An Economic Analysis of No-Till Rotations and Effects on Carbon Sequestration and Long Term Sustainability of Agriculture[1]

By

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[3] Funding support for this study was provided by the South Dakota Agricultural Experiment Station and grants from the South Dakota Corn Utilization Council and South Dakota Soybean Research and Promotion Council.

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Abstract

This study summarizes key economic results from 10 different no-till (NT) crop rotations and a conventional (CT) corn-soybean rotation based on agronomic data from Brookings County, South Dakota for 2001 – 2008. A 1200 acre model crop farm was constructed to conduct the farm management budget and simulation analyses. Results indicate: (1) the CT rotation had the highest average net returns, (2 Several four-crop no-till rotations were preferred as producer risk aversion increased, and (3) carbon credit payments would need to be $14 to $36 per acre for the top four NT rotations to be as profitable as the CT rotation.

Key Words: No-till crop systems Stochastic simulation Carbon Credit Payments

Categories Farm Management Production Economics

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Introduction

Increasing greenhouse gas emissions have become a growing concern for the global economy. These increases are being cited for contributing to increasing world temperatures, erratic climate behavior, and adverse geographical changes (EPA). In the agricultural sector, this has led to an emphasis on farming practices, such as reduced tillage and no-till (NT) crop rotation systems, which are environmentally friendly and mitigate or sequester greenhouse gas emissions.

Carbon sequestration is the process by which plants remove carbon dioxide from the air through photosynthesis. Practices that sequester carbon, including NT, also increase the quantity of soil organic carbon which is one of the most important indicators of soil quality and agronomic sustainability. It improves fertility, water holding capacity, and other beneficial traits. NT crop systems are also credited for increasing the long term sustainability of agriculture (Clay et.al, Paudel et.al, Dobbs et.al.).

The growing emphasis on agricultural carbon sequestration has also given producers and land owners the chance to gain extra revenue in the form of carbon credit sales. Trading of carbon credits is currently is a voluntary process that is overseen by the Chicago Climate Exchange (CCX). Current federal legislation, such as the "American Clean Air and Security Act," involving carbon credits could have a significant impact on the price farmers receive per unit of carbon sequestered. If new legislation, such as a cap-and-trade system, isn't introduced, steps could still be taken to help reduce the impact of increasing greenhouse gas emissions and future environmental changes. The main component to agricultural carbon sequestration is to examine if producers would be willing to adopt practices, such as NT crop rotations, that enhance soil carbon, and if so, at what costs? (Antle, et.al. 2002).

Overview of Research Purpose and Approach

The purpose of this research is to help analyze the profitability of adopting NT crop systems and understand the agro-economic impacts of carbon sequestering in these production systems. This research also has the intentions of finding the risk premium farmers would need to convert between conventional tillage (CT) and no-till (NT) practices; or, the minimum price a carbon credit would need to be to make a farmer indifferent between systems.

Eight years (2001 – 2008) of data from crop field trials conducted by the Agricultural Research Service (USDA-ARS) near Brookings, SD is used to empirically analyze the performance of 10 different NT crop rotation systems and a CT rotation that all include corn and soybeans within the rotation. This information is used to construct a 1200 crop acre representative farm model that is designed to gain insight on: 1) the profitability of various NT rotations versus a standard no-till corn-soybean rotation, 2) implications of NT farm management practices on the long term sustainability of agriculture, and 3) revenue to be gained from carbon credits and their feasibility. Profitability analysis is conducted for each crop rotation system for the eight year period. Stochastic simulation analysis is used to further compare the relative performance of alternative crop rotation systems for changes in yields, output prices, and level of carbon credit payments.

Background and Key Issues

The Kyoto Protocol established in 1997 by the United Nations called for significant reductions in greenhouse gas emissions. This protocol was not accepted by the United States, but there is still interest in reducing carbon emissions. For instance, in 2002 the Bush administration announced its intention to reduce greenhouse gas emissions per unit of economic activity. In October of 2007 a bill was introduced into the U.S. House of Representatives that would create a potential $24 billion dollar market for carbon credits. The Healthy Forests, Healthy Planet Act of 2008, Lieberman-Warner Climate Security Act of 2008, Climate Matters Act of 2008, and the Western Hemisphere Energy Compact Act of 2008 all included legislation pertaining to carbon credits (THOMAS). This market provides producers with an entirely new product for their farm operations. This is a value added opportunity for direct profit, with the possibility to improve long term sustainability. The problem is there has been very little research on the effects that this market will have on the management practices and profitability of farm land producers.

Currently, the market for carbon credits is a voluntary process overseen by the Chicago Climate Exchange (CCX). There are 111 members registered to monitor offsets listed on the CCX website (chicagoclimateex.com). The CCX certifies offset aggregators to collect and then sell these offsets to the 111 registered members. In South Dakota the aggregator is the North Dakota Farmers Union (NDFU). Farmers and ranchers enroll agricultural land into the program through online contracts. Once acres are enrolled and certified, carbon credit payments per acre through the NDFU are figured by Equation 1. A 10% commission deducted by the NDFU is represented by *(.9)*, and the *(.20)(Sequestration rate)* is a CCX offset registration fee.

Equation 2 represents payments per acre for Brookings County, which is in a carbon sequestration zone of 0.6 metric tons per acre for no-till practices**.**

Eq (1)

$$Payment\ Per\ Acre = (Sequesration\ Rate * Price\ \ per\ metric\ ton)(.9) - \ (.20)(Sequestration\ Rate)$$

Eq (2)

$$Payment\ Per\ Acre = (.6 * Price\ per\ Ton)(.9) - \ (.12)$$

Many studies have been conducted on the cost to sequester carbon in various regions of the United States including southern regions, the Corn Belt, and in Montana. These studies have found highly different costs for sequestering carbon between regions. Cost per metric ton of carbon for wheat grown in the southern states is estimated at $10.06, while cost per ton of carbon for wheat grown in the prairie states is estimated at $376.08 (Manley). Overall, costs per metric ton range from $1.94 to $500 depending on regional location, practices used, and soil types (Antle, et.al; Manley). No studies have been conducted for South Dakota. .

Many studies have shown that NT and organic farming can be as profitable as, or even more profitable than CT systems. For example, Pendell's study on the economic effects of carbon sequestration on corn in northeast Kansas found that the highest net returns were from NT systems, sometimes providing increased returns exceeding $30 per acre. Dobbs et.al.found different results from earlier studies conducted on South Dakota research farms. Results from their comparisons of conventional, organic, and no-till systems showed no-till systems had the lowest returns which averaged $20 per-acre less than net returns from conventional tillage systems.

NT rotations are regarded as one of the most efficient and effective practices for sequestering carbon. A study in Indiana found that NT sequesters five times as much carbon per acre than conventional tillage (Bongen). NT does tend to reduce yields, and on average has been found to reduce revenue by $28 per hectare ($11.33 per acre). The spread was even larger in the Cornbelt region where the difference was around $50 per hectare ($20.25 per acre).

Long term conservation studies suggest conservation tillage helps maintain or increase soil organic carbon (SOC). SOC is one of the key indicators of soil health, long term sustainability, and constitutes 50-60% of organic matter in the soil. The process of accumulating SOC is a slow process, and steady state levels of organic matter could take over 100 years to reach (Paudel et.al; Clay et.al.). Paudel's study of cotton farming in Georgia estimated a 0.92% - 1.15% increase in organic matter over 30 years in NT operations. The amount and rate that carbon is stored in soil is impacted by productivity, temperature, plant available water, bulk density, available nutrients, erosion, management, and native vegetation (Clay et al).

Two points should be considered. First, in most places creating carbon offsets through different practices is not cost-effective. The high cost of using NT with a low carbon uptake, leads to high per unit costs of carbon offsets. The second consideration, however, is that in some regions using NT to sequester carbon is relatively efficient and cheap (Manley). These cheaper regions tend to be in the southern U.S. states. Analysis completed for cotton farms in Georgia show that a system of NT over a 30-year period has the greatest profitability (Paudel, et.al). In some circumstances, NT systems may yield triple dividends of carbon storage, increased returns, and reduced soil erosion.

Data Sources and Model Farm Budget Assumptions

Crop Rotation Field Data

The crop rotation data for this study is from the North Central Agricultural Research Service (NCARS) farm located northwest of Brookings, SD. The soil on this site is a Barnes clay loam soil with nearly level topography and a 0.88 crop productivity index (Natural

Resources Conservation Service). The dataset is for the first half of the 16 years (2001 – 2016) of performance studies of NT crop rotations in east-central South Dakota.

Eight years of data (2001 – 2008) were available from this long-term study consists of 10 NT crop rotations planted on 148 plots that are each 20' x 50'. In addition, data was developed for a conventional tillage (CT) crop rotation in Brookings County. The list of crop rotations is shown in Table 1.

Eight NT crop rotations studied by the ARS are four-year rotations that include soybeans, corn, and various combinations of sunflowers, spring wheat, winter wheat, oats or canola. Rotation 10 (R10 in table 1) is a three year rotation that includes corn, soybeans, and spring wheat. The last NT system (R9 in table 1) is a two year rotation of corn and soybeans, which is used as a baseline rotation to compare relative profitability of NT systems. These ten rotations are each replicated four times across plots to reduce variability in yields, moisture, and test weight due to any differences in soil type.

Table 1: List and Description of 10 No-Till Rotations & 1 Conventional Tillage Rotation.

Rotation 1	C-Su-Sw-S			
Rotation 2	C-S-Sw-S	Ca	-	Canola
Rotation 3	C-P-Ww-S	C	-	Corn
Rotation 4	C-Ca-Ww-S	O	-	Oats
Rotation 5	C-S-Sw-Su	P	-	Peas
Rotation 6	C-C-S-Sw	S	-	Soybeans
Rotation 7	C-S-Sw-P	Sw	-	Spring Wheat
Rotation 8	C-O-Ww-S	Su	-	Sunflowers
Rotation 9	C-S	Ww	-	Winter Wheat
Rotation 10	C-S-Sw			
Con. Till	C-S			

Source: Crop rotation experiments conducted at the North Central Agricultural Research Service research farm near Brookings, SD

Farm management practices used in this study were jointly determined by ARS scientists and their producer board (Osborne, personal communication). A few practices differ from those typically used by crop farmers in the Brookings area. A major purpose of the field trials was to study the effects of different crop rotations on the flux of greenhouse gases, changes in biological activity, and to test if pest/disease cycles can be broken. Thus, nitrogen application rates were set at an 85% yield target so that measurements of mineralization rates were not distorted. Although fertilizer rates were lower than most farmers would use, it still allows for comparisons between crop rotations. These were also the same reasons that only BT (corn borer resistant) corn was planted instead of Roundup Ready corn, although Roundup ready soybeans were planted in the field plots. Data on fertilizer application rates, seeding rates, and chemical applications were taken from the NCARS field trials. Annual yields used are the average of actual observed yields for the four different plot replications of each crop per rotation.

Finally, one corn/soybean conventional tillage (CT) rotation was developed for comparison purposes. This rotation was established using an 85% yield goal of the average corn yield in Brookings County. This 85% yield goal was chosen for the CT rotation to match the same 85% yield goal for no-till corn in the NCARS field trials. Yield targets were then used to create fertilizer application rates based on South Dakota State University's Fertilizer Recommendations Guide (Gerwing et al). Seed rates were also adjusted to this lower yield goal.

Model Farm Budget Assumptions

Agronomic data from the field trials was incorporated into a model farm developed to conduct the economic analysis. The model farm contains 1200 crop acres and is fairly representative of large commercial family crop farms in east-central South Dakota.[7] Although maintaining a steady rotation system is an important key to NT agriculture, most crop farms do not allocate acres evenly to all crops. However, the assumption of equal number of acres per crop included in each rotation was made to simplify the budget analysis.

Other key assumptions related to crop output prices and input costs include:

a. Prices used to value each crop were statewide annual average prices for the marketing year and were obtained from NASS (National Agriculture Statistic Service) website.

b. Seed prices and fertilizer prices were based on Northern Plains or national average prices per unit (NASS) and converted to per acre prices based on field application rates. The fertilizer prices were based on a 32% nitrogen (32-0-0) mix as no phosphorus was used in any rotation.

c. Chemical prices were bulk prices based on annual records from Cenex Harvest States for eastern South Dakota and cross-checked with NASS annual price data for the Northern Plains. The chemical costs per acre were based on unit prices and field application rates.

d. Crop insurance costs were based on per acre costs from a 65% APH insurance policy using Brookings county T-yields for the entire period. The 65% yield guarantee insurance was used because it was one of the most widely used crop insurance selections in the county and because it was available for all crops included in the rotations examined. Crop

[7] For example farms with more than 1000 acres operated accounted for 65% of harvested cropland acres in Brookings county, SD in 2007. Farms with more than 1000 harvested cropland acres accounted for 57% of Brookings county harvested cropland acres in 2007 (USDA, 2007 Census of Agriculture – South Dakota, Vol.1, Part 41.

insurance revenues occurred if crop yields were below the 65% T-yield for Brookings county. The insurance indemnity payment was the amount of yield shortfall multiplied by the annual average crop price for the specific year. This approach approximates typical crop insurance costs and indemnity payments per acre in this county.

e. Drying costs for corn were based on the cost of drying each year's corn crop to 15% moisture using data from USDA – NASS and Iowa State University "Grain Drying Cost Calculator."

f. Machinery ownership and operating costs were based on data from the South Dakota Annual Report of Farm Business which is based on surveys of individual farm's machinery costs and were reported for all crops except canola and peas. Machinery costs for field peas and canola were assumed to be equal to machinery costs for soybeans and spring wheat respectively.

g. Land charge per acre was established using annual average cash rental rates for cropland in Brookings County (South Dakota Agricultural Statistics Service, 2001 - 2008).

h. Direct government payments, which are fixed per program crop acre and not dependent on specific crops grown, were the only federal farm program payments included in the budgets. The direct payment rate used in the model farm budgets was $12 per crop acre which is close to the county average rate during this time period (Brookings county FSA). Direct payments are included because of their influence on the level of cash rental rates, which is used to establish the land cost in the budgets, and because most crop farmers in eastern South Dakota are enrolled in federal commodity programs.

i. Lack of information on canola and peas grown in South Dakota led to the use of price and insurance data from North Dakota.

The crop rotation budgets developed for the model farm include sections on gross returns per acre, direct operating costs, machinery ownership and land costs, and net returns to labor and management.

Simulation Modeling Approaches

Simetar© is a simulation engine written to provide a transparent method for analyzing data, simulating the effects of risk, and providing clear, transparent results (Simetar©). Simetar© is an Excel add-in that allows any spreadsheet model to be made stochastic and simulated using Simetar© functions. Simetar© allows all functions to become dynamic, so if changes are made to the original data in this study, parameters, hypothesis tests, and ranking of risky alternatives are also updated. This study will be using Simetar© to simulate stochastic variables, rank risky alternatives, and present those results graphically.

Stochastic dominance with respect to a function (SERF) and stochastic efficiency with respect to a function (SERF) were used to rank risky alternatives. Simetar© uses risk aversion coefficients (RACs) to represent a decision makers' utility function. Upper and lower bound risk preferences are entered into Simetar© allowing assumptions to be made on how different decision makers might rank scenarios given a specific RAC. Along with ranking scenarios, Simetar© also creates cumulative distribution functions and probability tables emphasizing three levels of returns (referred to as StopLight tables) using simulated data.

Simetar© was used to stochastically simulate prices, yields, and carbon credit prices. Price distributions were established using normal distribution (=NORM (average, stdev)) so that it would result in a normally distributed random variable. Yearly average prices received by farmers were used for the yearly average, and monthly prices received by farmers were used to calculate the standard deviation.

Since yields are likely to coalesce around certain values, yield distributions were established using an empirical distribution (=EMP(S_i, F(S_i), [CUSD])) with multivariate random variables. This function assumes a continuous distribution so it interpolates between specified points on the distribution using the cumulative distribution probabilities (Simetar©).

Carbon credit payments were also established using an empirical distribution, but also used an independent random variable. Daily carbon price data from the Chicago Climate Exchange was used to establish normal distribution. Actual payments received by farmers were only available from the North Dakota Farmer Union from 2007, since 2006 was the first year contracts were signed (Enerson, Interview). An empirical distribution allows for simulated variables to be concentrated around the most observed values.

The Excel functions mentioned above were then entered into each cell for yields, prices, and carbon credit payments (32 cells for each variable in a 4 year rotation, 96 cells total). These cells and other cells of interest are then entered into the simulation engine of Simetar© and run through 500 iterations. Other cells of interest include gross return per acre, return to management and labor per acre, total gross return, total return to management and labor, and insurance indemnities. Once the simulation has run, there are 500 iterations per year in each crop rotation. These 4000 samples from each rotation are then compared against each other for the eight year period using stochastic dominance and probability (stoplight) analysis.

Empirical Results and Discussion

Budget Analysis

Return to Management and Labor (net returns) is the key variable reported in this study. Figure 2 displays the net return budget results for all ten NT crop rotations and for the 85% yield target CT rotation. The first two years of field trials led to net returns that were mostly negative, with only a few rotations showing signs of positive returns. These negative returns are the results of extremely low yields and low crop prices, and drought. The transition year when a field is first planted to NT generally results in low yields. This is a result of the changes in soil management practices and a disruption in the cycle of residue decomposition. It takes a few crop cycles for the residue cycle to return to normal. This is the reason for low returns in 2001. Low yields in 2002 were a result of lower than average rainfall and the continued disruption of residue decomposition.

For 2003 and 2004, crop yields improved and crop prices increased, resulting in modest returns to management and labor. Although 2005 resulted in the highest yields observed over the eight years, net returns slumped in 2005 as a result of low crop prices. Yields declined substantially in 2006 primarily due to low rainfall during most of the growing season
Over all rotations between 2005 and 2006, corn yields decreased by 36.5%. However, higher prices in 2006, compared to 2005, helped to increase returns.

For 2007, decreased yields occurred for fall season crops, while increase yields occurred for summer crops. Between 2006 and 2007, corn and soybean yields decreased 9.7% and 7% respectively, while spring wheat yields increased by 21.5%. Therefore, rotations that had a higher percentage of wheat, peas, or canola performed better than those with a larger proportion of acres planted to corn, soybeans, and sunflowers. Despite lower yield in certain crops, lower input costs and record crop prices helped to make 2007 a very lucrative year.

Average net returns to management and labor were positive for all rotations for the entire eight year period. Overall, the CT rotation was the most profitable and had the highest average net returns of $92,540 or $77.11 per crop acre. After the CT rotation the R3 (C-P-Ww-S), R7 (C-S-Sw-P), R8 (C-O-Ww-S), and R4 (C-Ca-Ww-S) rotations systems were ranked 2nd through

5th respectively. Field peas and Soybeans were extremely beneficial to profitability producing lower fertilizer costs, consistently high yields, and relatively high crop prices.

The NT corn-soybean rotation (R9) ranked 10th in average net return; ranking only better than the R6 (C-C-S-Sw) rotation. Low corn yields in these two crop rotations (R9 and R6) were the main explanations for lower net returns. Rotations with more crop diversity tended to have higher net returns.

Rotations with sunflowers performed poorly because of crop failures in 5 out of 8 years. This was a result of physical damage by pheasants. This would not happen on an actual production field.

Carbon Credits

Carbon credit payments were introduced to each of the ten NT rotations and ran through an identical 500 iteration simulation to show the effects that per acre payments would have on profitability. Contract specifications from the NDFU and daily historical price data from the CCX were used to calculate an empirical distribution for per acre carbon credit payments. Payments had an average of $1.24, minimum of $0.015, and maximum of $3.87. It was assumed that all 1200 acres were enrolled in the program. Probability (StopLight) analysis reported in Figures 3 & 4 show that carbon credit payments decrease the probability of returning a value less than $0.00 by 0.9%, decreased the probability of values between $0.00 - $50,000 by 0.3%, and increased the probability of values greater than $50,000 by 0.9%. The two NT rotations with the lowest probability of negative net returns were R3 (C-P-Ww-S) with a 16% probability and R8 (C-O-Ww-S) with a 14% probability did not see any reduction in probability of loss after adding carbon credit payments. The maximum decrease in the probability of loss that any rotation incurred was 2%.

Under current market conditions there is little incentive to switch to a NT rotation. Average net returns after simulation only increased by an average of $1,360.91 ($1.13/acre) across rotations, and reducing the average difference in net returns between CT and NT from $45,304.70 to $43,943.79 or from $47.75 to $36.62 per acre.

Carbon credits required per acre for all ten NT rotations to make average net returns equal to CT are presented in Table 2. These values only represent intrinsic value, and do not include risk premiums. Risk premiums will be established in the stochastic dominance results. The average carbon credit payment a farmer would have needed between 2001 and 2008 across NT rotations is between $14.81 and $56.18 per acre. The baseline NT corn-soybean rotation (R9) has the second highest required payment of $47.79 per acre or $79.65 per metric ton.

Most no-till crop rotations face too high of an opportunity cost for a carbon payment to be a realistic incentive. However, there are 3 or 4 NT rotations that may be able to compete with CT corn-soybean if Cap and Trade legislation was implemented. The R3 (C-P-Ww-S), R7 (C-S-Sw-P), and R8 (C-O-Ww-S) rotations only require a payment of $14.81 to $20.16 per acre. In 2001 and in 2008, the R3(C-P-Ww-S) rotation did have negative carbon credit payments, inferring that it had higher net returns to management and labor than the CT rotation. The R7 rotation (C-S-Sw-P) also had higher net returns than the CT rotation.

The equivalent prices that a metric ton of carbon would need to be trading at on the CCX are located in Table 3. These prices range average from $27.65 to $104.25 per metric ton and are much higher than the current seven year trading range of $0.10 - $7.20 on the CCX. Some of these averages are within the carbon price ranges traded on the European Climate Exchange which has seen metric ton prices of carbon reach over 30 €.

Stochastic Dominance and Risk Analysis

SDRF and SERF were performed through Simetar© , allowing the evaluation of different rotations based on alternative risk preferences. The cumulative distribution function for simulated net returns to management and labor can be seen in Figure 3. The cumulative distribution function shows the probability of obtaining a specific net return. Looking at Figure 3 shows again that the CT is the most dominant rotation, not taking into account risk preferences. Crop rotation systems of R3 (C-P-Ww-S), R8 (C-O-Ww-S), R7 (C-S-Sw-P), and R4 (C-Ca-Ww-S) are the next best crop management strategies. This list coincides with the rankings of mean return, but none of the four previous strategies can be chosen over another. Each strategy provides different probabilities for values of net returns, so which strategy an individual will choose is dependent on their risk preferences. Strategies with higher probabilities for higher net returns generally have higher probabilities for negative net returns.

Risk aversion coefficients (RACs) were determined by starting with a lower limit of 0 and increasing the upper limit until no more changes in rankings occurred between strategies. This left a RAC interval of 0.0 – 0.0002125. When a producer is risk neutral (RAC = 0), CT is ranked first followed by the R3 (C-P-Ww-S), R7 (C-S-Sw-P) and R8 (C-O-Ww-S) rotation systems, respectively. Once the RAC reaches .0002125, CT falls to the 7th most preferred scenario. Although CT ranks number one in almost all other categories, a high standard deviation of $81,039.46 causes it to drop rankings as the producer becomes more risk averse. At a RAC greater than 0.0002125, the R8 (C-O-Ww-S) rotation system becomes the most preferred scenario followed by the R4 (C-Ca-Ww-S) and R3 (C-P-Ww-S) rotation system. At a RAC value greater than 0.0000567, the baseline R9 no-till corn-soybean rotation is the 11th most preferred scenario due to a lower average net return and the highest standard deviation of all 11 scenarios. The R8 (C-O-Ww-S) rotation had the lowest standard deviation and ranked 4th in average income making it the most preferred rotation in the Stochastic Dominance and Efficiency tests. A full list of RAC values and rankings can be seen in Table 4.

Figure 5 shows how the 10 different NT rotations rank against the CT rotation at various RACs. The difference between the CT rotation and the NT rotation is the risk premium that would be needed at the RAC to be indifferent between the two systems. Looking at Figure 5, all of the NT rotations except R1, R6, R9, and R10 move above the CT rotation as RACs increase. These four are the only rotations that would always need a risk premium / carbon credit payment to be indifferent. Risk premiums needed to be indifferent between all NT rotations and the CT rotation (RAC = 0) range from $19.19 in the R3 (C-P-Ww-S) rotation to $60.56 in the R6 (C-C-S-Sw) crop rotation. These are the premiums needed per acre, and represent 0.6 ton of carbon.

Conclusions and Implications

The CT rotation had the highest average net returns to management and labor over the eight year study. NT rotations on average had a $45,304 lower total net return or $37.75 per-acre lower net return. Adding per acre carbon credit payment to each NT rotation only added an average of $1,360.91 in revenue, and decreased the probability of having a loss by an average of 0.9%. This still left a significant difference in return between CT and NT rotations. Without risk premiums, it would take between an average payment of between $14.81 and $56.18 per acre to be indifferent between the CT and NT rotations. When risk premiums were included through stochastic dominance, the carbon credit payment needs to increase to a range of $19.19 to $60.56 per-acre depending on no-till rotation.

When a producer has a RAC of 0, CT is the most preferred scenario. As the RAC value increases to 0.0002125, CT moves to the 7th most preferred scenario and is replaced by R8 (C-O-

Ww-S) as the most preferred rotation. Rotations that planted more acres of corn were less preferred as RAC increased as a result of lower net returns and higher standard deviations. The rotations that performed the best had a four year rotation including combinations of oats, peas, and canola and winter wheat along with corn and soybeans. Winter wheat, corn, and soybeans were in the top three most preferred rotations at a RAC greater than 0.0000779 suggesting that a combination of those three crops, in conjunction with another summer crop is an excellent strategy for a risk-averse producer.

These findings support Dobbs (et al) earlier study that showed conventional tillage had higher returns than minimum tillage or no-till systems. However, this study is limited in that the CT yield were estimated using a 85% yield target of the Brookings County average. Even after taking 85% of average yields, the CT rotation had corn yields that averaged 18.5 bushels per acre higher. If a CT rotation had been established as a control these findings would be more concrete. There is yield data available for a conventional tillage corn/soybean rotation on the same research farm, using similar fertilization techniques for 2001 – 2006. This data has not been provided yet, but will be included in the final thesis.

Despite its limitations, this study shows clear comparisons and insights across all no-till rotations for this specific region. Producers in regions north and west of the study location, typically have lower rainfall, may have more economic incentive to switch from conventional tillage to no-till practices. The next 8 years of this study may also show that differences in net returns between no-till and conventional tillage rotations diminish as no-till net returns and yields trend higher. Most of the negative net returns for no-till systems occurred in the first two transition years.

Figure 1: Returns to Management and Labor by Crop Rotation and Year

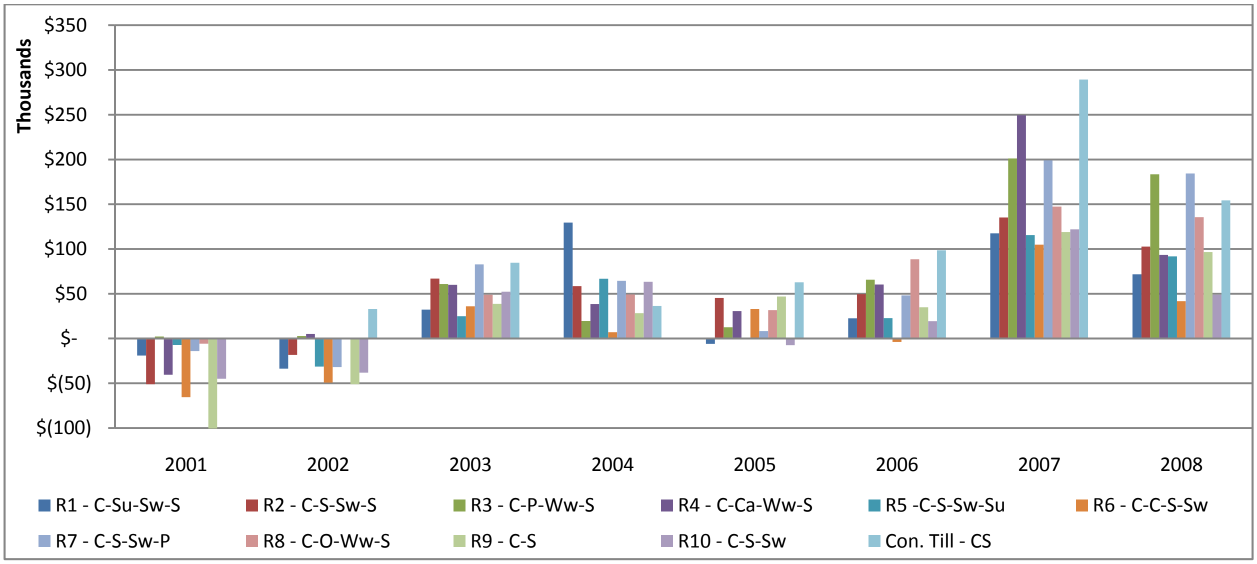

Figure 2: Cumulative Distribution of Return to Management and Labor

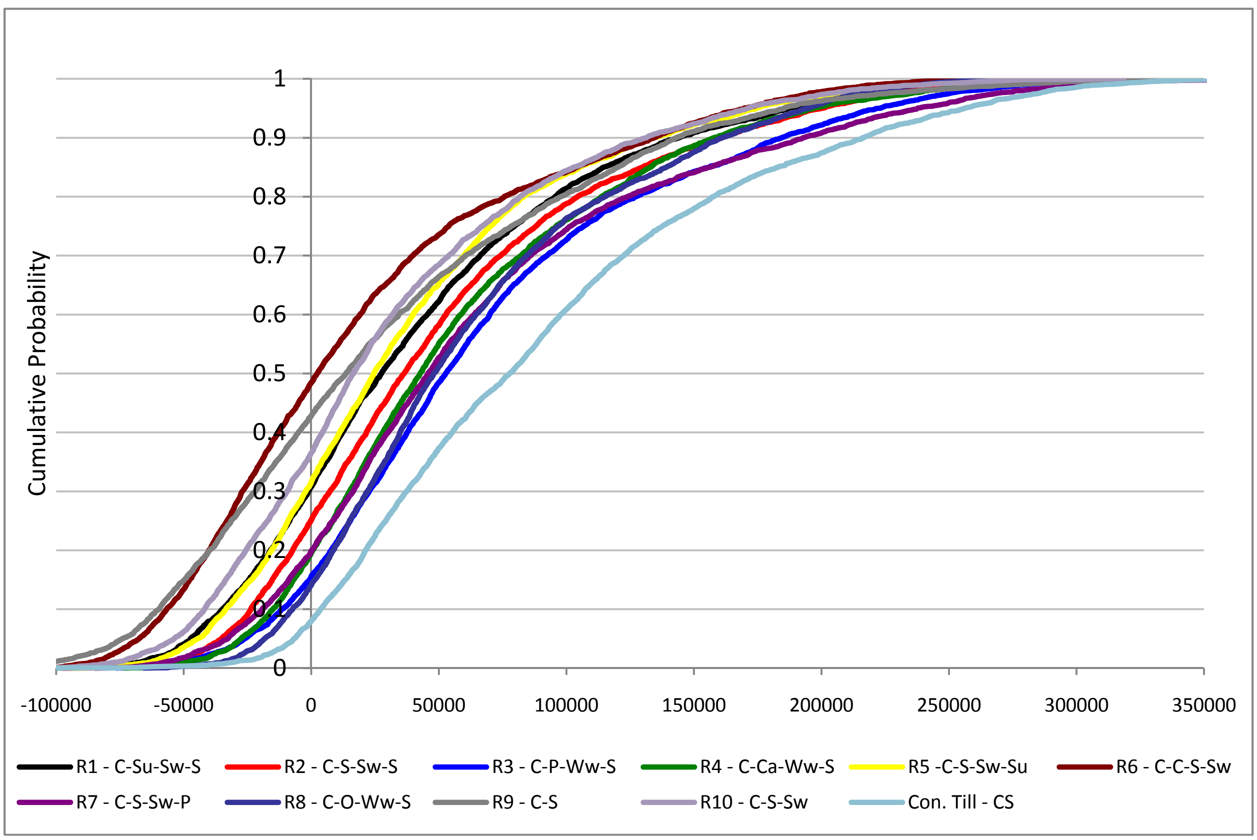

Figure 3: Probabilities of Net Returns To Management and Labor Less Than 0 and Greater Than 50,000: Carbon credits **are not** figured into percentages.

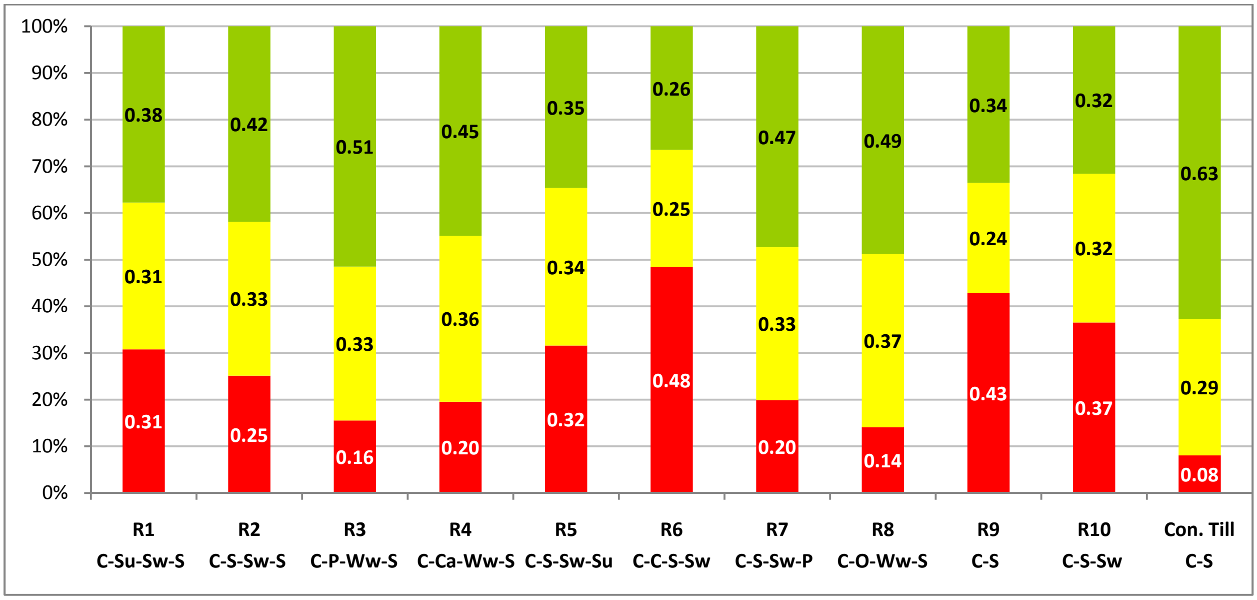

Figure 4: Probabilities of Net Return to Management and Labor Less Than 0 and Greater Than 50,000: Carbon credits **are** figured into percentages.

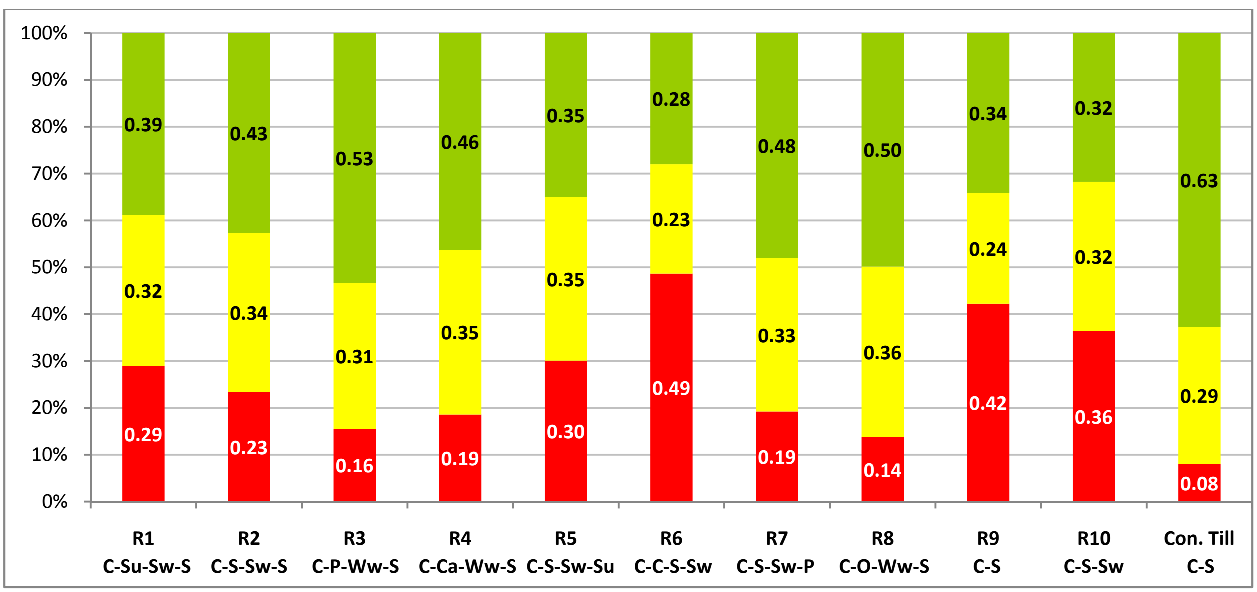

Table 2: Carbon Payment Per Acre Needed to Equalize NT Returns to CT Returns:
(Return to mgt. & labor CT – Return to mgt. & labor NT)/1200

	R1 C-Su-Sw-S	R2 C-S-Sw-S	R3 C-P-Ww-S	R4 C-Ca-Ww-S	R5 C-S-Sw-Su	R6 C-C-S-Sw	R7 C-S-Sw-P	R8 C-O-Ww-S	R9 C-S	R10 C-S-Sw
2001	$ 30.71	$ 23.97	$ (4.51)	$ 8.08	$ 33.58	$ 49.44	$ 5.25	$ 4.91	$ 42.48	$ 39.43
2002	$ 22.21	$ 29.95	$ 4.57	$ 15.08	$ 25.37	$ 47.72	$ 10.34	$ 1.30	$ 54.39	$ 35.38
2003	$ 67.83	$ 51.06	$ 39.68	$ 50.26	$ 70.14	$ 82.47	$ 49.27	$ 57.32	$ 60.40	$ 72.91
2004	$ 10.47	$ 4.98	$ 11.80	$ 8.76	$ 17.56	$ 48.31	$ 9.42	$ 9.27	$ 31.27	$ 26.63
2005	$ 18.76	$ 11.90	$ 9.44	$ 8.01	$ 19.41	$ 42.26	$ 11.01	$ 2.70	$ 42.14	$ 23.81
2006	$ 43.23	$ 44.18	$ 29.93	$ 34.76	$ 47.37	$ 64.15	$ 38.64	$ 24.69	$ 53.30	$ 57.92
2007	$ 65.42	$ 57.26	$ 36.30	$ 55.90	$ 71.68	$ 72.25	$ 28.40	$ 51.81	$ 66.93	$ 76.16
2008	$ 36.18	$ 9.52	$ (8.74)	$ 9.76	$ 40.87	$ 42.82	$ (8.74)	$ 9.24	$ 31.41	$ 38.32
Average	$ 36.85	$ 29.10	$ 14.81	$ 23.83	$ 40.75	$ 56.18	$ 17.95	$ 20.16	$ 47.79	$ 46.32

Table 3: Equivalent Price per Metric Ton on Chicago Climate Exchange:

- NDFU contract specifications

	R1 C-Su-Sw-S	R2 C-S-Sw-S	R3 C-P-Ww-S	R4 C-Ca-Ww-S	R5 C-S-Sw-Su	R6 C-C-S-Sw	R7 C-S-Sw-P	R8 C-O-Ww-S	R9 C-S	R10 C-S-Sw
2001	$ 57.10	$ 44.62	$ (8.12)	$ 15.18	$ 62.40	$ 91.77	$ 9.95	$ 9.32	$ 78.90	$ 73.23
2002	$ 41.36	$ 55.69	$ 8.68	$ 28.14	$ 47.21	$ 88.59	$ 19.37	$ 2.64	$ 100.95	$ 65.74
2003	$ 125.83	$ 94.78	$ 73.70	$ 93.30	$ 130.12	$ 152.95	$ 91.46	$ 106.38	$ 112.08	$ 135.24
2004	$ 19.61	$ 9.44	$ 22.08	$ 16.44	$ 32.75	$ 89.69	$ 17.66	$ 17.38	$ 58.13	$ 49.53
2005	$ 34.96	$ 22.26	$ 17.70	$ 15.06	$ 36.18	$ 78.49	$ 20.62	$ 5.22	$ 78.26	$ 44.32
2006	$ 80.27	$ 82.04	$ 55.65	$ 64.60	$ 87.94	$ 119.01	$ 71.77	$ 45.94	$ 98.93	$ 107.47
2007	$ 121.38	$ 106.27	$ 67.44	$ 103.74	$ 132.97	$ 134.02	$ 52.81	$ 96.17	$ 124.18	$ 141.26
2008	$ 67.21	$ 17.85	$ (15.96)	$ 18.30	$ 75.91	$ 79.51	$ (15.96)	$ 17.34	$ 58.39	$ 71.18
Average	$ 68.46	$ 54.12	$ 27.65	$ 44.34	$ 75.68	$ 104.25	$ 33.46	$ 37.55	$ 88.73	$ 86.00

- Equivalent price on Chicago Climate Exchange needed to obtain carbon credit payments shown in Table 2 given NDFU contract specifications.

Figure 5: Neg. Exponential Utility Weighted Risk Premiums Relative to CT: No Carbon Credits.

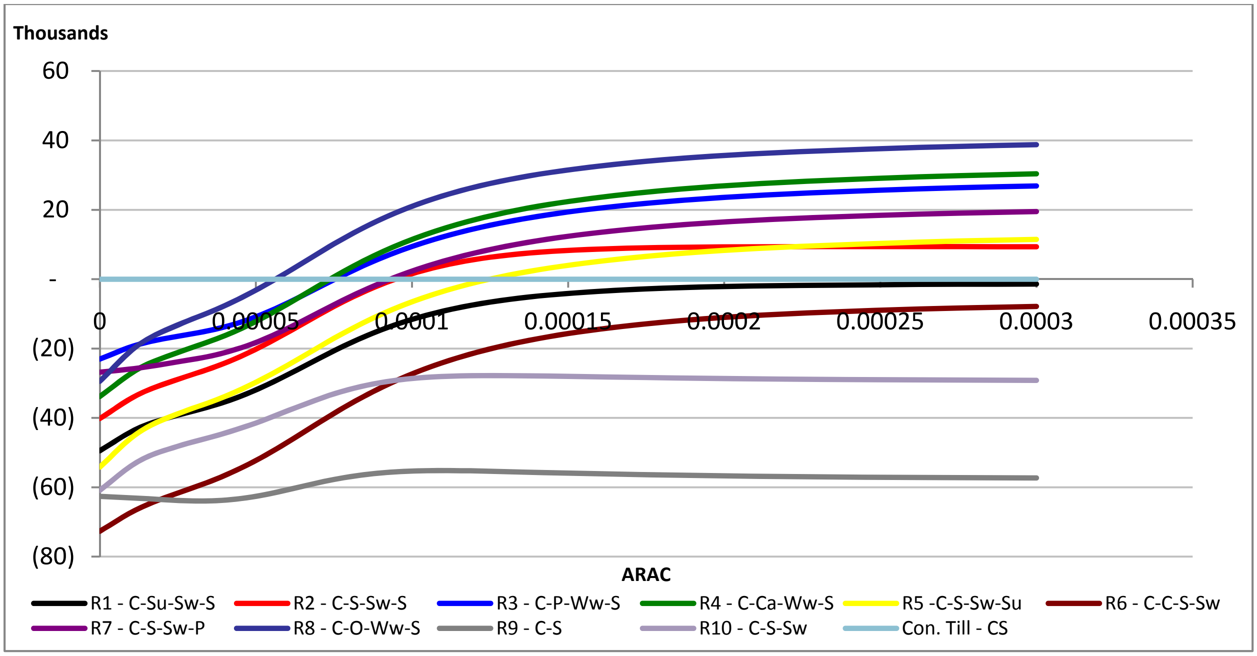

Table 4: Stochastic Efficiency Analysis of Crop Rotation Systems

	Slightly Risk Averse	RAC →							Extremely Risk Averse
Rank	0.00 - 0.0000070	0.0000071 - 0.0000141	0.0000142 - .0000566	0.0000567 - 0.0000707	0.0000708 - 0.0000778	0.0000779 - 0.0000991	0.0000992 - 0.0001274	0.0001275 - 0.0002125	>0.0002125
1st	Con. Till	Con. Till	Con. Till	R8	R8	R8	R8	R8	R8
2nd	R3	R3	R8	Con. Till	Con. Till	R4	R4	R4	R4
3rd	R7	R8	R3	R3	R4	R3	R3	R3	R3
4th	R8	R7	R4	R4	R3	Con. Till	R7	R7	R7
5th	R4	R4	R7	R7	R7	R7	R2	R2	R5
6th	R2	R2	R2	R2	R2	R2	Con. Till	R5	R2
7th	R1	R1	R1	R5	R5	R5	R5	Con. Till	Con. Till
8th	R5	R5	R5	R1	R1	R1	R1	R1	R1
9th	R10	R10	R10	R10	R10	R10	R6	R6	R6
10th	R9	R9	R9	R6	R6	R6	R10	R10	R10
11th	R6	R6	R6	R9	R9	R9	R9	R9	R9

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