difference in C for no-till ‡	NA	0.234	NA	0.202
Carbon price required §	NA	$95.99	NA	$57.62
Carbon incentive required †	NA	$22.44	NA	$11.66
Soil carbon sequestered ‡¶	0.295	0.524	0.118	0.276
Difference in C for no-till ‡	NA	0.229	NA	0.158
Carbon (soil) price required §	NA	$98.29	NA	$73.60
Carbon (soil) incentive required †	NA	$22.44	NA	$11.66

* Refer to Table 1 for an explanation of cropping system codes.

† In $/acre.

‡ In Tons/ac/yr.

§ In $/ton.

¶ Carbon sequestered only in the soil, excluding CO_2 emissions.

Table 9. Carbon value analysis to change tillage preference for a 50% herbicide cost reduction in no-tillage.

	Individual Crop Systems *			
	CTWW	NTWW	CTSS	NTSS
New net return to land/mgmt †	\$34.91	\$30.03	\$63.52	\$76.29
Net carbon gain/loss ‡	0.246	0.480	-0.017	0.185
Difference in C for no-till ‡	NA	0.234	NA	0.202
Carbon price required §	NA	\$20.85	NA	NA
Carbon incentive required †	NA	\$4.88	NA	NA
Soil carbon sequestered ‡¶	0.295	0.524	0.118	0.276
Difference in C for no-till‡	NA	0.229	NA	0.158
Carbon (soil) price required §	NA	\$21.35	NA	NA
Carbon (soil) incentive required †	NA	\$4.88	NA	NA

* Refer to Table 1 for an explanation of cropping system codes.

† In \$/acre.

‡ In Tons/ac/yr.

§ In \$/ton.

¶ Carbon sequestered only in the soil, excluding CO_2 emissions.