

**A Risk Analysis of Carbon Sequestration in Claypan Soil
With Conservation Tillage Systems and Nitrogen Fertilizers
For Grain Sorghum and Soybean**

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Abstract

The economic feasibility of using conservation-tillage rather than conventional-tillage to sequester carbon with the use of alternative nitrogen fertilizer sources for a grain sorghum-soybean rotation is evaluated. Results indicate which system provides the highest net returns, which system is preferred by risk averse managers, and the price of carbon credits required for management system adoption under alternative risk aversion preferences.

Keywords: carbon sequestration, carbon credits, nitrogen, risk, tillage

JEL: Q12

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 (CO₂) 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.). 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 carbon permanently or temporarily sequestered or reduced in atmospheric releases by altering farming practices with its value (\$/ton C) determined in a carbon emissions market. Farm managers who reduce CO₂ emissions below current levels or sequester additional soil C will receive a C credit that can potentially be sold in a carbon market (Williams, Peterson, and Mooney).

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; Eve et al.). Other research areas include the effects of forest management practices on carbon sequestration (Cacho, Hean, and Wise) and converting cropland to forest uses (Parks and Hardie; Stavins). 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.; Feng et al.). The marginal costs reported range from a few dollars to over \$300/ton of C (Williams, Peterson, and Mooney).

Although there have been some recent studies that have examined the economic feasibility of reducing tillage (Ribera, Hons, and Richardson; Williams, Roth, and Claassen), there has been

only one study that examined both the economic feasibility of reducing tillage and sequestering carbon at the crop enterprise level (Williams, Roth, and Claassen). Williams, Roth, and Claassen 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. 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 (NH₃), 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 while assuming managers were either risk neutral or adverse to risk.

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 over the twenty years of the study (1983-2002) of 45.45 inches, 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 NH₃, UAN, or urea. The nine production systems studied include:

1. CT NH₃ - conventional-tillage with NH₃
2. CT UAN - conventional-tillage with UAN
3. CT Urea - conventional-tillage with urea
4. RT NH₃ - reduced-tillage with NH₃
5. RT UAN - reduced-tillage with UAN
6. RT Urea - reduced-tillage with urea
7. NT NH₃ - no-tillage with NH₃
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 NH₃, 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 P₂O₅ and 71 lbs/acre of K₂O was applied to grain sorghum while 6-23-37 of N, P₂O₅, and K₂O 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. 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 NH₃ 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 NH₃, 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 carbon 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 CO₂ 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 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. 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 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.

$$\text{C Value to make } NR_j \text{ equivalent to } NR_i = (NR_i - NR_j) / (C \text{ Rate}_j - C \text{ Rate}_i) \quad (1)$$

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 (Table 1). UAN had the lowest net return for all three 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). As will be discussed later, this system was also preferred to all others by risk averse managers. 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 (Table 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). The NT NH₃ 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 NH₃ 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). 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 CO₂.

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. 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.) and 0.60 tons C/acre/year for a no-till wheat-sorghum rotation (Williams, Nelson, Claassen, and Rice). 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).

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 sequestered in the soil on an annual basis. There was no change in rank order of sequestration by system (Table 1).

Derived Carbon Credit Values

The RT Urea and NT NH_3 systems sequestered the most soil carbon and net carbon, but they were only the third and fourth most profitable systems, respectively (Table 1). Therefore, carbon credits

would be needed as an incentive to encourage use of these systems, rather than RT NH₃ or CT NH₃, which were the two most profitable systems. Derived net C credit values (\$/ton/yr.) using equation (1) for all technically feasible comparisons, assuming risk neutrality 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 NH₃; the system with the highest net return, and the rows labeled RT Urea and NT NH₃; 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 NH₃ and either the RT Urea or NT NH₃ 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 NH₃ 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 NH₃ rather than RT NH₃ is \$77.23/ton of C (dashed line blocked value). If the manager was originally using CT NH₃, the second most profitable system, the C credit values are \$21.68 and \$55.48/ton of C, respectively.

Some producers have moved away from NH₃ systems due to safety and security reasons. The results show that producers using RT Urea which is the most profitable system that does not use NH₃ 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 CO₂ 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 NH₃ from RT NH₃ or CT NH₃ systems were slightly larger than the C credit values when emissions were subtracted, but the general results did not change.

Risk Analysis

Examining average net returns are important, but considering the difference in variability or risk of net returns between production strategies is also useful to test the robustness of the results and determine if the general results change when the risk of each system is considered. Ranking the production strategies with the use of risk premiums calculated for managers with various degrees of risk aversion was conducted. A risk premium is the amount of additional money that a farm manager would need to be indifferent between a given strategy and another strategy that has different variability in net returns or risk characteristics. For risk neutral managers, the risk premium for one strategy versus another is simply the difference in net returns between the two strategies. In other words, the risk premium is the additional return needed for the lower return strategy to be equivalent to the higher return strategy. In this analysis, the risk premium represents the additional return (\$/acre) needed to be indifferent between one production strategy instead of another such as RT UAN instead of RT NH₃ for various degrees of risk aversion. Richardson, Schumann and Feldman developed new a procedure to calculate risk premiums based on a range of

absolute risk aversion coefficients which encompasses a wide range of managers that have risk attitudes ranging from risk neutral to extremely risk averse.¹

Risk premiums were calculated for all systems using pair wise comparisons of the distributions of net returns from each production system versus every other system using an increasing range of risk aversion or curvature of the utility function. SIMETAR©, developed by Richardson, Schumann, and Feldman was used to calculate the risk premiums. This procedure requires the use of the distribution of net returns based upon annual yields and prices, and current production costs for each production strategy.

The results showed that a farm manager using the RT NH₃ system required a risk premium to switch to any other system at any level of risk aversion and as a result was the preferred system by risk averse managers. Although the results for all strategies are not reported for purposes of clarity, the results of the risk premium calculations for the four most relevant system comparisons, over a wide range of risk aversion levels, are presented in Figure 1. This includes the evaluation of the use of RT Urea instead of RT NH₃, NT NH₃ instead of RT NH₃, RT Urea instead of CT NH₃, and NT NH₃ instead of CT NH₃. The RT NH₃ and CT NH₃ are the systems with the two highest net returns and RT Urea and NT NH₃ are the systems with the two highest carbon sequestration rates. For a risk averse manager to be indifferent to using NT NH₃ instead of RT NH₃, the risk premium ranges from \$7.32 to \$4.72/acre and generally declines as the degree of risk aversion increases (Figure 1). Although risk averse managers prefer the RT NH₃ system over the entire range of risk aversion levels, these results indicate that as the manager's degree of risk aversion increases, the strength of their preference for RT NH₃ over NT NH₃ actually decreases because the

¹This method is Excel spreadsheet based and is a new extension of stochastic dominance techniques that are frequently used for evaluating alternatives choices with respect to a manager's attitude toward risk.

risk premium decreases. The risk premium required for a manager to be indifferent between RT Urea and RT NH₃ ranges from \$5.88 to \$4.27/acre. The risk premium to use RT Urea rather than CT NH₃ declines from \$1.40 to -\$2.76/acre as risk aversion increases (Figure 1). The payments to use NT NH₃ rather than CT NH₃ increase to \$2.84/acre to a maximum of \$3.23/acre and then decline to -\$2.31/acre as risk aversion increases. When the value is negative it indicates that risk averse managers actually prefer NT NH₃ to CT NH₃ even though CT NH₃ is more profitable. Although the risk premiums changed, the general results were unaffected by the use of historical fertilizer prices.

The risk premiums were also converted to the carbon credit incentive (\$/ton of C) needed for a manager to be indifferent between the systems. This calculation was performed by substituting the risk premiums (\$/acre) into the location in equation (1) where the difference in net returns between the systems was previously used. Figure 2 presents the results. The carbon credit (\$/ton of C) required to encourage the use of the system with the highest sequestration rate (RT Urea) instead of most profitable system (RT NH₃) ranges from \$54.98/ton of C to \$39.48/ton as risk aversion increases. The C credit needed to encourage the use of NT NH₃ rather than RT NH₃ range from \$77.23 to \$49.82/ton as risk aversion increases. The credit to adopt NT NH₃ rather CT NH₃ ranges from \$55.48 to -\$45.02/ton. Risk averse managers with risk aversion greater than 0.21 actually prefer NT NH₃ to CT NH₃.

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 NH₃ and CT NH₃ systems had the highest and second highest net returns, respectively.

Risk analysis using risk premiums also found that RT NH₃ was the preferred system over the entire range of risk aversion levels. The RT Urea and NT NH₃ 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 NH₃ and CT NH₃ under risk neutral and risk averse conditions. The value needed for the C credits ranged from \$0.00/ton to \$77.23/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 CO₂, or \$33 to \$117/ton of C (The Economist). 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 known as the Kyoto Protocol and carbon credits from soil sequestration are currently not being accepted. There is also a 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. Carbon credit prices on the CCX during 2005 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 NH₃ and CT NH₃. However, for some risk averse managers it would be enough to encourage the use of RT UAN rather than CT Urea, and NT NH₃ rather than CT NH₃.

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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	\$70.13	\$71.58	\$75.08	\$71.43	\$70.12	\$73.28	\$72.74	\$75.93	\$72.48
C.V. ^d	5.58	NA	42.70	4.19	47.49	6.56	7.48	NA	NA
Maximum ^c	\$165.90	\$151.23	\$164.65	\$177.29	\$140.12	\$180.01	\$161.90	\$135.98	\$127.24
Minimum ^c	-\$103.60	-\$102.60	-\$99.10	-\$91.75	-\$91.87	-\$88.87	-\$98.25	-\$102.92	-\$98.25
Soil Carbon ^e	0.11006	-0.01930	0.00499	0.06278	0.15518	0.17021	0.15737	0.05764	0.12745
Direct ^f	0.01684	0.01684	0.01618	0.01313	0.01313	0.01248	0.00879	0.00879	0.00814
Embodied ^f	0.03540	0.03540	0.03540	0.03540	0.03540	0.03540	0.03951	0.03951	0.03951
Total Emissions ^f	0.05223	0.05223	0.05158	0.04853	0.04853	0.04787	0.04830	0.04830	0.04765
Net Carbon ^g	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 Coefficient of Variation (C.V.) is a unitless measure of relative risk; the standard deviation divided by the mean.

^e Carbon sequestered in the soil (tons/acre/year).

^f C emissions from production inputs (tons/acre/year).

^g 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
<u>Inputs</u>									
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	\$11.48	\$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	-	NC	NC	NC
NT NH ₃ \$9.73 0.10907	\$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 -\$9.61 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. Risk Premiums (\$/acre)

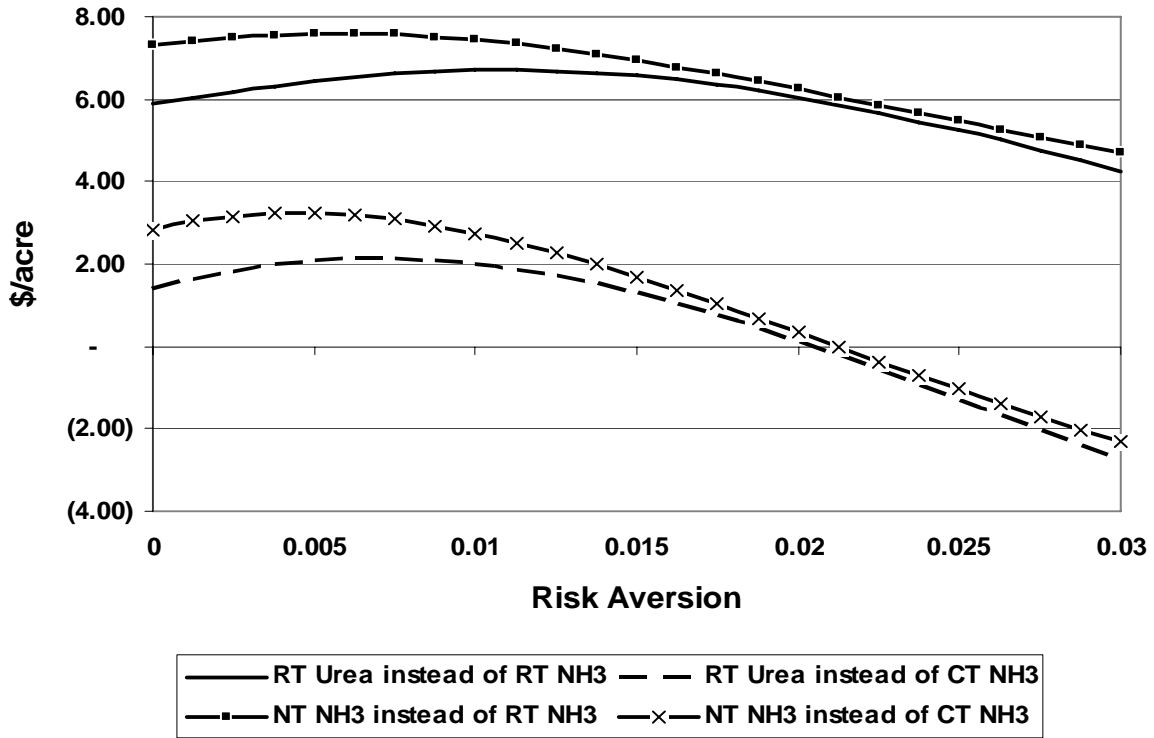


Figure 2. Risk premiums (\$/ton C).

