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Derived Carbon Credit Values for Carbon Sequestration: Do CO_2 Emissions from Production Inputs Matter?

by

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Abstract

An economic analysis was conducted involving wheat and grain sorghum production systems that affect carbon dioxide emissions and sequester soil carbon. Parameters examined were expected net returns, changes in net carbon sequestered and the value of carbon credits necessary to equate net returns from systems that sequester more carbon to those that sequester less with and without adjustments for CO_2 emissions from production inputs. Evaluations were based on experiment station cropping practices, yield, and soil carbon data for continuously cropped and rotated wheat and grain sorghum produced with conventional and no-tillage. 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. However, no-till systems had higher total atmospheric emissions of C from production inputs. The differences were relatively small. The C values estimated in this study that would equate net returns of no-tillage to conventional tillage range from $7.82 to $58.69/ton/yr when C emissions from production inputs were subtracted from soil carbon sequestered and $7.79 to $54.99/ton/yr when atmospheric emissions were not considered.

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

Introduction

Burning of fossil fuels releases carbon dioxide (CO_2) into the atmosphere, which may directly and indirectly contribute to climatic changes. Some of these changes, which vary geographically, include more volatile weather patterns. Drennen and Kaiser reported that seven of the 10 hottest years in history occurred in the previous 10 years. Others report that environmental changes can be linked to increasing levels of specific greenhouse gases, the most critical being CO_2 (USDA; Sandor and Skees).

Agricultural activities contribute about 3% to the total annual 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 (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; McMahon). 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 reported estimates of 0.5 MT/ha/yr, which is equivalent to sequestering C at the rate of 0.22 ton/ac/yr.

Sequestering C in agricultural soils or plant material is accomplished by producing more crops or biomass within a given time period, coupled with reduced or no-tillage strategies to maintain or increase soil organic matter (Havlin et al.). 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). 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; Paudel and Lohr). 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.; Smith et al.).

In the future, firms may choose to purchase C "offset" credits from agricultural producers as a cost-effective approach to 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. 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 expenses. 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; McConkey et al.). These producers would be paid per ton of C sequestered. 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).

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 management practices' to enhance C sequestration in soils. As Antle et. al 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; and Caspers-Simmett 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 (Richards). The net effect of C storage from tillage reduction and C release from production inputs is vital to understanding 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 of conventional and no-tillage systems with and without carbon credit payments for wheat and grain sorghum produced continuously and in rotation, as a means to sequester C in soils. The value of carbon credits needed to adopt practices that sequester carbon in the soil are derived with and without a factor accounting for carbon released from production inputs to the atmosphere. This was done because the net amount of carbon sequestered will affect the value of the credit required by farm managers to undertake practices to sequester additional carbon.

Methodology and Data

Net returns to land and management were calculated using enterprise budgets for each cropping system. These budgets were developed based on a representative farm for the South Central region of Kansas. Yields, input levels, field operations, and carbon sequestration rates from soil tests were obtained from 10 years of experiment station data. Carbon release values (tons of C/ac) from direct, embodied or indirect, and feedstock energy for the fertilizers and chemicals applied were estimated along with estimates from direct energy used in field operations such as application of herbicide and fertilizers, tillage, planting, and harvesting for each system; these data were calculated using a method developed by Nelson and Schrock. From soil C sequestered and estimates of C emissions, the net change in C resulting from each cropping system was determined. The value of carbon credits needed to adopt less-profitable practices that sequester more carbon were derived with and without an accounting of carbon released from the production inputs.

Study region and cropping systems

The Harvey County Experiment Field, from which the yield and soils data were 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.

The crop production systems studied include: CTSS - conventional tillage continuous sorghum; NTSS - no-till continuous sorghum; CTWW - conventional tillage continuous wheat; NTWW - no-till continuous wheat; CTSNTW - conventional tillage sorghum rotated with no-till wheat; and NTSNTW - no-till sorghum rotated with no-till wheat. The major difference between tillage systems is the type of weed control, either mechanical or chemical.

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 pre-emergence 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. Pre-emergence 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.

The CTSNTW system included tillage operations of chiseling and disking after wheat harvest. Four field cultivations were used, one in the fall and three in the spring before sorghum was planted. After sorghum planting, only 14% of crop residue remained on the surface, but 66% of the residue remained after wheat planting.

The NTSNTW system did not include any tillage operations. After wheat harvest, herbicides were applied. Other applications occurred in the fall, late April, and in mid-June before sorghum was planted. Pre-emergence herbicides were also used following sorghum planting. Under this system, 63% of the crop residue remained on the surface after sorghum planting, and 86% was maintained following wheat planting.

Net returns, price and yields

Net returns per acre for each cropping system were determined with regard to farm size for a representative farm. Net returns compared in this study are net returns to land and management and equal to gross income minus all variable and fixed costs, excluding a cost for owned land and managerial expertise. These costs included opportunity costs (i.e., 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.

Crop prices were the annual averages from the Central, South Central, East Central, and Southeast districts of the Kansas Crop and Livestock Reporting Service for 1985-1996. These prices were used with yield data obtained from the Harvey County Experiment Field for 1986-

1995 to calculate annual gross return. The annual gross returns were used in the enterprise budgets with 2001 costs to calculate annual net returns. No-till wheat and sorghum grown in a continuous pattern both resulted in lower yields (about four to five bushels per acre less) than the same crop under conventional tillage. Crop yields in rotation were essentially the same for conventional and no-till. Claassen reports additional details concerning the field experiments. Table 1 provides a summary of the net returns, prices, and yields.

Establishing farm size

Weighted average data from 137 cash crops from 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). On a per farm basis, 540 acres were planted to wheat and 260 acres to sorghum. A machinery complement was developed that could handle 540 acres of continuous wheat and 260 acres of continuous grain sorghum or 400 acres of wheat and grain sorghum grown continuously or in rotation. Therefore, the machinery complement selected was suitable for a typical South Central Kansas farm. For the analysis, continuous wheat and sorghum cropping strategies used 400 acres each, and the wheat-sorghum rotation used 400 acres for each crop. Remaining acres were typically planted to soybean and hay crops. This equipment complement was also large enough to handle an additional 60 acres of soybean, the next largest acreage category found on the typical farm.

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 (i.e., fertilizer and chemical application rates to estimate costs) were gathered from actual field operations at the Harvey County Experiment Field. Required tillage implement sizes and tractor horsepower were estimated using an engineering equation (Schrock). These equipment estimates accounted for acres, equipment efficiency, daily hours available for field work, and available work days (Buller et al.).

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 (gal/ac) were taken from a study that estimated average fuel use per acre for certain tillage operations on actual farms (Schrock, Kramer, and Clark). 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 experiment field practices. The types and amounts and herbicides used were updated for this analysis to reflect currently available herbicides and typical farm application practices that reflect application rates, and timing and number of applications. Input 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, chemical and fertilizer application, and harvest costs. Table 2 provides a summary of costs.

Soil carbon data

Carbon data for the experiment were obtained by soil tests of organic matter content pre-experiment in 1985, again in 1990, and post-experiment in 1995. Changes in soil organic matter by soil depth over this period were determined for each crop and tillage system. This experiment focused on the top 12 inches of the soil because this layer is where the producer has the greatest potential management influence. The mean percentage of soil organic matter for each system was converted to percent total soil C, and then into tons of C/ac. The average annual change was then calculated and reported in tons of C/ac/yr. Table 1 provides a summary of the soil sequestration data.

Equation [1] was used to convert the measured percent organic matter from the soil tests to grams of carbon per kilogram of soil.

$$\text{g C/kg soil} = (\text{OM\%} / 1.724) \times 10 \qquad [1]$$

Equation [2] converts g C/kg soil to MTC/ha. A measured average bulk density of 1.35 g/cm^3 was used in the calculation. Twelve inches are equal to .3048 meter. A multiplication factor of 10,000 was used because 10,000 m^2 are equal to 1.0 ha. A factor of 1000 was used to convert kilograms to metric tons because 1000 kg are equal to 1 metric ton.

$$\text{MTC/ha} = (\text{g C/kg soil} \times 1.35\ \text{BD} \times 0.3048 \times 10{,}000)/1000 \qquad [2]$$

Equation [3] was used to convert MTC/ha to tons C/ac. A factor of 0.4453 was used as .4453 ton of C/ac is equivalent to 1 metric ton of C/ha.

$$\text{Tons C/ac} = \text{MTC/ha} \times 0.4453 \qquad [3]$$

Where:

g = gram

kg = kilogram

OM% = percent organic matter

MTC = metric tons of carbon

ha = hectare

BD = bulk density in g/cm^3

ac = acre

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 used in field operations, such as tillage, fertilizer and herbicide application, planting, and harvest. In addition, there are C releases associated with energy used in the production of fertilizers and other chemicals. Carbon release values (pounds of CO_2 per Btu expended converted to pounds of C per Btu) from direct, embodied or indirect, and feedstock energy for the fertilizers and chemicals applied were estimated using data from Bowers and a procedure developed by Nelson and Schrock. Carbon release estimates from direct energy used in field operations were also included. The end result was an estimate of the amount of C released into the atmosphere from field operations and the production of fertilizers and other chemicals.

Equation [4] was used to estimate C equivalent emissions with respect to direct energy consumption for field operations. The same format was used in calculating emissions for all field operations, although the fuel consumption per acre varied depending on the field operation performed.

$$\text{C emissions} = \text{Fuel consumption} \times \text{Btu/gal} \times \%\ \text{C} \times \%\ \text{occurrence} \qquad [4]$$

Diesel fuel contains 140,000 Btu/gal and is 87 percent C.

Equation [5] was used to estimate C equivalent emissions with respect to embodied or indirect energies, which is the energy used in manufacturing and processing of chemicals. It was also used to estimate the emissions from feedstock energy, which is defined as the energy content of the raw materials used to make the input such as fertilizers and chemicals.

$$\begin{aligned}&\text{Embodied or Feedstock C Emissions} = \text{AI lb/ac} \times \text{Btu/lb of AI}\\ &\times \text{lb C/Btu of AI} \times \%\ \text{occurrence} \qquad [5]\end{aligned}$$

Where:

C emissions = pounds of C emissions per acre

Fuel consumption = gallons of diesel fuel per acre

Btu/gal = British thermal units per gallon of diesel

% C = percent carbon content of diesel fuel

% occurrence = percent of time the field operation occurs annually

AI = active ingredients in lb/ac applied

Btu/lb = British thermal units per lb of ingredient

C/Btu = CO_2 released to atmosphere per Btu content of input converted to C/Btu

The soil sequestration data and estimates of C emissions were used to calculate the net change in C resulting from a cropping system. The net change of C for each crop and tillage system was equal to sequestered soil C less atmospheric loading of C in tons/ac. Table 1 provides a summary of the net carbon sequestration rates.

Carbon credits

Equation [6] was used to determine the dollar value of C required to make a more C-efficient system (with lower net returns) economically equivalent to a system with higher returns (which was less C-efficient). The dollar value of C would be the required incentive (per ton of C) for a producer to switch production strategies (tillage or cropping) and not be negatively impacted by lower net returns.

$$\text{C Value to make } NR_j \text{ equivalent to } NR_i = (NR_i - NR_j)/(\text{C Rate}_j - \text{C Rate}_i) \qquad [6]$$

Where:

C Value = C credit value in $/ton/yr

$NR_i - NR_j$ = difference in net returns ($/ac) between systems i and j

$\text{C Rate}_j - \text{C Rate}_i$ = difference in C sequestration rates (tons/ac/yr) of systems j and i

Results and Analysis

Average annual net return to land and management per acre using 2001 cost-of-production estimates were positive for all cropping systems with the exception of NTWW (Table 2). Although NTWW was part of the field experiment, farm managers do not typically produce wheat in a continuous no-till cropping system in the region due to persistent weed problems. These results reflect the additional cost incurred to control such problems. Conventional tillage systems had higher net returns to land and management than the no-tillage systems for the continuous crops and the crop rotation. Herbicide costs were higher for no-tillage production strategies, but labor, fuel, and repair costs were less than under conventional systems (Table 2). 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 in the continuous no-till wheat and no-till wheat-sorghum rotation. Lower yields and/or accompanying higher overall costs for no-tillage resulted in lower net returns for these tillage systems. Because of these results, carbon credit payments may be necessary to induce farm managers in this area of the Great Plains to use cropping practices that may sequester more soil C.

Sorghum is relatively more profitable than wheat, whether using a conventional or a no-tillage system. Recent acreage data supports this result. Because of relatively higher returns 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. Therefore, the results pertaining to sorghum and the wheat-sorghum rotations are the most relevant.

Soil carbon changes

Total tons C/ac/yr sequestered in the top 12 inches of the soil is an important factor influencing the economic feasibility of C sequestration practices. As expected, the no-till systems had higher annual soil C gains than conventional tillage for each crop (Table 4). The highest C gain was in the NTWW system at 0.96 tons C/ac/yr. This was followed by NTSNTW with .66 tons C/ac/yr. CTSS had the lowest rate of gain at .39 tons C/ac/yr. Sorghum sequestered less carbon than wheat.

Atmospheric carbon release

The soil C gains referred to above did not account for C released to the atmosphere in the form of CO_2 from field operations, or from chemical and fertilizer applications and manufacture. These releases would affect the total net C sequestered in a cropping system. Therefore, C released into the atmosphere was considered. Emissions of CO_2 for inputs were converted to C equivalents in tons of C/ac/yr (Table 3). Total C emissions were generally higher for the no-till systems. In this study, C equivalent emissions from direct energy use were highest for the conventional tillage systems due to greater trips over the field, while embodied emissions were highest for the no-till systems due to the use of more manufactured inputs. Feedstock energy was highest for the no-till systems as well, also the result of greater use of manufactured inputs.

To determine net C gain or loss resulting from a cropping system, the total atmospheric C emissions were subtracted from C sequestered in the soil. The rate of sequestration for no-tillage relative to conventional systems decreased when carbon emissions were considered. The impact that emissions had on reducing net carbon sequestered varied considerably across systems (Table 4). Emission of C reduced net sequestration by as little as 7.5 percent in NTWW and as much as 45.2 percent in the CTSS system. NTWW had the highest net sequestration rate and CTSS the lowest.

Derived carbon credits

The initial set of derived C credits ($/ton/yr) were limited to the values that would make the net returns of no-tillage systems equivalent to conventional tillage systems for the same crop (Table 4). The per acre C incentive values that are reported in Table 4 were determined by the difference in net returns per acre between tillage systems of the same crop. A $58.69/ton/yr value for C would make the net returns of NTWW equal to CTWW (Table 4). As stated previously, NTWW is unlikely to be adopted in this region because of persistent weed problems that are expensive to control. Only $7.82/ton/yr would be needed to make NTSS equal to CTSS and $12.58/ton/yr to make NTSNTW equivalent to CTSWTW. This translates to an annual per acre incentive needed of $19.19, $2.11, and $3.56, respectively.

When the atmospheric release of C was not considered, the carbon credit to make NTWW equivalent to CTWW was reduced slightly to $54.99/ton/yr (Table 4). The credits for NTSS and NTSNTW were reduced to $7.79 and $12.25/ton/yr, respectively. Therefore, accounting for atmospheric C release in this study had a small impact on the carbon credit values.

Carbon credits for all technically feasible system comparisons are reported in Table 5. These results indicate that it would be costly to encourage a switch to NTWW from any other system, even though it sequestered the most C. The carbon payment to encourage a change from CTSS to NTSS is relatively reasonable. A credit is not required to switch from CTSNTW to NTSS because NTSS sequesters more C and is more profitable than CTSNTW. However, other systems sequestered more C than NTSS, so a carbon credit is not appropriate for encouraging a switch from other systems to NTSS. The carbon credits needed to encourage a switch to NTSNTW from CTSS, NTSS or CTSNTW are all less than $20/ton. NTSNTW is already more economical and sequestered more C than CTWW so an incentive would not be required.

Summary and Implications

The CTSS cropping system had the highest net return per acre of the systems examined and it would take an additional return of $2.11/ac for NTSS to have the same return as CTSS. This equates to an approximately 1 bushel/ac difference in yield. However, CTSS sequestered the least C. A payment of $7.82/ton/yr for C sequestered in NTSS or $13.53/ton/yr in NTSNTW would be required to make them equivalent to CTSS. The next most profitable cropping system was CTSNTW. This system had a return of $2.31/ac greater than NTSNTW. CTWW achieved net returns $21.83/ac higher than that of NTWW. No-tillage systems sequestered the most C, both before and after C emissions from field operations and production inputs were included in the analysis. A credit of $12.58/ton was required to make NTSNTW equivalent to CTSNTW and $7.82/ton was required to make NTSS equivalent to CTSS. Systems where continuous no-till sorghum or a rotation of sorghum and wheat is more typical of this area of the Great Plains than continuous no-till wheat, so the derived credit for these systems are more likely relevant than credits for no-till wheat. The results also indicated that it is reasonably economical to encourage the switch to NTSNTW from CTSS and NTSS to sequester more carbon.

The impact of including C emissions had a significant impact on net sequestration rates of some systems, but little impact on the derived carbon credit. The average change in carbon credit values for all feasible cropping system comparisons was $1.46/ton. Additional research is necessary with other carbon sequestration practices and data from other regions to test the consistency of this result.

Carbon 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. Producers may benefit from obtaining monetary rewards for their C and from payments for other environmental quality improvements associated with C sequestration.

An important limitation to this study is that the 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 in no-tillage than are used on a typical farm field, where time between operations is more limited. Further, no-tillage 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 reduce fixed costs even more with a no-tillage system to increase returns from no-till over time, and, therefore, be able to accept a lower carbon credit.

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Table 1. Yields, prices, net returns, number of field operations, carbon sequestration and carbon emissions by cropping system.

	Systems[1]					
	CTWW	NTWW	CTSS	NTSS	CTSNTW	NTSNTW
Average yield[2]						
Wheat	37.5	32.6	--	--	34.2	34.0
Sorghum	--	--	77.8	73.8	84.0	84.6
Average price[3]						
Wheat	3.21	3.21	--	--	3.21	3.21
Sorghum	--	--	2.01	2.01	2.01	2.01
Field operations/ac/yr	8.4	6.5	8.6	5.5	7.7	5.5
Net return[4]	8.19	(11.80)	25.70	23.59	21.96	18.46
Soil carbon gain[5]	.5978	.9613	.1222	.3932	.3720	.6576
Carbon emissions[6]	.0495	.0724	.0553	.0565	.0478	.0553
Emissions as a percent of soil carbon	8.3	7.5	45.2	14.4	12.9	8.4
Net carbon gain	.5483	.8889	.0669	.3367	.3242	.6023

[1] CTWW - Conventional-tillage continuous wheat
NTWW - No-till continuous wheat
CTSS - Conventional-tillage continuous sorghum
NTSS - No-till continuous sorghum
CTSNTW - Conventional-tillage sorghum no-till wheat
NTSNTW - No-till sorghum, no-till wheat

[2] Bu/ac

[3] $/bu

[4] Return to land and management in $/ac

[5] Tons/ac/yr

[6] Tons/ac/yr Refer to Table 3 for details

Table 2. Returns and selected costs ($/ac) by cropping system.

	Systems[1]					
Cost & Returns[2]	CTWW	NTWW	CTSS	NTSS	CTSNTW	NTSNTW
Variable costs[3]	$82.18	$96.46	$104.31	$103.81	$91.72	$101.16
Fixed costs[4]	31.79	23.58	29.12	25.08	29.60	22.80
Total costs[3]	113.97	120.04	133.43	128.88	121.32	123.96
Gross return[5]	120.25	104.49	156.42	148.42	139.32	139.64
Net return						
Mean[6]	8.19	(11.80)	25.70	23.59	21.96	18.46
Standard Deviation	49.41	38.91	40.90	40.68	39.10	36.55
Maximum	82.32	48.47	82.57	73.27	82.28	69.29
Minimum	(56.07)	(71.62)	(31.53)	(35.29)	(48.69)	(48.68)
Selected costs						
Labor	6.93	1.49	6.05	1.96	4.99	1.72
Fuel/Oil	5.83	0.47	4.15	0.58	3.36	0.52
Repairs	10.46	3.32	9.16	4.19	8.06	3.75
Subtotal	23.23	5.27	19.35	6.72	16.41	6.00
Herbicide	2.42	28.08	18.42	31.84	13.74	30.98
Insecticide/Fungicide	0.97	0.97	4.85	4.85	2.91	2.91
Fertilizer	20.14	18.61	21.91	20.27	20.26	19.44
Custom Hire[3]	22.76	30.20	30.15	30.52	27.32	30.31
Subtotal	46.29	77.86	75.33	87.48	64.23	83.64
Depreciation	13.62	9.26	12.43	9.88	12.49	8.94
Interest	14.40	10.71	12.98	11.56	13.39	10.27
Subtotal	28.02	19.98	25.41	21.44	25.88	19.20

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

[2] Costs and returns to the operator

[3] Based on average yield

[4] Excludes charges on land values

[5] Equal to gross crop income using average yield excluding government payments

[6] Average of annual net returns to land and management

Table 3. Carbon equivalent emissions from field operations (tons/ac/yr).

	Systems[1]					
Energy Type	CTWW	NTWW	CTSS	NTSS	CTSNTW	NTSNTW
Direct energy	0.021	0.009	0.018	0.008	0.015	0.009
Embodied/Indirect energy	0.012	0.057	0.020	0.041	0.020	0.040
Feedstock energy	0.016	0.007	0.019	0.007	0.012	0.007
Total emissions	0.049	0.072	0.055	0.057	0.048	0.055

From: Nelson, R.G., and M.D. Schrock, 2002. Direct and Embodied Energy and CO_2 Emission Analysis of Selected Kansas Agricultural Cropping Rotations. Kansas State University. Unpublished data.

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

Table 4. Carbon value analysis to change tillage preference.

	Individual Crop Systems[1]					
	CTWW	NTWW	CTSS	NTSS	CTSNTW	NTSNTW
Net return[2]	8.19	(11.80)	25.70	23.59	21.96	18.46
Soil Sequestered[3]						
Soil carbon sequestered[4]	.5978	.9613	.1222	.3932	.3720	.6576
Difference in C for no-till[4]	-	.3635	-	.2710	-	.2856
Carbon credit required[5]	-	54.99	-	7.79	-	12.25
Carbon incentive required[6]	-	19.99	-	2.11	-	3.56
Net Carbon Sequestration[7]						
Net carbon gain per year[4]	.5483	.8889	.0669	.3367	.3242	.6023
Difference in C for no-till[4]	-	.3406	-	.2698	-	.2781
Carbon credit required[5]	-	58.69	-	7.82	-	12.58
Carbon incentive required[6]	-	19.99	-	2.11	-	3.50

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

[2] Average of annual net returns to land and management ($/ac)

[3] Carbon sequestered in the soil excluding C emissions adjustment

[4] Tons/ac/yr

[5] Value required to make no-till equal to conventional tillage ($/ton)

[6] Value required to make no-till equal to conventional tillage ($/ac)

[7] Carbon sequestered including C emissions adjustment

Table 5. Carbon credit required for net return equivalency between systems ($/ton/yr).[1]

	Net	Net	System[2]					
System	Return	Carbon	CTWW	NTWW	CTSS	NTSS	CTSNTW	NTSNTW
CTWW	8.19	0.5483	-	NA	36.37	72.78	61.38	NA
NTWW	(11.80)	0.8889	58.69	-	45.62	64.09	59.76	105.51
CTSS	25.70	0.0669	NA	NA	-	NA	NA	NA
NTSS	23.59	0.3367	NA	NA	7.82	-	(127.78)	NA
CTSNTW	21.96	0.3240	NA	NA	14.55	NA	-	NA
NTSNTW	18.46	0.6021	(190.95)	NA	13.53	19.33	12.58	-

[1] Dollar amounts are the amount required for the system in a row to be equivalent to a system in a column. Negatives are the penalty the system in the row would need to equal the system in the column because the system in the row has a higher return and sequestration rate. NA appears when the system in the row has a lower sequestration rate than the system in the column, therefore, a credit is not feasible.

[2] Refer to Table 1 for an explanation of system codes