An Economic and Risk Analysis of the Effects of Tillage and Nitrogen Source on Soil Carbon Sequestration in Corn Production

Dustin L. Pendell
Graduate Research Assistant
Department of Agricultural Economics
342 Waters Hall
Kansas State University
Manhattan, KS 66506-4011
785-532-6702
dpendell@agecon.ksu.edu

Scott B. Boyles
Former Graduate Research Assistant
Department of Agricultural Economics
342 Waters Hall
Kansas State University
Manhattan, KS 66506-4011
785-532-6702

Jeffery R. Williams
Professor
Department of Agricultural Economics
342 Waters Hall
Kansas State University
Manhattan, KS 66506-4011
785-532-4491
jwilliam@agecon.ksu.edu

Charles W. Rice
Professor
Department of Agronomy
2701 Throckmorton Hall
Kansas State University
Manhattan, KS 66506-5501
785-532-7217
cwrice@ksu.edu

Richard G. Nelson
Director, Engineering Extension Programs
Kansas Industrial Extension Service
133 Ward Hall
Kansas State University
Manhattan, KS 66506-2508
785-532-6026
rnelson@ksu.edu

Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Tulsa, Oklahoma, February 14-18, 2004

Abstract

The economic potential of no-tillage versus conventional tillage to sequester soil carbon using either commercial nitrogen or manure for continuous corn production is evaluated. Results indicate which system provides the highest net returns, which system is preferred by risk averse decision makers, and the price of carbon credits under alternative risk aversion preferences.

Introduction

Sequestering carbon (C) in agricultural soils or plant material to reduce the impact of carbon dioxide emissions (CO_2) can be accomplished by producing more crop biomass within a given time period, reducing or eliminating tillage to maintain or increase soil organic matter, or adding an external source of C to the soil, such as organic fertilization (i.e., manure) (Havlin et al.). More research is needed to improve the understanding of the C sequestration process in agricultural soils and the economic feasibility of adopting alternative cropping, tillage, and fertilizer systems to enhance C sequestration in soil. Little, if any, economic analysis of C sequestration using manure fertilizer as a substitute for commercial fertilizer while accounting for the CO_2 release and change in atmospheric C has been conducted.

Estimated sequestration costs will vary widely due to location, soil type, estimated C uptake, land rental rate, management techniques, and resulting crop yields. Marginal costs of C sequestration rise as forest or agricultural establishment moves from land with low productivity and/or low opportunity costs to areas of higher productivity and/or opportunity costs (Richards). McCarl and Schneider, and Caspers-Simmett estimated that the marginal costs of U.S. agriculture to sequester C were in the range of $9 to $23/metric ton/yr. Antle et al. found, that payments to induce producers from crop/fallow to continuous cropping begin at $4.50/metric ton/yr. and increase to $64/metric ton/yr. as more acres in continuous cropping are desired.

This study examines net returns and risk of continuous corn production using conventional and no-tillage with either ammonium nitrate or manure fertilization to sequester C in soils. The values of C credits needed to adopt practices that sequester C in the soil are derived while accounting for C released from production inputs to the atmosphere. The preferred strategies under various risk preferences were determined using stochastic dominance with respect to a function (SDRF) and certainty equivalent (CE) risk premiums.

Methodology and Data

Yields, input types and rates, and field operations, were obtained from 9 years (1991-1999) of data from a northeastern Kansas experiment station. Annual average C sequestration rates were calculated from 10 years of experiment station soil sample data (1992-2002). Carbon release values (tons of C/ac.) from direct, embodied/indirect, and feedstock 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. Historical yield and price data were used to simulate a distribution of net returns for each strategy using Simetar©, (Richardson). The net return distributions were constructed by simulating empirically correlated yield distributions, multiplying the yield results by a simulated price distribution, and subtracting 2002 costs. The difference in risk between systems is, therefore, due to the difference in yield variability. The values of C credits needed to adopt less-profitable practices that sequester more C were derived.

Study region and Production systems

The North Agronomy Experiment Field at Kansas State University, from which the yield and soils data were obtained, is located in the Kansas River Valley in northeastern Kansas. The landscape is fairly level and consistent with that of a river valley. Average annual precipitation in Riley County during the study period was 32.01 inches. The soil is Kennebec silt loam (fine-silty, mixed, mesic Cumulic Hapludolls).

The production systems studied include the use of either conventional tillage (CT) or no-tillage (NT) with applications of either 75 or 150 lbs. of ammonium nitrate (N) or manure (M). The eight systems studied were as follows:

CT75N	conventional tillage with 75 lbs. N/ac. from NH_4NO_3
NT75N	no-tillage, with 75 lbs. N/ac. from NH_4NO_3
CT75M	conventional tillage, with 75 lbs. N/ac. from manure
NT75M	no-tillage, with 75 lbs. N/ac. from manure
CT150N	conventional tillage, with 150 lbs. N/ac. from NH_4NO_3
NT150N	no-tillage, with 150 lbs. N/ac. from NH_4NO_3
CT150M	conventional tillage, with 150 lbs. N/ac. from manure
NT150M	no-tillage, with 150 lbs. N/ac. from manure

The CT system field operations consisted of disking in the spring, field cultivation prior to planting, row cultivation after planting, and chiseling in the fall after harvest. Ammonium nitrate or manure was applied to the fields shortly after the final disking. Herbicides were applied at the same time and rate to both CT and NT systems in all years. This was done for convenience and ease of application on the experimental plots, rather than necessity (Lamond). Some applications that were determined to have no affect on yield in the CT system due to the use of tillage to control weeds were omitted from the costs and the calculation of C emissions (Lamond). Therefore, herbicide costs in the CT system are smaller. The NT systems did not have any tillage operations.

Fertilizer treatments were either 75 lbs. or 150 lbs./ac. of ammonium nitrate, or 75 or 150 lbs./ac. of N equivalent beef manure. The nine-year average application rate for manure was 8.75 tons/ac. for the 75/lbs./N equivalent treatment and 17.5 tons/ac. for the 150 lbs. treatment.

Prices, Yields, and Costs

Northeastern Kansas's average annual corn prices from the United States Department of Agriculture (USDA), for the period of 1991-1999, were used to form an empirical price distribution to simulate the net return distributions. The average price of this distribution was \$2.51/bu. and the standard deviation was \$0.48/bu. Yields from the experiment station were used for simulating correlated empirical yield distributions. Table 1 provides a summary of yields. The difference between the actual average yield and the mean of the simulated distributions were 0.5 bu./ac. or less and the standard deviations were 1.6 bu./ac. or less. The mean and standard deviation of the simulated price distribution was equal to the actual average price statistics. Custom rates obtained from Beaton were used for costs for each field operation. Custom rates for manure application were obtained from custom applicators (Bar Six Construction; Jones Construction). Prices for seed, ammonium nitrate and the herbicides were obtained from input dealers and Kansas State University.

Soil carbon data

Carbon data for the top 12 inches (30 cm) of the soil in the experiment was obtained by soil tests of organic carbon content taken post harvest in 1992 and again in 2002 rather than 1999 because there were no 1999 soil samples for 75 lbs. treatments. The annual average soil C changes are reported in Table 1. Refer to Williams, et al. for additional detail on the methodology used to calculate the soil carbon change.

Carbon release from production inputs

Carbon in the form of CO_2 is also released into the atmosphere from direct energy use such as the combustion of diesel used in field operations. In addition, there are C releases associated with energy used in the production of fertilizers and other chemicals which are inputs in the crop production system. Carbon release values from direct, embodied/indirect, and feedstock energy for the fertilizers and chemicals applied were estimated using data from Bowers and a procedure described by Williams, et al. and are reported in Table 1.

Carbon credits

Equation [1] was used to determine the dollar value of C required to make a system which sequesters more C but has lower net returns, economically equivalent to a system with higher returns that sequesters less C. The dollar value of C would be the incentive ($/ton of C/yr.) a manager would need to be indifferent between production systems.

C Value to make NR_j equivalent to $NR_i = (NR_i - NR_j)/(C\ Rate_j - C\ Rate_i)$ [1]

Where:

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

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

$C\ Rate_j - C\ Rate_i$ = difference in C sequestration rates (tons/ac./yr.) for systems j and i

Results and Analysis

The average net return to land and management was positive for all systems (Table 1). No-tillage systems had higher net returns than CT systems for all fertilization strategies. This result occurred largely because herbicide costs were only slightly higher for NT systems, but field operation costs were substantially less than those in the CT systems. The difference in herbicide cost was very small due to light weed populations in the NT systems. Yield differences were relatively small between CT and NT systems. Ammonium nitrate systems had higher net returns compared to manure fertilized systems. This was largely due to substantially higher yields from ammonium nitrate systems because costs for using manure as a fertilizer source were actually smaller than for ammonium nitrate.

Soil carbon and net carbon sequestration

The NT systems had higher annual soil C gains than CT (Table 1). The highest C gain was in the NT150M system at 1.19 tons C/ac./yr. The next highest gain in soil C was for NT150N, at 1.13 tons C/ac./yr. CT75N had the lowest rate of gain at 0.52 tons C/ac./yr.

In this study, C equivalent emissions from direct energy use were highest for the CT systems due to greater trips over the field, while embodied emissions were highest for the NT systems due to the use of more manufactured inputs. Overall, C emissions were highest for the CT systems (Table 1). Once again, this is primarily due to substantially more tillage in the CT systems, hence significant C emissions from diesel fuel.

The net rate of C sequestration for NT relative to CT systems increased when C emissions were considered because they had fewer C emissions. NT150M had the highest net sequestration rate and CT75N had the lowest (Table 1).

Derived carbon credits

The derived C credit values for all technically feasible system comparisons are reported in Table 2 and indicate that there is a substantial range in C credit values. The values in Table 2 where a NT system row intersects with a CT system column are frequently negative (blocked with solid line). These negatives indicate that the NT system not only sequesters more C, but also has higher net return than the CT system it is being compared to. These results indicate that for the same level of fertilizer application the NT system is preferred to the CT system. There are two cases where the NT system does not sequester as much C as a CT system leading to an NA result; NT75N versus CT150M and NT75M versus CT150M. In these cases, the lower sequestration rate of the NT system was due to lower fertilizer use. Therefore, there are some cases where higher fertilizer use in a conventional tillage system is better than lower fertilizer use in a no-tillage system.

The values in Table 2 where an M system row intersects with an N system column are frequently positive (blocked with dashed line). The positives indicate that the manure fertilized system would need a C credit to be economically equivalent to the ammonium nitrate fertilized system. It also indicates that for the same tillage type ammonium nitrate is preferred. In some cases a lower amount of ammonium nitrate is preferred to the use of manure; CT75N versus CT150M, and NT75N versus NT150M.

There are also situations where NT with ammonium nitrate is preferred to CT with manure; NT75N versus CT75M, and NT150N versus CT150M (solid underline in Table 2). Two situations exist where NT with a lower fertilizer rate is preferred to CT with a higher fertilizer rate; NT75N versus CT150N, and NT75M versus CT150N (dashed underline in Table 2).

Carbon credits were also derived without accounting for carbon in the CO_2 emissions from production of inputs and energy used in the cropping systems. When these results are compared to the credits derived for changing from ammonium nitrate systems to manure fertilizer systems (dashed blocks in Table 2), the value of the carbon credit increases by $1.85/ton/yr. ($34.29 to $36.14) for CT150M vs. CT150N to as much as $133/ton/yr. ($339 to $472) for NT150M vs. NT150N. The necessary credit increases because the relative difference in net sequestration declines for the M systems relative to the N systems. Therefore, the dollar value per ton of C sequestered increases.

Although a carbon credit is not necessary to use NT systems instead of CT systems (solid blocks in Table 2), the reader is reminded that these negatives are the penalty an NT system in the row would need to be equivalent to a CT system in a column. The increase in penalties range from $1.04/ton/yr. ($-71.08 to $-72.12) for NT150N vs. CT150N to $19.83/ton/yr. ($-235.80 to $-255.63) for NT150M vs. CT150M. Again, this increase is caused by the relatively larger decline in net sequestration in NT systems than CT systems.

These results indicate the range in carbon credit changes is large. This change is dependent on the relative differences in the net sequestration rates between systems.

Risk analysis

Although, examining average net return is useful, it is also important to examine the net return variation and preference for production systems under alternative risk preferences. SDRF was used to select the best strategies for producers with various risk preferences. Stochastic dominance uses risk aversion coefficients (RACs) defined by Pratt as, $r(x) = -u''(x)/u'(x)$, which represents the ratio of derivatives of the decision maker's utility function, $u(x)$. In this case, an exponential function was assumed. Risk preference intervals bounded by lower and upper risk RACs, $r_1(x)$ and $r_2(x)$ can be used to define risk preference and make inferences about how different decision makers might rank the different strategies given these risk aversion preferences. The simulated net return data for each strategy was sorted into cumulative distribution functions (CDFs) which are used in the SDRF analysis (Figure 1).

The upper and lower RACs for SDRF were initially determined by converting suggested whole farm RACs for a typical size farm in northeast Kansas to per acre RACs. This conversion was done by implementing the procedure suggested by Raskin and Cochran which involves multiplying the higher RAC value suggested for a whole farm from previous literature of 0.00001 by 775.6 acres which is the typical size farm in northeast Kansas. The initial risk aversion interval ranged from 0.00 to 0.00776. This range was divided into several segments until the preferred rank of strategies within each interval was different. This was done by using an option in Simetar© that calculates the RACs where the ranking of the strategies change. The final RACs ranged from 0.00 to 0.0406. For RACs above 0.0406 the preference ranking did not change. Decision makers with risk neutral behavior would exhibit a RAC of 0.00. Those above this range would exhibit more risk averse behavior (the greater the RAC the more risk averse).

For the slightly risk averse manager NT150N was selected as the most preferred system (Table 3). As the degree of risk aversion increases the NT75N system is preferred to the NT150N system. The NT75M and NT150M systems are always the third and fourth most preferred system, respectively. The ranking of the CT systems change as risk aversion increase, but none are ever more than fifth in rank. For the CT system the ones using manure move up in rank as risk aversion increases.

Simetar© was also used to calculate CEs for all eight strategies for 25 RACs ranging from 0.00 to 0.05 (Figure 2). Figure 2 reveals that NT150N is the preferred system when the RAC is between 0.00 and 0.0208, but when the RAC increases above 0.0208, NT75N is the preferred system. At the point where two lines cross, a decision maker is indifferent between the two strategies. These results are consistent with the stochastic dominance analysis. The reader should note that 0.0208 is a higher RAC than is suggested by previous literature so there is some reason to believe that managers may not be as risk averse as the analysis assumes. However, RACs higher than the suggested 0.00776 value are used to indicate how the rankings change under increased risk aversion.

The CE option in Simetar© also has the option to derive risk premiums. The procedure compares the absolute differences in the CEs for a base strategy (NT75N in this case) to the seven other strategies for each RAC. When the decision maker is risk neutral, the RAC is 0.00 and NT150N is preferred to NT75N and all other strategies. The risk premium in this case is $9.80/ac. which indicates the risk neutral manager would need to receive $9.80/ac. (the difference in net return between NT150N and NT75N) to use NT75N instead of NT150N or would pay up to $9.80 not to use NT75N. For a risk neutral decision maker the risk premium is the difference between the mean net returns of the two compared strategies. As indicated in Figure 2, NT150N is the preferred system until the RAC is approximately 0.0229. At 0.0229 a risk averse decision maker ranks NT75N as the preferred system while NT150N is second. The decision maker would need to be paid slightly greater than $0.65/ac. to use NT150N rather than NT75N at this RAC or would pay up to $0.65/ac. not to switch from NT75N to NT150N. The risk premiums to use NT150N versus NT75N increase as the RAC increases and range from $0.00 at a RAC of 0.0208 to $0.65/ac. at 0.0229, to $4.75/ac. at 0.04 (Figure 3). This result indicates more risk averse producers may prefer a system that sequesters less C, therefore, a C credit to induce the use of a system that generates more C and is more profitable, but is more risky at the same time may be needed. If the risk premium is $0.65/ac. for NT75N versus NT150N, the carbon credit needed is equal to ($0.65/ac.)/(1.0685/tons/ac./yr. for NT150N - 0.6803tons/ac./yr. for NT75N) or $1.67/ton/ac./yr. If the premium is $4.75/ac. for NT75N versus NT150N, the C credit is equal to ($4.75/ac.)/(1.0685ton/ac./yr. - 0.6803/ton/ac./yr.) or $12.24/ton/ac./yr.

Summary and Implications

The manure-fertilized systems had lower net returns but higher sequestration rates than the ammonium nitrate fertilized systems. Therefore, some incentive would be required to entice producers to adopt the use of manure as a means of sequestering C. No-tillage systems had the highest net returns and highest sequestration rates. Therefore, a C credit is not needed to entice producers to adopt NT as a means of sequestering C under risk neutrality or when risk preference was considered. No-tillage systems were always preferred to CT. However, because NT75N was preferred by more risk averse managers to NT150N which sequestered more C than NT75N a C credit would be required for more risk averse managers. This credit would range upward from $1.67/ton/ac./yr.

References

Antle, J., S. Capalbo, S. Mooney, E. Elliot, and K. Paustian. "Economics of Agricultural Carbon Sequestration in the Northern Plains." Research Discussion Paper No. 38 Department of Agricultural Economics and Economics, Montana State University: Bozeman, MT. 2002.

Bar Six Construction. Personal Communication. Custom Manure applicator, June 2002.

Beaton, A.J. "Per Unit Costs to Own and Operate Farm Machinery on Kansas Farms." Unpublished M.S. Thesis, Department of Agricultural Economics, Kansas State University, Manhattan, KS. April 2003.

Bowers, W. "Agricultural Field Equipment." In Energy in World Agriculture, R.C., Fluck. ed. Elsevier Publishers, NY. 1992.

Caspers-Simmet, J. Carbon Credits: A New Crop for Grain Producers. *Agri-Marketing*. December 2, 1999.

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

Jones Construction. Personal Communication. Custom manure applicator, June 2002.

Kansas State University. "Chemical Weed Control for Field Crops, Pasture, Rangeland, and Noncropland." Manhattan, Kansas. 2002.

Lamond, R. Department of Agronomy, Kansas State University. Personal communication, March 2002.

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

Pratt, J.W. "Risk Aversion in the Small and in the Large." Econometrica 32(1964):122-36.

Raskin, R. and M.J. Cochran. "Interpretations and Transformations of Scale for the Pratt-Arrow Absolute Risk Aversion Coefficient: Implications for Generalized Stochastic Dominance." *West. J. Agr. Econ.* 11(1986):204-10.

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

Richardson, J.W. "Simulation For Applied Risk Management with an Introduction to the Software Package SIMETAR©: Simulation for Excel to Analyze Risk. Department of Agricultural Economics, Texas A&M University. January 2003.

Williams, J.R., R.G. Nelson, M.M. Claassen, and C.W. Rice. "Carbon Sequestration in Soil with Consideration of CO_2 Emissions from Production Inputs: An Economic Analysis." *Environmental Management.* December, 2003.

Acknowledgements

This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, Under Agreement No. 2001-38700-11092. Any opinions, findings, conclusions, or recommendations expressed are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

Table 1. Yield, economic, and sequestration characteristics for each corn production system.

	System[1]							
	CT75N	NT75N	CT75M	NT75M	CT150N	NT150N	CT150M	NT150M
Mean Yield[2]	78.5	75.7	68.8	69.2	85.8	87.6	77.9	74.3
Std. Dev Yield[2]	25.8	24.8	23.5	28.9	26.1	26.9	25.6	24.4
Total costs[3]	157.11	127.16	152.38	122.83	176.29	146.92	173.33	143.27
Gross return[3]	196.96	190.07	172.67	173.59	215.47	219.90	195.60	186.56
Net Return[3]	39.89	63.48	20.30	51.43	39.19	73.28	22.86	44.04
Soil Carbon[4]	0.5172	0.7193	0.6237	0.7501	0.6547	1.1274	1.1066	1.1894
Emissions[5]	0.0460	0.0391	0.0339	0.0269	0.0659	0.0589	0.0416	0.0346
Net Carbon[6]	0.4712	0.6803	0.5898	0.7232	0.5889	1.0685	1.0650	1.1548

[1] CT75N conventional tillage, with 75 lbs. N per ac. from NH_4NO_3
NT75N no-tillage, with 75 lbs. N per ac. from NH_4NO_3
CT75M conventional tillage, with 75 lbs. N per ac. from manure
NT75M no-tillage, with 75 lbs. N per ac. from manure
CT150N conventional tillage, with 150 lbs. N per ac. from NH_4NO_3
NT150N no-tillage, with 150 lbs. N per ac. from NH_4NO_3
CT150M conventional tillage, with 150 lbs. N per ac. from manure
NT150M no-tillage, with 150 lbs. N per ac. from manure

[2] bu./ac.

[3] $/ac.

[4] Carbon sequestered in the soil excluding C emissions adjustment (tons/ac./yr.).

[5] C emissions from production inputs (tons/ac./yr.).

[6] Carbon sequestered including C emissions and adjustments (tons/ac./yr.).

Table 2. Carbon credit required for net return equivalency between systems ($/ton/yr.)[1]

			System[4]							
System	Net[2] Return	Net[3] Carbon	CT75N	NT75N	CT75M	NT75M	CT150N	NT150N	CT150M	NT150M
CT75N	39.89	0.4712	-	NA	NA	NA	NA	NA	NA	NA
NT75N	63.48	0.6803	-$112.84	-	-$477.59	NA	-$265.82	NA	NA	NA
CT75M	20.30	0.5898	$165.20	NA	-	NA	$19,396.92	NA	NA	NA
NT75M	51.43	0.7232	-$45.79	$280.46	-$233.43	-	-$91.15	NA	NA	NA
CT150N	39.19	0.5889	$6.01	NA	NA	NA	-	NA	NA	NA
NT150N	73.28	1.0685	-$55.89	-$25.23	-$110.68	-$63.27	-$71.08	-	-$14,259.34	NA
CT150M	22.86	1.0650	$28.69	$105.59	-$5.39	$83.61	$34.29	NA	-	NA
NT150M	44.04	1.1548	-$6.06	$40.98	-$42.02	$17.14	-$8.57	$338.93	-$235.80	-

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

[2] $/ac.

[3] tons/ac./yr.

[4] Refer to Table 1 for an explanation of the production systems.

Table 3. Stochastic dominance analysis results

	Risk preference category[1]							
Preferred Rank	Very Slight Risk Averse	Slightly Risk Averse	Very Moderate Risk Averse	Moderately Risk Averse	Very Risk Averse	Strongly Risk Averse	Very Strong Risk Averse	Extremely Risk Averse
1st	NT150N[2]	NT150N	NT75N	NT75N	NT75N	NT75N	NT75N	NT75N
2nd	NT75N	NT75N	NT150N	NT150N	NT150N	NT150N	NT150N	NT150N
3rd	NT75M	NT75M	NT75M	NT75M	NT75M	NT75M	NT75M	NT75M
4th	NT150M	NT150M	NT150M	NT150M	NT150M	NT150M	NT150M	NT150M
5th	CT75N	CT75N	CT75N	CT75N	CT75N	CT75M	CT75M	CT150M
6th	CT150N	CT150N	CT150N	CT75M	CT75M	CT75N	CT150M	CT75M
7th	CT150M	CT75M	CT75M	CT150N	CT150M	CT150M	CT75N	CT75N
8th	CT75M	CT150M	CT150M	CT150M	CT150N	CT150N	CT150N	CT150N

[1] The intervals used for the risk analysis are: very slight risk averse = 0 to 0.0077, slightly risk averse = 0.0078 to 0.0209, very moderate risk averse = 0.021 to 0.0314, moderately risk averse = 0.03145 to 0.03223, very risk averse = 0.03224 to 0.03383, strongly risk averse=0.03384 to 0.0344, very strong risk averse = 0.0345 to 0.0405, extremely risk averse = 0.0406 to 0.05.

[2] Refer to Table 1 for an explanation of the production systems.

Figure 1. CDF of the net returns.

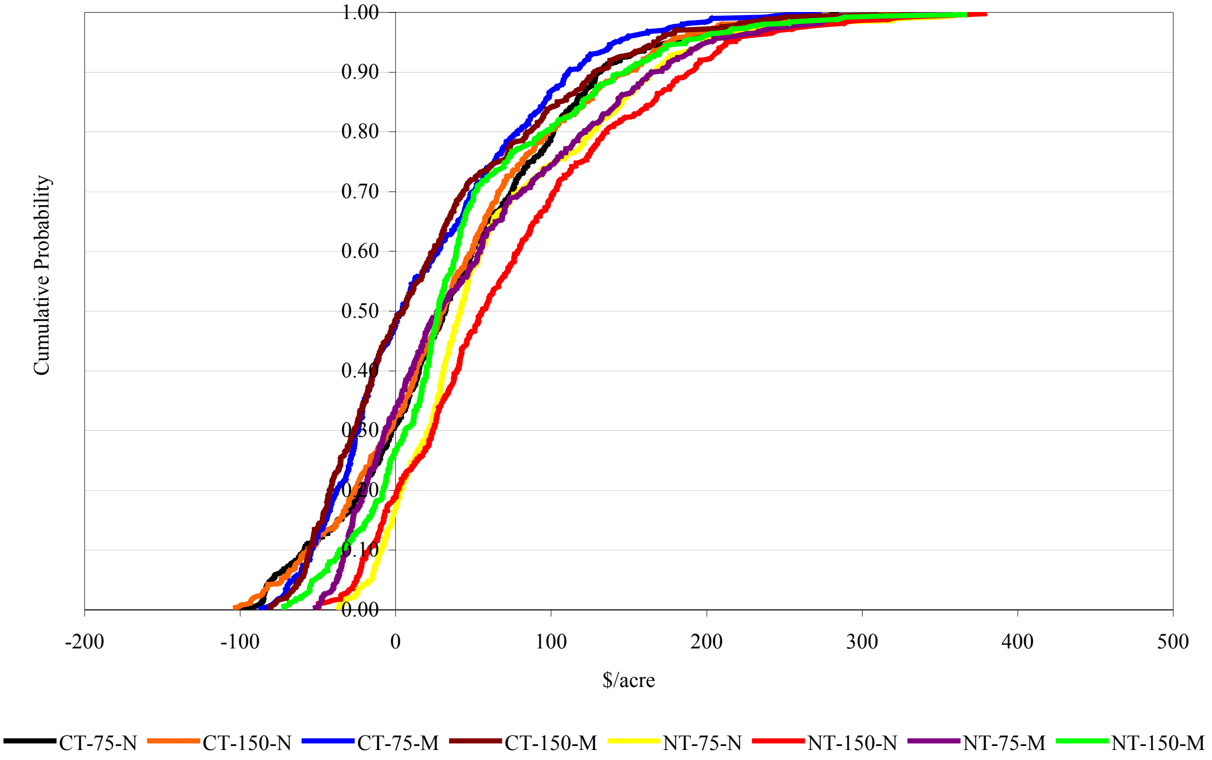

Figure 2. Certainty equivalents under an exponential utility function.

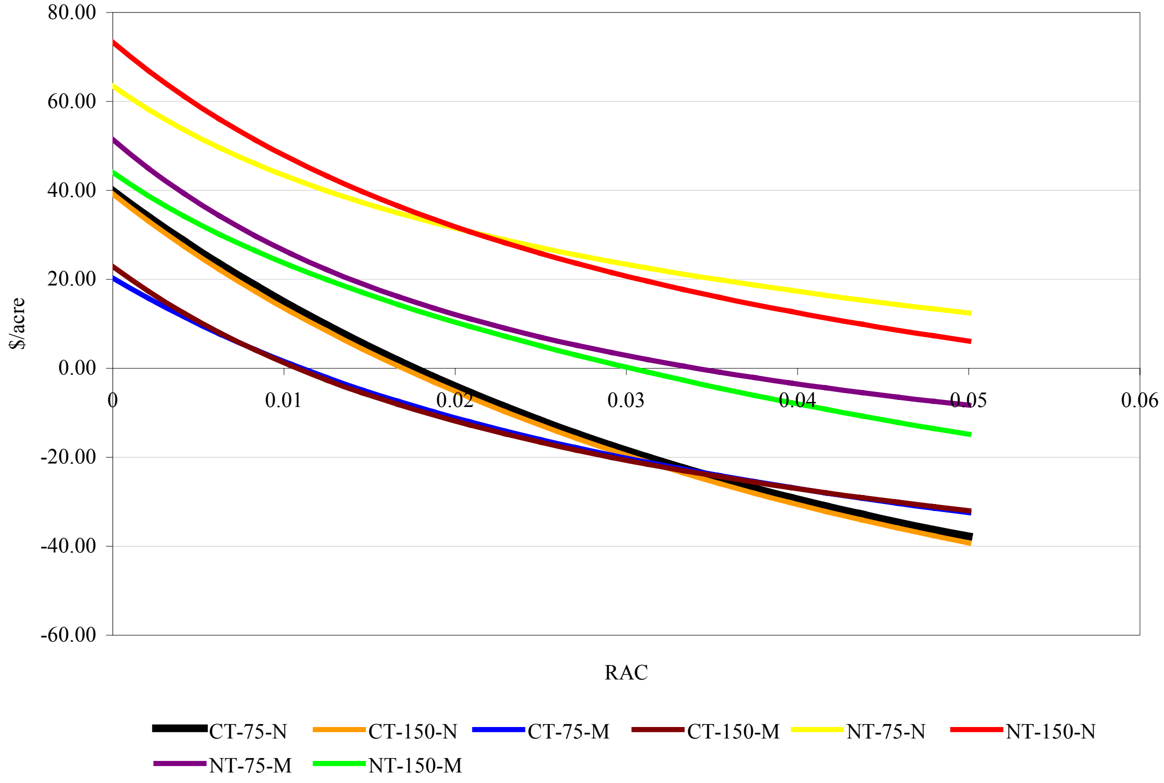

Figure 3. Absolute certainty equivalent risk premiums under an exponential utility function relative to NT75N.