Economic Feasibility of Carbon Sequestration with Alternative Tillage Systems

By Dustin L. Pendell, Jeffery R. Williams, Daniel W. Sweeney, Richard G. Nelson, and Charles W. Rice





Dustin L. Pendell is pursuing a Ph.D. in agricultural economics at Kansas State University. He received his B.S. degree in Agribusiness from Illinois State University and M.S. in Agribusiness Economics from Southern Illinois University.

Jeffery R. Williams is Professor of agricultural economics at Kansas State University. He received his B.S. degree in Environmental Resource Management from The Pennsylvania State University and, M.S. and Ph.D. degrees from Michigan State University. He teaches courses in natural resource and environmental economics, agribusiness risk management, and advanced farm economics. His research interests include natural resource and agricultural policy impacts on farm managmeent strategies.

Daniel W. Sweeney is Professor and soil and water management agronomist at the Kansas State University Southeast Agricultural Research Center in Parsons, KS. He received his B.S. degree in Chemistry from Kentucky Wesleyan College, his M.S. degree in Agronomy from Purdue University, and Ph.D. degree in soil science from University of Florida. Dr. Sweeney is a member and Fellow of the American Society of Agronomy and a member of the Soil Science Society of America and the Crop Science Society of America.

Richard G. Nelson is director of Engineering Extension Programs at Kansas State University. He received his B.S., M.S., and Ph.D. degrees from Oklahoma State University. He has considerable experience in detailed bioenergy resource, assessments and technical and economic feasibilities with respect to alternative energy development including sustainable utilization of agricultural crop residues and herbaceous energy crops, carbon sequestration, and water quality improvements associated with bioenergy crop production.

Charles Rice is Professor in the Department of Agronomy at Kansas State University. He received his B.S. from Northern Illinois University and M.S. and Ph.D. from the University of Kentucky. His research interests include carbon and nitrogen cycling and microbial ecology of grassland and agricultural ecosystems. He is a Fellow and member of the Soil Science Society of America, American Society of Agronomy, and the American Association for the Advancement of Science.

Abstract

Sequestration of carbon has gained increased attention in recent years because of environmental and economic motives. This study examined the economic feasibility of using reduced-tillage (RT) and no-tillage (NT) rather than conventional-tillage (CT) to sequester soil carbon with the use of either anhydrous ammonia (NH_3), urea-ammonium nitrate solution (UAN), or urea for a grain sorghum-soybean rotation. The results show that RT with NH_3 had the highest net return but not the highest level of carbon sequestration. Carbon credits ranging from $0.00 to $77.23/ton of C/year were needed to entice producers to adopt either RT Urea or NT NH_3, the systems that sequestered the highest and second highest amount of carbon per year, depending upon the farming system originally being used.

Introduction

Sequestration of carbon (C) in soil has gained increased attention in recent years because of environmental and economic motives. Carbon sequestration is the process of transforming carbon dioxide (CO_2) in the atmosphere to C stored in agricultural soils or plant material which reduces the potential for global warming. Farm managers can increase the amount of C in the soil by producing more biomass within a given time period, reducing or eliminating tillage, or by maintaining or increasing soil organic matter, or adding an external source of C to the soil (Havlin et al., 1990). The economic feasibility of adopting practices to sequester carbon in agricultural soils is likely to increase due to the potential for farm managers to sell carbon credits in a carbon market. A carbon credit is one ton of C permanently or temporarily sequestered or reduced in atmospheric releases by altering farming practices with its value ($/ton C) determined in a carbon credit market. Farm managers who reduce CO_2 emissions below current levels or sequester additional soil C will receive a carbon credit that can potentially be sold in a carbon market (Williams, Peterson, and Mooney, 2005).

Several studies have examined the issues with regard to sequestering carbon in agriculture. Most of these studies examined the bio-physical effects that cropping rotations and tillage operations have on sequestering carbon (Deen and Kataki, 2003; Eve et al., 2002). Other research areas include the effects of forest management practices on carbon sequestration (Cacho, Hean, and Wise, 2003; Scott, et al., 2004) and converting cropland to forest uses (Parks and Hardie, 1995; Stavins, 1999). Most of the previous economic analyses estimated the marginal costs of sequestering C to derive a carbon supply curve at the regional level (Antle et al., 2001; Feng et al., 2004). The marginal costs reported range from a few dollars to over $300/ton of C (Williams, Peterson, and Mooney, 2005).

Although there have been some recent studies that have examined the economic feasibility of reducing tillage (Ribera, Hons, and Richardson, 2004; Williams, Roth, and Claassen, 2004), there has been only one study that examined both the economic feasibility of reducing tillage and sequestrating carbon at the crop enterprise level (Williams, Roth, and Claassen, 2004). Williams, Roth, and Claassen (2004) reported payments to induce producers to use no-tillage rather than conventional tillage in wheat and grain sorghum production to sequester carbon ranging from $0 to $59/ton C/yr.

Research is needed to improve the understanding of the economic feasibility of adopting alternative tillage and fertilizer systems to enhance C sequestration in soil at the crop enterprise level. Eve, et al. (2002) suggest that basing economic analysis of carbon sequestration on experimental work is also important. It is expected sequestration costs will vary widely due to location, soil type, estimated C uptake, land rental rate, management techniques, and resulting crop yields. Because there are a number of factors that can affect soil carbon sequestration costs, examining the economic feasibility of alternative management techniques by using experimental data for specific locations are useful.

This study examines the economic feasibility of using reduced-tillage and no-tillage rather than conventional-tillage to sequester soil carbon with the use of either anhydrous ammonia (NH_3), urea-ammonium nitrate solution (UAN), or urea for a grain sorghum-soybean rotation. The objectives include determining the production system that has the highest net returns, and the dollar value of a carbon credit incentive needed for farm managers to use no-tillage or reduced-tillage, as opposed to conventional-tillage to sequester additional soil C. The values of C credits needed to motivate adoption of practices that sequester additional C in the soil were derived, while accounting for C released to the atmosphere from production inputs used in each tillage and fertilizer production system.

Procedures and Data

Annual yields, input types and rates, and field operations were obtained from twenty years (1983-2002) of data from a research center in Parsons, Kansas. Annual average C sequestration rates were calculated from the experiment soil sample data measured in 1983 and 2002. Carbon release values (tons of C/acre) from direct and embodied energies were estimated for each system. Estimates of C emissions were subtracted from soil C changes to calculate the net change in C resulting from each production system. Production costs were based upon actual field operation and input rates. Field operation costs were based on costs derived from actual farm data in the region the experiment field is located.

Study Region

The Kansas State University Southeast Agricultural Research Center located near Parsons in southeastern Kansas, where the yield and soils data were obtained, had an annual average precipitation of 45.45 inches over the twenty years of the study (1983-2002), with a standard deviation of 5.74 inches. Annual average precipitation during the growing season from May through October during 1983-2002 was 26.59 inches with a standard deviation of 5.66 inches. The topsoil at the research center is a Parsons silt loam (fine, mixed, thermic Mollic Albaqualf) of approximately 12 inches, overlying a "claypan" B horizon. Moisture is often the limiting factor for grain sorghum and soybean production in this area because of poor rainfall distribution and the high clay-content subsoil.

Production Systems

The study evaluated a grain sorghum-soybean rotation under conventional-tillage, reduced-tillage, and no-tillage with applications of 125 lbs. of N as NH_3, UAN, or urea. The nine production systems studied include:

1. CT NH_3 - - conventional-tillage with NH_3
2. CT UAN - conventional-tillage with UAN
3. CT Urea - conventional-tillage with urea
4. RT NH_3 - reduced-tillage with NH_3
5. RT UAN - reduced-tillage with UAN
6. RT Urea - reduced-tillage with urea
7. NT NH_3 - no-tillage with NH_3
8. NT UAN - no-tillage with UAN
9. NT Urea - no-tillage with urea

The CT grain sorghum-soybean systems used a variety of field operations, including chiseling, disking, and field cultivating. Chiseling and disking occurred in late spring. The field was disked again in late May or early June if there were soil clods that needed to be broken apart. During June, field cultivation was used to control for weeds and to prepare the seedbed. Field cultivation was performed more often for grain sorghum while a disk was used more often for soybean. The RT systems field operations were the same as those in the CT systems, with the exception that the chiseling operation was not used. No-tillage did not include any tillage operations for either crop. Nitrogen fertilizer from NH_3, UAN, or urea was applied in all three tillage systems shortly before planting to grain sorghum. A starter fertilizer consisting of 54 lbs/acre of P_2O_5 and 71 lbs/acre of K_2O was applied to grain sorghum while 6-23-37 of N, P_2O_5, and K_2O at a rate of 120 lbs/acre was applied to soybean during planting in June. A herbicide was applied to both crops and all three tillage systems shortly after planting. In addition to this herbicide, both crops in the NT system also received an application of an additional herbicide in early June. The type of herbicides varied by crop.

Yields, Prices, Costs, and Net Returns

Yield data obtained from the experiment field for 1983-2002 for each crop was from every other year. Grain sorghum was planted and harvested in odd years while soybean production occurred in even years. Yields and crop prices were used to calculate gross returns for each year that grain sorghum was produced and each year that soybean was produced. Prices were not allowed to fall below the 2005 commodity marketing loan rate of \$1.95/bu. for grain sorghum and \$5.00/bu. for soybean. The average price for grain sorghum was \$2.21/bu. and soybeans were \$5.88/bu. Net returns to land, management, and risk were calculated by subtracting total costs excluding a charge for land and management from gross income (Table 1). Costs for each field operation were obtained from Beaton et al. (2005). Input costs were based on actual experiment application rates. Prices for seed, fertilizers, and herbicides were obtained from input dealers and Kansas State University. Net returns were calculated in two ways. Fertilizer prices from spring of 2005 were used for the detailed analysis reported in the paper. For comparative purposes, a historical series of fertilizer prices that correspond to the experiment time period were used to calculate another set of net returns. From 1983 through 2003 N from NH_3 ranged from a low of \$0.11 to \$0.23/lb. and averaged \$0.15/lb. Nitrogen from UAN ranged from \$0.20 to \$0.36/lb. with an average of \$0.24/lb while N from urea ranged from \$0.17 to \$0.30/lb. with an average of \$0.22/lb. over the historical period. Because of increasing natural gas prices since 2002, nitrogen fertilizers have increased significantly in price. The spring 2005 N prices for NH_3, UAN, and urea used in the analysis were \$0.24/lb., \$0.37/lb., and \$0.35/lb., respectively. Table 1 provides a summary of yields, net returns, and total costs for each system.

Soil Carbon Data

Soil carbon data for this experiment were obtained from soil tests of organic matter content after grain sorghum was planted in 1983 and again after grain sorghum was harvested in November in 2002. Changes in C by soil depth over this period were determined for each tillage system. This experiment focused on the top 12 inches of the soil, because this layer is where the producer has the greatest potential to influence soil C. The annual average soil C sequestered is reported in Table 1.

Carbon Release from Energy Use in Crop Production

Carbon in the form of CO_2 is also released into the atmosphere from direct energy consumption, primarily from diesel fuel combustion in field operations. In addition, C releases associated with energy expenditures in the production of fertilizers, chemicals, and equipment (embodied energy) as well as C contained in the hydrocarbon feedstocks for each fertilizer and chemical input (feedstock energy) occur. Energy consumption rates from West and Marland (2002) were used to determine corresponding C emissions for direct, embodied, and feedstock energies relevant to field management operations and chemical inputs for each production system using methods discussed in Williams, Roth, and Claassen (2004). These include emissions from diesel fuel for tillage, planting, and harvesting as well as energy in the form of natural gas, fuel oil, and electricity required to obtain, manufacture, and distribute fertilizers, herbicides, and pesticides.

The soil sequestration data and estimates of C emissions were used to calculate the net change in C resulting from each cropping system. The net change of C for each system is equal to sequestered soil C less atmospheric loading of C in tons/acre. Table 1 and Figure 1 provide summaries of the net C sequestration rates.

Carbon Credits

Equation (1) was used to determine the dollar value of a one ton carbon credit or the breakeven dollars per ton of C required to make a system with a greater sequestration rate (C $Rate_j$), but smaller net returns (NR_j) economically equivalent to a system with a lesser sequestration rate (C $Rate_i$), but with larger net returns (NR_i). The dollar value of a carbon credit is the incentive a manager would need to be indifferent between any two production systems.

$$\text{C Value to make NRj equivalent to NRi} = (NR_i - NR_j)/(C\ Rate_j - C\ Rate_i) \qquad (1)$$

where:

C Value	=	C credit value in $/ton/year,
$NR_i - NR_j$	=	the difference in net returns ($/acre) between systems i and j, and
$C\ Rate_j - C\ Rate_i$	=	difference in C sequestration rates (ton/acre/year) for systems j and i.

Results

Tillage Impact on Yield

Soybean yields for the CT, RT, and NT systems were similar, and no statistically significant differences in the mean yield between production systems were found. Yields for grain sorghum in the NT systems were considerably less compared to CT and RT systems and they were statistically different (Table 1). Conventional-tillage systems for each respective fertilizer had the highest mean yield and RT systems had the second highest mean yield with one exception: RT Urea had a higher yield when compared to CT Urea.

Tillage Impact on Costs and Net Return

Because CT and RT systems had the highest and second highest mean yields, respectively, gross returns for these systems were the highest and second highest, respectively. When total costs were compared, CT systems had the highest costs while RT systems had the lowest costs for both current and historical N fertilizer prices. Reduced-tillage systems had lower costs when compared to the CT systems because of the reduction of tillage. When RT systems were compared to the NT systems, the lower chemical costs resulted in lower overall costs. Although the field operations cost savings from the NT systems, excluding harvest, when compared to the RT systems was $11.54/ac.; the chemical costs were $15.31/ac. larger which offset the tillage savings (Table 2). Net returns were higher for the RT systems than for the CT and NT systems for both current and historical N fertilizer prices. Although CT systems had the highest mean yields for grain sorghum, their costs were also the highest.

Impact of Fertilizer on Yields

The use of NH_3 resulted in statistically significant higher average grain sorghum yields across all three tillage systems.

UAN had the lowest grain sorghum yield for the RT and NT systems while urea in the CT systems had the lowest average yield. There was very little difference in soybean yields for any residual fertilizer type. The differences in average yield between all three N fertilization systems, NH_3, UAN, and urea, for soybean were not statistically significant.

Fertilizer Impact on Costs and Net Returns

UAN had the highest costs of the three fertilization systems ($25.59/ac. for spring 2005 UAN prices and $18.17/ac. for historical UAN prices) while NH_3 had the lowest costs ($18.85/ac. for spring 2005 NH_3 prices and $13.62/ac. for historical NH_3 prices). When comparing the three N fertilizer systems, NH_3 had the highest net return for all three tillage systems (Table 1). This was also true when historical fertilizer prices were used. The total cost of purchasing and applying NH_3 was lower and the average yield for grain sorghum was higher for NH_3 when compared to UAN and urea. These factors contributed to NH_3 having the highest returns for each tillage system (Figure 2). UAN had the lowest net return for the CT, RT, and NT systems.

Overall Results

The RT system that used NH_3 had the highest net return under current and historical fertilizer prices. The RT NH_3 system also had the highest minimum net return or smallest loss using either current or historical fertilizer prices when net returns for each year were compared (Table 1). This system had the lowest costs and next to highest grain sorghum yield of any of the systems. The systems with the second and third highest net returns were the CT NH_3 and the RT urea systems, respectively. These results have implications for the economic potential to enhance carbon sequestration with reduced and no-tillage and are discussed further in the following sections.

Soil Carbon Sequestration

A single type of tillage system did not consistently have the highest annual rate of C sequestration across fertilizer types (Figure 1). Two of the three highest rates were from RT systems while the two lowest rates were from CT systems. No-tillage systems did not consistently have the highest sequestration rates as might be expected (Table 1 and Figure 1). The NT NH_3 system did have the second highest rate. There is a potential for greater immobilization of surface applied fertilizers in NT systems which may have reduced the effectiveness of the N fertilizers. Also, volatilization from urea in NT systems can increase N loss. Grain sorghum yields were lower with urea containing fertilizers in NT than the other tillage systems which could have reduced the plant biomass C contribution to the soil and, therefore, C sequestration. Alternative no-till N management in these high clay content soils needs to be explored to improve the soil C sequestration and crop yields relative to RT systems. The relatively low rate of C sequestration in the RT NH_3 system was unexpected given that the yields were equal or higher than most other systems. This result may be an anomaly that requires additional experimental study. The RT and NT systems that used UAN or urea had greater annual soil C gains than the CT systems that used these fertilizers (Table 1 and Figure 1). These results were expected and occurred because more soil disturbance with tillage in the CT systems results in greater oxidization of organic matter and loss of C to the atmosphere as CO_2.

The rates of C sequestration reported at this site are slightly lower than the global average for no-tillage soils of 0.25 tons C/acre/year as reported by West and Marland (2002). Other studies in eastern and central Kansas have reported higher rates of 0.44 tons C/acre/year for no-till corn (Pendell et al. in press) and 0.60 tons C/acre/year for a no-till wheat-sorghum rotation (Williams et al., 2004). These soils at the experiment field also cover a large region stretching from Oklahoma, through eastern Kansas, and into western Missouri. The characteristics of these soils likely mitigate the economic potential of C sequestration by no-till systems. A single fertilizer type did not consistently have the highest rates of C sequestration across tillage systems. NH_3 use resulted in a higher soil C sequestration rate for the CT and NT systems compared to UAN or urea, but this was not true for the RT systems (Table 1 and Figure 1).

Carbon Emissions and Net Carbon Sequestration

Emissions from direct energy use, diesel fuel were the greatest for the CT systems because there were more tillage operations in this system than the others (Table 1). Reduced-tillage systems had higher emissions from direct energy than NT systems. Embodied emissions from inputs were highest in the NT systems. This was a result of more chemicals being applied in the NT systems compared to the RT and CT systems. Embodied emissions for CT and RT systems were identical because the amount of chemicals and fertilizers applied were the same for both systems. Because there was no impact on embodied emissions by type of N fertilizer, the difference between the CT and RT systems was due to the fewer number of field operations that occurred per year in the RT systems. Total C emissions were the greatest for CT systems and lowest for the NT systems (Table 1). Again, this was because there were more tillage operations in the CT systems and the smaller embodied emissions from the reduced use of herbicides in CT and RT did not outweigh the impact of the larger direct emissions from diesel fuel.

Net carbon sequestration was calculated by subtracting C emissions from the amount of C sequestrated in the soil on an annual basis. There was no change in rank order of sequestration by system (Figure 1).

Derived Carbon Credit Values

The RT Urea and NT NH_3 systems sequestered the most soil carbon and net carbon (Figure 1), but they were only the third and fourth most profitable systems, respectively (Figure 2). Therefore, carbon credits would be needed as an incentive to encourage use of these systems, rather than RT NH_3 or CT NH_3, which were the two most profitable systems. Derived net C credit values ($/ton/yr.) using equation (1) for all technically feasible comparisons are reported in Table 3, and indicate a substantial range in C credit values. To interpret the values in the table the reader should assume the system at the top of any column is the production system or strategy currently in use and the system in any row is the system that a manager may change to. The most relevant results are found at the intersection of the column labeled RT NH_3; the system with the highest net return, and the rows labeled RT Urea and NT NH_3; the systems with the two highest net C sequestration rates. The C credit values in $/ton of C are the breakeven values to be indifferent between RT NH_3 and either the RT Urea or NT NH_3 systems. The C credit value needed from additional carbon sequestered from the RT Urea system for the manager to be indifferent between RT Urea and RT NH_3 is $54.39/ton C (solid line blocked value). This value is the result of the difference in net returns between the two systems ($17.05 - $11.18) divided by the difference in net carbon sequestration rates of the same two systems (0.12233 - 0.01425). The minimum C credit value to use NT NH_3 rather than RT NH_3 is $77.23/ton of C (dashed line blocked value). If the manager was originally using CT NH_3, the second most profitable system, the C credit values are $21.68 and $77.24/ton of C, respectively.

Some producers have moved away from NH_3 systems due to safety and security reasons. The results show that producers using RT, the most profitable system that does not use NH_3, increases the net sequestration rate.

Some locations in Table 3 have an NC or an NA rather than a dollar value. A NC in Table 3 indicates that a C credit is not needed for a system in the row to be preferred to the system in the column. This is because the system in the row has a higher C rate and a higher net return than the system in the column, (i.e., RT UAN (row) compared to CT UAN (column)). The dollar value of the carbon credit is effectively $0.00. A NA indicates a credit is not feasible because the system in the row sequestered less C than the system in the column, (i.e., CT Urea (row) vs. RT UAN (column)).

Carbon credits were also derived without accounting for C in CO_2 emissions from production of inputs and energy used in the systems. When emissions were not subtracted from the soil sequestration rates, the C credit values required to motivate a switch to RT Urea or NT NH_3 from RT NH_3 or CT NH_3 systems were slightly larger than the C credit values when emissions were subtracted, but the general results did not change.

Summary

The purpose of this study was to examine the net returns of three tillage systems with three N fertilizers and to determine the economic feasibility of systems that use less tillage to enhance carbon sequestration. Carbon credit values, the dollar amount per ton of net carbon sequestered needed to encourage adoption of systems that enhanced carbon sequestration, was determined. The RT NH_3 and CT NH_3 systems had the highest and second highest net returns, respectively. The RT Urea and NT NH_3 systems had the first and second largest net sequestration rates, respectively. Carbon credits ($/ton of C) were needed to entice producers to use these systems for sequestering additional C when compared to RT NH_3 and CT NH_3. The value needed for the C credits ranged from $0.00/ton to $54.39/ton.

There are currently two primary carbon credit markets. The European Union has a market where trades have ranged from \$10 to \$35/metric ton of CO_2, or \$33 to \$117/ton of C (The Economist, 2005). However, U.S. credit suppliers including farm managers cannot participate in this market because the U.S. has not ratified the International Treaty on Climate Change commonly know as the Kyoto Protocol and carbon credits from soil sequestration are currently not being accepted. Although farm managers cannot participate in this market, many state and regional initiatives have been created to help reduce greenhouse gases (Williams, Peterson, and Mooney, 2005). One such initiative is the pilot carbon credit trading market on the Chicago Climate Exchange (CCX). Farmers in parts of the Midwest that use no-tillage crop production practices are receiving credits to sell on the exchange that are equal to 0.5 tons of C/acre/year. During 2005, carbon credit prices on the CCX ranged from \$3.70 to \$6.79/ton of C. These values would not provide enough incentive for a manager to use RT Urea to sequester additional carbon when compared to the most profitable systems; RT NH_3 and CT NH_3.

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Table 1. Yield, Costs, Returns, and Carbon Sequestration Characteristics for each Production System

	System[a]								
	CT NH_3	CT UAN	CT Urea	RT NH_3	RT UAN	RT Urea	NT NH_3	NT UAN	NT Urea
Mean Yield[b]									
Sorghum	81.4	74.2	72.7	75.4	68.3	74.7	67.8	55.6	57.0
Soybean	22.0	21.7	22.8	22.3	21.8	22.3	23.6	21.1	22.6
Total Costs[c]	$145.33	$151.66	$149.98	$135.41	$141.73	$140.76	$138.68	$144.53	$143.03
Gross Return[c]	$157.90	$149.99	$151.74	$152.46	$143.20	$151.93	$148.41	$128.37	$133.41
Net Return[c]	$12.57	-$1.67	$1.76	$17.05	$1.48	$11.18	$9.73	-$16.15	-$9.61
Std. Dev.[c]	$69.83	$73.16	$76.76	$71.94	$71.31	$75.19	$73.28	$75.79	$71.59
Maximum[c]	$153.00	$134.37	$152.74	$168.16	$134.64	$152.03	$157.68	$129.06	$120.78
Minimum[c]	-$65.67	-$97.95	-$95.15	-$61.26	-$90.95	-$83.86	-$73.02	-$102.58	-$91.73
Soil Carbon[d]	0.11006	-0.01930	0.00499	0.06278	0.15518	0.17021	0.15737	0.05764	0.12745
Direct[e]	0.01684	0.01684	0.01618	0.01313	0.01313	0.01248	0.00879	0.00879	0.00814
Embodied[e]	0.03540	0.03540	0.03540	0.03540	0.03540	0.03540	0.03951	0.03951	0.03951
Total Emissions[e]	0.05223	0.05223	0.05158	0.04853	0.04853	0.04787	0.04830	0.04830	0.04765
Net Carbon[f]	0.05782	-0.07154	-0.04659	0.01425	0.10665	0.12233	0.10907	0.00934	0.07980

[a] Refer to the text for a description of production systems.
[b] bu./acre.
[c] $/acre with 2005 fertilizer prices.
[d] Carbon sequestered in the soil (tons/acre/year).
[e] C emissions from production inputs (tons/acre/year).
[f] Carbon sequestered after subtracting C emissions (tons/acre/year).

Table 2. Selected Costs ($/acre)

	System[a]								
	CT NH_3	CT UAN	CT Urea	RT NH_3	RT UAN	RT Urea	NT NH_3	NT UAN	NT Urea
Tillage	$30.12	$30.12	$30.12	$18.49	$18.49	$18.49	$0.00	$0.00	$0.00
Planting	$12.61	$12.61	$12.61	$15.21	$15.21	$15.21	$15.21	$15.21	$15.21
Herbicide	$7.72	$7.72	$7.72	$7.72	$7.72	$7.72	$14.67	$14.67	$14.67
Fertilizer	$3.85	$2.46	$2.38	$3.85	$2.46	$2.38	$3.85	$2.46	$2.38
Total	$54.30	$52.91	$52.83	$45.27	$43.88	$43.80	$33.73	$32.34	$32.26
Harvest	$27.76	$27.11	$27.01	$27.25	$26.59	$27.18	$26.63	$25.51	$25.59
Total	$82.06	$80.02	$79.84	$72.52	$70.47	$70.98	$60.36	$57.85	$57.85
Inputs									
N Fertilizer	$15.00	$23.13	$21.69	$15.00	$23.13	$21.69	$15.00	$23.13	$21.69
Chemical	$17.54	$17.54	$17.54	$17.54	$17.54	$17.54	$32.85	$32.85	$32.85
Seed	$9.35	$9.35	$9.35	$9.35	$9.35	$9.35	$9.35	$9.35	$9.35
Other Fertilizer	$15.80	$15.80	$15.80	$15.80	$15.80	$15.80	$15.80	$15.80	$15.80
Total	$57.69	$65.82	$64.38	$57.69	$65.82	$64.38	$73.00	$81.13	$79.69
Interest	$5.59	$5.83	$5.77	$5.21	$5.45	$5.41	$5.33	$5.56	$5.50
TOTAL	$145.34	$151.67	$149.99	$135.42	$141.74	$140.77	$138.69	$144.54	$143.04

[a] Refer to the text for a description of the production systems

Table 3. Carbon Credits Required for Net Return Equivalency between Systems ($/ton/year)[a]

	System[b]								
	CT NH_3	CT UAN	CT Urea	RT NH_3	RT UAN	RT Urea	NT NH_3	NT UAN	NT Urea
Net Return[c]	$12.57	-$1.67	$1.76	$17.05	$1.48	$11.18	$9.73	-$16.15	-$9.61
Net Carbon[d]	0.05782	-0.07154	-0.04659	0.01425	0.10665	0.12233	0.10907	0.00934	0.07980
System									
CT NH_3 $12.57 0.05782	-	NC	NC	$102.81	NA	NA	NA	NC	NA
CT UAN -$1.67 -0.07154	NA	-	NA	NA	NA	NA	NA	NA	NA
CT Urea $1.76 -0.04659	NA	NC	-	NA	NA	NA	NA	NA	NA
RT NH_3 $17.05 0.01425	NA	NC	NC	-	NA	NA	NA	NC	NA
RT UAN $1.48 0.10665	$227.28	NC	$1.84	$168.59	-	NA	NA	NC	NC
RT Urea $11.18 0.12233	$21.68	NC	NC	$54.39	NC	-	$703.40	NC	NC
NT NH_3 $9.73 0.109077	$55.48	NC	NC	$77.23	NC	NA	-	NC	NC
NT UAN -$16.15 0.00934	NA	$179.05	$320.32	NA	NA	NA	NA	-	NA
NT Urea 0.07980	$1,009.47	$52.45	$89.96	$406.81	NA	NA	NA	NC	-

[a] Dollar amounts required for the system in a row to be equivalent to a system in a column. NC appears when a credit is not needed for a system in the row to be equal to the system in the column because the system in the row has a higher return and sequestration rate than the one in the column. The system in the row would have to be penalized to be equivalent to the system in the column. NA appears when the system in the row has a lower sequestration rate than the system in the column; therefore, a credit to make the system in the row equal to the system in the column is not feasible. The first value is for net carbon and the second value is for credits without adjusting soil sequestration for emissions.
b Refer to the text for a description of the production systems.
c $/acre.
d Tons/acre/year.

Figure 1. Soil Carbon and Net Carbon Sequestration Rates by System (tons/acre/year)

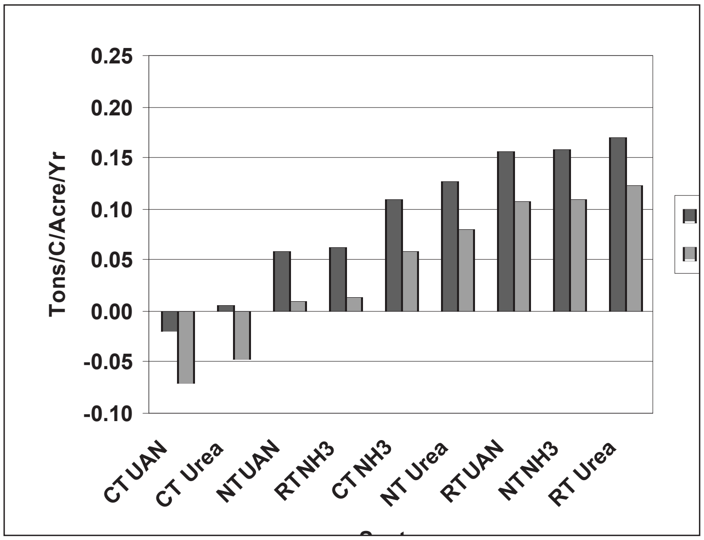

Figure 2. Net Returns by System ($/acre)