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Agricultural Land And Energy Use Implications Of Changes In Energy Prices

Stephen Michael Randall
North Carolina Agricultural and Technical State University

Agricultural Land and Energy Use Implications

of Changes in Energy Prices

Stephen Michael Randall

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Stephen Michael Randall

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Approved by:

Lyubov Kurkalova, Ph.D. Major Professor	Mark Burkey, Ph.D. Committee Member
Stephen Holland, Ph.D. Committee Member	Robert Powell Committee Member
Keith Schimmel, Ph.D. Department Chairperson	Sanjiv Sarin, Ph.D. Associate Vice Chancellor for Research and Graduate Dean

Dedication

This dissertation is dedicated to my son Soren James Blue. He has sacrificed more than anyone to allow me the time to complete this work. Hopefully through this he will learn the value of education, of persistence, and of pursuing your goals. Hopefully, he will forgive me for the times that I could not be there to play with him on all those Saturday afternoons. He has changed my life in wonderful ways.

Biographical Sketch

Stephen Randall was born on March 9, 1964 in Providence, RI. He received a Bachelor of Science degree in Mathematics in 1986 from Bates College, a Master of Science degree in Energy Management & Policy in 1992 from the University of Pennsylvania, and a Master of Business Administration in 2005 from the University of North Carolina at Greensboro. He is a candidate for the Ph.D. in Energy & Environmental Science and Economics.

While pursuing this degree he has won the Woodland Ellroy Hall Graduate Assistantship, the Department of Energy's Savannah River Site Scholarship, the North Carolina A&T State University 4.0 Scholars Award, and North Carolina Beautiful's Governor & Mrs. Dan K. Moore Fellowship.

Since November 2008 he has been the Energy & Sustainability Manager for the City of Greensboro, North Carolina. He has served in various managerial roles in the commercial and institutional energy efficiency industry for the past 20 years. He served five years as a high school mathematics teacher including one year in Cochabamba, Bolivia.

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I would like to thank my parents Ray & Carol Randall for teaching us all the value of education and the meaning of public service, my brother Tom who has always been my role model, my sister Karen who has always inspired me, my brother David who has always challenged me, and my grandfather Frederic Oscar Sorensen who was always there for me. I would like to acknowledge John Menzies, Jim Oates, and Pete Mulvihill who have always stood by me.

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Nomenclature

CC	Continuous Corn Rotation
CCS	Corn - Corn - Soy Rotation
CME	Chicago Mercantile Exchange
CRP	Conservation Reserve Program
CS	Corn - Soy Rotation
CSR	Corn Suitability Rating
HEL	Highly Erodible Land

Abstract

Field level farm management decisions such as crop rotation, tillage, and nitrogen application are impacted by the energy and other input costs, by the land quality, and by the anticipated grain prices. These decisions can significantly impact the acres planted, the yield, and the crop production, as well as both the fertilizer and energy use.

This study develops an Excel based profit-maximizing optimization model for these farm management decisions, all varying by the field level Corn Suitability Rating land quality indicator for the agricultural land in the State of Iowa. The model developed for this analysis incorporates production costs, production yield impacts, the anticipated crop revenue, and profit at all land quality levels in production.

This analysis identified a general trend towards less intensive rotations, tillage, and nitrogen levels as fuel prices increase. The results of the study estimate that the state-level elasticity of corn production to the price of diesel is -0.294, and for soybeans the estimate is 0.269. Corn production decreases in response to higher diesel prices because fewer acres are included in corn production. Soybean production increases because of an increase in the acres of soybeans planted.

However, these impacts are not spatially uniform due to varying land quality. Within the model, changes in energy prices impacted these farm management decisions distinctly unevenly throughout the range of the land quality. Clear trends emerged as changes that impacted lower land quality at lower price levels progressed through to the higher land quality as the price continued to rise.

CHAPTER 1

Introduction

This analysis estimates changes in field level farm management decisions for crop rotations, tillage choice, and nitrogen application levels based on field level agricultural land quality in the State of Iowa for a range of potential fuel and crop prices. These decisions can significantly impact the acres planted, the yield, and the crop production of both corn and soy, as well as both the nitrogen fertilizer and the production energy use.

This analysis utilizes an Excel based profit-maximizing optimization model for the farm management decisions. The calculations are based upon the field level Corn Suitability Rating (CSR) land quality indicator for the agricultural land in the State of Iowa. By incorporating field level land quality into the analysis, the present study improves upon previous work that was based upon aggregated state level analysis. This approach not only has the potential to estimate better state level results by estimating field-level results rather than estimating results based on average state conditions, but can also help to identify both the mechanisms of the change, and the potential regional/spatial differences in response to the changes in energy prices and the resulting farm management decisions.

This analysis reveals a general trend towards less intensive crop rotations, tillage options, and nitrogen application levels as fuel prices increase. Within the model, rising energy prices impact these farm management decisions distinctly unevenly throughout the range of the land quality. Clear trends emerged as changes that impacted lower land quality at lower price levels progress through to the higher land quality as the price continues to rise. A small increase in the price of diesel for example may have negligible impacts on the majority of the acres, but will substantially change a small percentage of selected acres based on CSR at a tipping point from one rotation or tillage choice to another.

1.1. Why is this Topic Important?

While energy prices fluctuate, there is an historical trend towards rising energy prices that is generally expected to continue in the foreseeable future. Rising energy prices are considered likely to increase the use of conservation tillage and decrease nitrogen application levels (Werblow, 2005; Daberkow et al., 2007) although the magnitude of the response is unknown. This also does not account for other potential responses such as changes in crop rotation.

Energy prices along with other input costs, soil quality, and expected grain prices significantly impact farm management practices, which are chosen primarily to maximize individual farm profits. Field level farm management decisions such as tillage choice, crop rotation, and nitrogen application levels can significantly impact the acres planted per crop, the average yield per crop, the overall grain production by crop, and the total nitrogen and energy use in grain production.

The primary purpose of this analysis is to assess the potential changes in compositional patterns of farm management decisions based on changes in energy prices in the State of Iowa. An understanding of the possible impacts on state level grain crop production, nitrogen and energy use based on changes in the price of fuels is important for forecasting, planning and policy making at the local, state and national levels. An understanding of the underlying location-specific mechanisms of the changes has even more potential value. As the environmental impacts of crop production are often soil, climate, topography, and management practice specific, an understanding of the nitrogen application at the local level could inform local, state and national planners of potential environmental down-stream implications of nitrogen run-off into the local watershed.

In addition to the analysis of energy price changes presented here, the modeling system developed in this study has the potential to assess other economic and policy implications such as potential subsidy strategies and costs for reducing tillage intensity in the Highly Erodible Land (HEL) acres that account for approximately 29% of the agricultural land in Iowa. Such future analysis could help target appropriate subsidy levels and regions for additional monitoring based on the cost of compliance with reduced tillage requirements.

1.2. Research Questions

1.2.1. What are the land use implications of changes in energy prices? The agricultural land use implications quantified in this analysis include: Acres planted by crop and tillage, yield by crop, and production by crop. The study uses the model developed to estimate the price of diesel elasticities of state-total crop acreage, yield, and production; and to describe the changes by land quality.

1.2.2. What are the energy use implications of changes in energy prices? The agricultural energy use implications quantified in this analysis are the diesel use and the nitrogen use in crop production at the various fuel prices, both by land quality and for the state as a whole.

CHAPTER 2

Literature Review

This chapter reviews the principle sources that summarize the current knowledge on the impact of the changes in energy prices on land and energy use in corn-soybean production systems and the studies that contributed to the economic model developed for this analysis. The major limitations of previous analysis on the impact of changes in energy prices are the relative age of the majority of the previous work, failing to account sufficiently for the possibility of substitutions, and the aggregate nature of the data for the previous analysis.

The simulation model of farmers' choices of rotation, tillage, and nitrogen fertilizer application developed in the present study accounts for the production costs, and the yield impacts based on the farm management decisions of tillage choice, crop rotation, and nitrogen application level, all by soil quality.

2.1. Impacts of Changes in the Energy Prices

The major limitations of the previous analysis on the impact of changes in energy prices are the relative age of the majority of the previous work which no longer represent the current technology, failing to account sufficiently for the possibility of input and output substitutions, and the aggregate nature of the previous analysis which did not fully account for the heterogeneity of production conditions.

The agricultural production process has changed significantly as a result of the energy crisis in the late seventies outdating the results of many of the early detailed work from that time frame including: Kliebenstein and Chavas, 1977; Kliebenstein and McCamley, 1983; Zinser et al., 1985; Tewari and Kulshreshtha, 1988; Uri and Herbert, 1992. The major preharvest equipment has shifted from small, single function, gas powered equipment to larger, multi-function, diesel powered equipment.

Further, changes in tillage practices, the energy intensity of fertilizers, improvements in seeds, and pest management requirements have impacted production costs and traditional crop rotation choices (Uri and Day, 1992; Chen et al., 2001; Collins and Duffield, 2005; Miranowski, 2005; De Bruin and Pedersen, 2009). In addition, the rate of growth in yield has varied significantly by crop and region impacting the relative profitability and trade-offs between crop rotation choices (Egli,2008; Malone et al., 2009) based on changes in energy prices and so the results of previous studies may no longer be valid.

Although previous models have incorporated potential multiple input and output choices for crop rotation, tillage choice, fuel and fertilizer, (Kliebenstein and Chavas, 1977; Kliebenstein and McCampley, 1983; Zinser et al., 1985) none have incorporated all these choices together. This analysis combines all these choices and increases the flexibility of the nitrogen application in the model from the fixed levels of most previous models (Kliebenstein and Chavas, 1977; Kliebenstein and McCampley, 1983) to a profit maximizing level by continuous increments.

Finally this analysis builds on past studies that typically selected regionally representative homogeneous plots (Kliebenstein and Chavas, 1977; Kliebenstein and McCampley, 1983; Zinser et al., 1985; Uri and Herbert, 1992; Raulston et al., 2005) by incorporating the regionally diverse heterogeneity of natural resources and growing conditions by incorporating land quality as an integral component of the model. Previous studies that utilized regionally aggregated data are limited by the measurement error associated with aggregated prices, yields, quantities, and farm management decisions across crops and diverse regional production conditions and inputs (Uri and Herbert, 1992).

Without adequate data to perform econometric estimation this analysis is based on a deterministic model to simulate farm management decisions at each land quality level based on varying assumptions regarding potential exogenous energy and crop prices.

2.2. Production Costs

Duffy and Smith (2009) maintain the Iowa State University, Agricultural Extension Ag Decision Maker (http://www.extension.iastate.edu/agdm/). This widely-used, broad based agricultural production cost model captures all the major production costs including pre-harvest and harvest machinery, seeds, fuels, chemicals, labor and land. The Ag Decision Maker Excel-based accounting model assumes typical machinery and fertilizer use in computation of the costs. Farmers can also populate the model with the farm-specific information on the use of production inputs for estimation of farm-specific costs of production. The present study adapts the (Duffy & Smith, 2009) cost accounting scheme in the development of a comprehensive Iowa agricultural land use model that accounts for varying land quality.

2.3. Tillage Choice Impacts

Since both conventional and conservation tillage could be accomplished in multiple ways, and many agronomic studies evaluated more than one form of conventional and/or conservation tillage in order to consolidate the results from the five selected recent regional studies we had to define conventional verses conservation tillage for each site. For this analysis conventional tillage is defined as the use of moldboard or chisel plow, or for the Vetsch & Randall study where they identified the tillage as conventional. No-till were all identified by the study authors. All other tillage choices were included as some degree of conservation tillage.

Tillage choice impacts grain yield and the extent of this impact depends upon the crop and the rotation. Vetch & Randall (2002) used data from controlled field experiments in southeastern Minnesota to quantify these interrelated impacts. The study found that in a four year average for corn following corn the no-till yield was 6.7% lower than for conventional tillage. However, "In corn following soybean, tillage system did not significantly affect corn grain yields when averaged across years." (Vetch & Randall, 2002)

In 2004 Al-Kaisi & Yin identified similar results in a study at five experimental sites in Iowa. "In general, a yield decline with NT compared with other tillage systems was within 5% for a corn-soybean rotation, but often greater in continuous corn." (Al-Kaisi & Yin, 2004) Further in this time response study (1978 – 2001) of seven tillage options, the tillage yield difference was robust over time and concluded that the "Differences in both corn yield and economic return between NT and other tillage systems did not change markedly with time." (Al-Kaisi & Yin, 2004)

Wilhelm and Wortmann (2004) found that the mean yields of corn following corn, corn following soy, and soy following corn were all reduced for no-till compared to other tillage systems. These reductions for no-till compared to conventional tillage were the largest for corn following corn at 8.3%, corn following soy at 2.5%, and soy following corn at 2.5%.

2.4. Crop Rotation and Nitrogen Application Impacts

The foundations of the model developed for this analysis are primarily rooted in the Secchi et al. (2009) model for land quality, and the Hennessy (2006) model for crop rotation and nitrogen yield impacts. It is a comprehensive model of the impacts of changes in the price of energy on agricultural land and energy use in the State of Iowa.

In the recent analysis of data for crop rotation choices and the impact of those choices on yield and nitrogen requirements for experimental plots in northeastern Iowa, Hennessey (2006) identified a "one-year memory" for corn and a "two-year memory" for soybeans for impacts based on the previous crop. The study found that corn yield and nitrogen requirements varied by the previous crop, but not by any crops prior to the immediate previous crop. Thus corn following soy differed from corn following corn, but corn following one year of corn did not differ from corn following two years of corn. However, Hennessy (2006) found that soy following two-years of corn had a greater yield than soy following only one year of corn.

Zinser et al. (1985) created an early model that tried to incorporate differences in soil characteristics including type and slope. Nine representative farms were defined based on these characteristics and linear programming sub-models were developed to analyze annual sales and production costs for each representative farm. Their results illustrated “the need to consider relative input price adjustments in the design of environmental policy” (Zinser et al., 1985).

Secchi et al. (2009) introduced a comprehensive model for the State of Iowa that accounted for the variation in land quality and used it to model the farmers’ choices between cropping land and retiring it in the Conservation Reserve Program (CRP). Modifications of this model have been used in Kurkalova et al. (2009, 2010) and Secchi et al. (2011) to study the changes in Iowa crop rotations attributable to the increases in relative corn prices. These models were not well suitable for explicit modeling of the impact of changing energy prices because state-average rates of fertilizer applications were assumed on all land regardless of quality.

The Secchi et al. (2009) model developed the comprehensive accounting method for land quality in Iowa based on CSR, but did not explicitly include the profit-maximizing use of energy inputs. The model in this analysis adjusts the Secchi et al. (2009) model in two important ways, by introducing the crop rotation-specific nitrogen fertilizer yield effects as in Hennessy (2006) and Sawer et al. (2006), and the tillage yield effects based on the works cited above.

CHAPTER 3

Data and Model Construction

This chapter presents the foundations of the analysis, and details the structure of the Excel-based model of farmer's profit-maximization. The Data section identifies the sources for the primary data and the economic relationships explicitly included in the Excel-based profit-maximizing economic model. The Model Construction section describes how the economic and agronomic functional dependencies concerning the costs of production, energy prices, and expected crop yields are integrated into the model.

The model developed in this study identifies for each land quality level the profit maximizing crop rotation, tillage, and nitrogen application level given the various input parameters including fuel and fertilizer prices, and anticipated grain prices. The output of the model includes for each land quality level the distribution of the agricultural land in the State of Iowa by crop rotation, tillage, and the use of diesel fuel and nitrogen fertilizer. The output also includes the resulting crop yield and production at the land quality level. The model analysis includes various potential fuel and grain price scenarios.

3.1. Data

The primary data used in this analysis is the distribution of all the agricultural land in the State of Iowa by land quality index. The field quality in Iowa is measured based on the Corn Suitability Rating (CSR). "CSRs provide a relative ranking of all soils mapped in the state of Iowa based on their potential to be utilized for row-crop production. The CSR is an index that can be used to rate one soil's potential yield production against another over a period of time" (Miller, 1988).

This simulation model utilizes a 56 square meter grid including all the Iowa land that was cropped in 2009. The grid comes from the U.S. Department of Agriculture (USDA) National Agricultural Statistical Service (NASS) GIS-based remote sensing crop cover maps for the year 2009 (USDA/NASS, 2009). For each grid unit, the measures of soil productivity and environmental vulnerability that come from the Iowa Soil Properties and Interpretations Database (ISPAID) GIS soil data layer (Iowa Cooperative Soil Survey, 2003) have been identified (Secchi et al., 2009). See Figure 3.1 for a State of Iowa map by CSR.

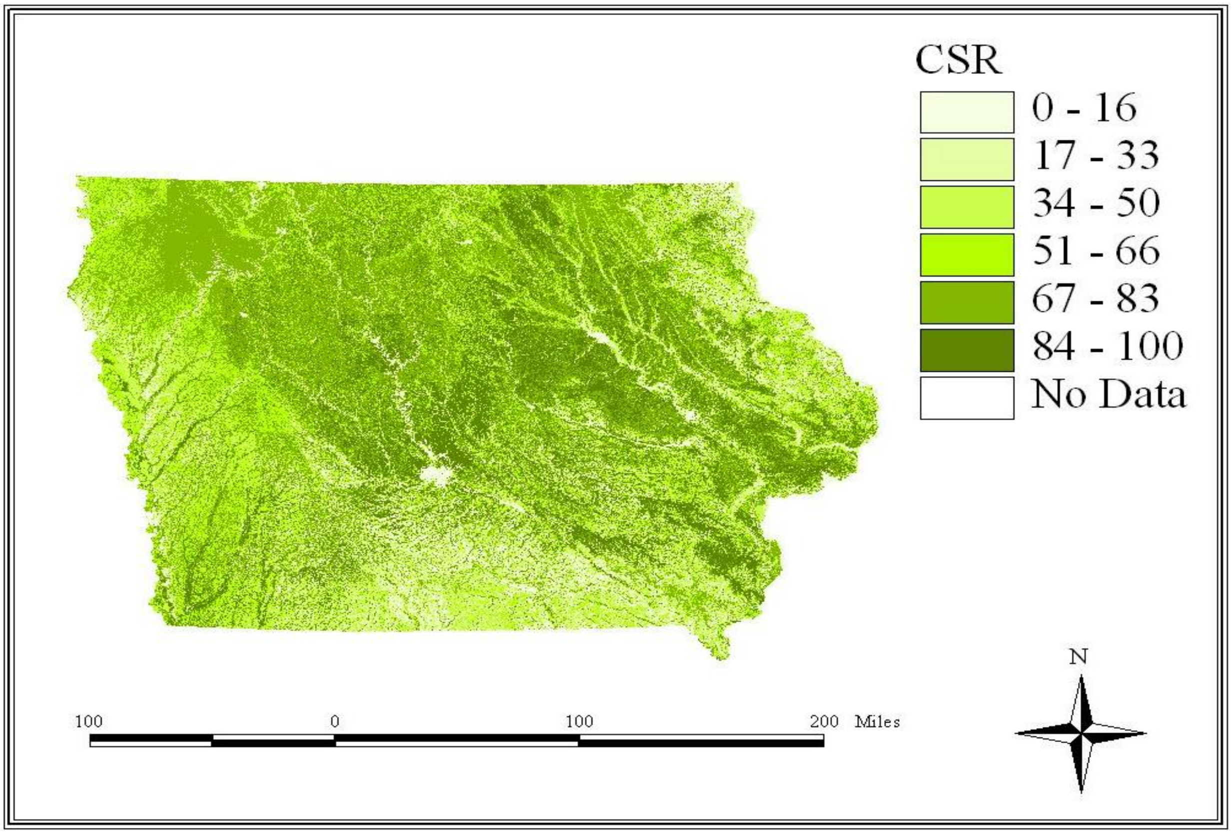

Figure 3.1. Corn Suitability Rating Map of the State of Iowa

In this study, the data on all the land that has been cropped in 2009 and has positive CSR and HEL map code values is used. Out of the total of 21,771,106 acres in the 2009 GIS-based crop-cover data, CSR and HEL indicators are missing for only 0.22% and 0.42% of the total area, respectively. Because of the missing values, we exclude from the analysis some 91,859 acres or 0.42% of the GIS-based crop-cover data. Overall, the simulations include 21,679,247 acres. In comparison, USDA/NASS (2010) reports that corn and soybeans were harvested on some 22,930,000 acres in Iowa in 2009, implying that the study data covers approximately 95% of the state's cropped land.

The primary model parameters, i.e., the exogenous variables that can be changed by the model users, are the corn and soybean prices, and the price of diesel. In this analysis the results of the various scenarios are meant to simulate a multiyear equilibrium based on the given fuel and fertilizer costs for that scenario. Given that goal, the base case price for corn and soy were selected to be the price that could best estimate a long term future price expectation. Therefore the price at the Chicago Mercantile Exchange (CME) was selected for the trade date of March 17, 2010. The last settle date with a significant estimated trade volume was December 2011 with a settle price of 421'0. Based on this the model's medium term price for corn was assumed at $4.21/bushel.

Similarly the price of soy for the base case was selected using the CME with the same selected trade date of March 17, 2010. The last settle date with a significant estimated trade volume was November 2011 with a settle price of 959'0. Based on this the model's long term price for soy was assumed at $9.59/bushel.

In this study, thirteen different diesel prices from $2.00/gallon to $6.28/gallon each with a 10% incremental price increase from the previous price are considered. The simulations assume that the prices of all energy inputs considered (diesel fuel, LP gas, and fertilizer) are positively correlated. These assumptions are based on a published assessment of historical data (Huang, 2009). Huang (2007) estimates the correlation between prices of ammonia (the main input source for all Nitrogen fertilizers) and natural gas (the primary raw material used to produce ammonia) ranging between 0.7 and 0.8 in the period from 2000 to 2006. Kurkalova (2012) estimated the simple correlation coefficients computed from the 1994-2006 annual data on diesel fuel prices (Energy Information Administration, http://tonto.eia.doe.gov/dnav/pet/pet_pri_gnd_dcus_nus_ a.htm, accessed June 2008), October LP gas prices (Energy Information Administration, http://www.eia.doe.gov/oil_gas/petroleum/data_publications/weekly_petroleum_status_report/w psr.html, accessed September 2009), and fertilizer prices (National Agricultural Statistical Service, http://www.ers.usda.gov/Data/FertilizerUse/, accessed June 2008) as 0.97, 0.92, 0.90, and 0.73 for diesel fuel price versus LP gas price, Nitrogen fertilizer, all fertilizer, and Phosphate fertilizer, respectively. In simulations, the following computation formulas obtained via linear regression analysis of the 13 annual observations is used (Kurkalova, 2012):

$$P_N \text{ (\$/lb Nitrogen)} = \underset{(0.018)}{0.069} + \underset{(0.011)}{0.089} * P_D \text{ (\$/gallon Diesel)} \quad (3.1)$$
(standard errors) (0.018) (0.011)

$$P_{PH} \text{ (\$/lb Phosphate)} = 0.315 + 0.064 * P_D \text{ (\$/gallon Diesel)} \quad (3.2)$$
(standard errors) (0.029) (0.018)

$$P_K \text{ (\$/lb Potash)} = 0.120 + 0.056 * P_D \text{ (\$/gallon Diesel)} \quad (3.3)$$
(standard errors) (0.013) (0.0080)

$$P_P \text{ (\$/gal Propane)} = 0.058 + 0.680 * P_D \text{ (\$/gallon Diesel)} \quad (3.4)$$
(standard errors) (0.082) (0.052)

3.2. Model Construction

The primary instrument of this analysis is an Excel-based economic optimization model. The data described above serve as inputs to the model, while the previous works cited throughout this section serve in part as the theoretical framework and as the origin of the functional agronomic and economic relationships integrated in the model. This section describes how the production costs are calculated in the model. In addition, the assumed tillage choice, crop rotation, and nitrogen application impacts on the yield are explained, and how these effects are integrated in the model.

Individual farmers face several input parameters including the CSR rating of their land, fuel and fertilizer prices, and anticipated crop prices. Given these parameters, the farmers have to decide what crop rotation, tillage option, and nitrogen application level will maximize their profit. The different rotation and tillage combinations utilize different equipment and input costs. They also generate different crop combinations and yield factors. Applying nitrogen to corn increases crop yield but with diminishing returns. Therefore our model identifies the profit maximizing nitrogen application level. This level varies by CSR, crop rotation, input costs, and anticipated crop prices.

For each given fuel and crop price the model calculates the profit maximizing nitrogen application for each CSR for both corn following corn, and corn following soy based on the nitrogen relationship from the Hennessy (2006) derived equation. Then the yield is calculated for all three tillage choices for each of the rotation components: corn following corn, corn following soy, soy following one year of corn, and soy following two years of corn, based on the yield relationship from the Hennessy derived yield equations. Profits for each of the yield components are calculated, and the rotation and tillage with the greatest positive profit is selected. Acres without a positive profit are considered fallow.

The input fuel and fertilizer prices are based on adjustments to the price of diesel. The model was run with thirteen different prices for diesel from $2.00 to $6.28, and five corn prices from $4.21 to $5.02. Each price of diesel was 10% higher than the previous. Each corn price was run at five prices of diesel. Subsequent prices of corn were run with overlapping prices of diesel such that the middle diesel price for the first price of corn was the first diesel price for the next price of corn. Corn prices were each 4.5% higher than the previous price in order to maintain equal acres in profitable production between each price of corn.

3.2.1. Production costs. The production costs considered in this model consist of the costs for pre-harvest machinery, seeds and chemicals, harvest machinery, and labor, as developed in the Iowa State University Extension's Ag Decision Maker (Duffy & Smith, 2009). Land costs are not included in total production costs because these costs are the same regardless of the farm management decisions made, and are essentially a fixed cost regardless of whether the field is even cultivated. A total of nine production cost formulas are included, all based on the Ag Decision Maker model, at each price level for diesel. The costs are calculated for the three tillage choices (conventional, conservation, and no-till) for each of the three cropping sequences (corn following corn, corn following soy, and soy following corn).

The per acre cost of corn by tillage and rotation (C_C) is equal to the fixed cost of corn per acre (CF_{RT}) plus the variable cost of corn per bushel (CV_B) times the yield of corn per acre (q^{corn}) plus the gallons of diesel consumption per acre (D_{RT}) times the price of diesel per gallon (P_D) plus the gallons of propane use per bushel (P_B) times the yield of corn per acre by (q^{corn}) times the price of propane per gallon (P_P) plus the nitrogen application level per acre (N) times the price of nitrogen per pound (P_N).

$$C_C = CF_{RT} + CV_B * q^{corn} + D_{RT} * P_D + P_B * q^{corn} * P_P + N * P_N \quad (3.5)$$

The per acre cost of soy by tillage and rotation (C_S) equals the fixed cost of soy per acre CF_{RT} plus the variable cost of soy per bushel (CV_B) times the yield of soy per acre (q^{soy}), plus the diesel fuel use (D_{RT}), times the price of diesel P_D.

$$C_S = CF_{RT} + CV_B * q^{soy} + D_{RT} * P_D \quad (3.6)$$

The original Ag Decision Maker formulas were adapted to account for varying CSR in Kurkalova et al. (2009). To further adapt the Ag Decision Maker formulas to the model in this study, fuel and fertilizer costs are backed-out in order to allow the model to adjust these for the different price scenarios. The resulting formulas are provided in Appendix B.

3.2.2. Tillage choice yield impact. A critical component of the profit maximization model developed in this study is the yield impact based on the selected tillage method. Tillage choice impacts crop yields for both corn and soybeans, and impacts corn to a different extent depending on the previous crop (crop rotation). Conservation tillage and no-till options tend to generate yields that are typically somewhat less than the yield from conventional tillage. These impacts vary by rotation. For example, the percentage reduction in yield for corn under conservation tillage is different for corn following corn vs. corn following soybeans. These are both different than for soybeans following corn. The tillage choice yield impact is independent from the rotational yield impact which is also identified in this paper and included in our model.

To develop the estimates of the typical effect of tillage on yields, we have averaged the yield impacts estimated in previous regional studies for each crop and rotation under consideration. These final estimates are summarized in Table 3.1. The tillage choice has the most dramatic impact on no-till continuous corn. There is approximately a 2.2% yield reduction for conservation tillage compared to conventional tillage, and nearly a 6.8% reduction for no-till. In corn following soybeans these impacts are 1.6% and 3.0% respectively. For soybeans following corn the percentage reductions respectively are approximately 3.5% and 4.1%. The following sections detail the derivation of these average effects.

Actual yields by tillage were converted to relative yields in order to be compared to the conventional tillage option. For each site the yields from all conventional tillage results were averaged and the average was used as the base yield for that site. The yields for the conservation tillage options were likewise averaged for each site. This average yield for conservation tillage was divided by the average yield of the conventional tillage, and the resulting percentage was the yield reduction for that site. The no-till reduction for each site was calculated similarly. Finally all the site conservation and no-till reduction percentages were average for the model tillage reductions.

Table 3.1

Relative Yield for Tillage Choice by Rotation

Crop Rotation	Conventional	Conservation	No-till
Corn Following Corn	100%	97.8%	93.2%
Corn Following Soybeans	100%	98.4%	97.0%
Soybeans Following Corn	100%	96.5%	95.9%

The remainder of this section documents the estimation of the tillage yield impact organized by the three cropping sequences considered, corn following corn, corn following soybeans, and soybeans following corn.

3.2.2.1. Tillage impact for corn following corn. For corn following corn, results are used in this analysis from three studies. Al-Kaisi and Yin (2004) included the results from Nashua and Crawfordsville in Iowa. The Vetsch and Randall (2002) study was based in southeastern Minnesota, and the Wilhelm and Wortmann (2004) study was based in southeastern Nebraska.

3.2.2.1.1. Conventional tillage yield. The conventional tillage is used as the baseline tillage option so the conventional tillage yield impact is considered 100% yield. The average conventional yield for each site is calculated in order to compare the conservation and no-till yield options.

In the Al-Kaisi and Yin (2004, p. 99) study for Nashua there was both moldboard and chisel plow data. The average of the moldboard plow yield (8.61 bu./acre) and the chisel plow yield (8.29 bu./acre) is 8.45 bu./acre, and is used as the baseline conventional tillage yield to compare the conservation and no-till yields for the Nashua site. The Crawfordsville site (Al-Kaisi and Yin, 2004) included chisel plow tillage but no moldboard conventional tillage. The yield for the chisel plow was 7.48 bu./acre and is used as the baseline conventional tillage yield to compare the conservation and no-till yields for the Crawfordsville site.

The conventional tillage in the Vetsch and Randall (2002, p.536) study had a yield of 10.5 bu./acre and this is used as the baseline conventional yield to compare the conservation and no-till yields for this site. The Wilhelm and Wortmann (2004, p.429) study included both a plow tillage yield of 6.19 bu./acre and a chisel tillage yield of 5.68 bu./acre. The average of 5.94 bu./acre is used as the conventional tillage yield to compare to the conservation and no-till yields for this site.

3.2.2.1.2. Conservation tillage yield impact. For each of the four sites discussed above, the conservation tillage yield is compared as a percentage of the conventional tillage yield. The average of these four percentages from the individual sites is 97.8% and is used as the conservation tillage yield impact for corn following corn in this analysis.

In the Al-Kaisi and Yin (2004, p. 99) study for Nashua, ridge tillage was the only conservation tillage considered. This yield of 8.07 bu./acre is divided by the calculated conventional tillage yield of 8.45 bu./acre, resulting in a site conservation tillage yield impact of 95.5%. Similarly in the Al-Kaisi and Yin (2004, p. 99) study for Crawfordsville ridge tillage was the only conservation tillage considered. This yield of 7.44 bu./acre is divided by the conventional (chisel plow) tillage yield of 7.48 bu./acre, resulting in a site conservation tillage yield impact of 99.5%.

The Vetsch and Randall (2002, p.536) conservation tillage yield data included fall strip till yield and rawson zone till yield each of 10.2 bu./acre. This yield is divided by the conventional tillage yield of 10.5 bu./acre for a site conservation tillage yield impact of 97.1%. The Wilhelm and Wortmann (2004, p.429) study included disk, ridge till, and subsoil tillage as conservation tillage options. The yield results were 5.77 bu./acre, 5.94 bu./acre, and 5.96 bu./acre respectively, with an average of 5.89 bu./acre. The site conservation tillage yield impact is 5.89 bu./acre divided by the site conventional tillage yield of 5.94 bu./acre, or 99.2%.

3.2.2.1.3. No-till yield impact. For each of the four sites discussed above, the no-till yield is compared as a percentage of the conventional tillage yield. The average of these four percentages from the individual sites is 93.2% and is used as the no-till yield impact for corn following corn in this analysis.

In the Al-Kaisi and Yin (2004) study for Nashua, the no-till yield was 7.71 bu./acre. This yield is divided by the calculated conventional tillage yield of 8.45 bu./acre resulting in a site no-till yield impact of 91.2%. Similarly in the Al-Kaisi and Yin (2004) study for Crawfordsville the no-till yield was 7.23 bu./acre. This yield is divided by the conventional (chisel plow) tillage yield of 7.48 bu./acre, resulting in a site no-till yield impact of 96.7%.

The Vetsch and Randall (2002) no-till yield data was 9.8 bu./acre. This yield is divided by the conventional tillage yield of 10.5 bu./acre for a site no-till yield impact of 93.3%. In the Wilhelm and Wortmann (2002) study no-till yield was 5.44 bu./acre. Therefore the site no-till yield impact is 5.44 bu./acre divided by 5.94 bu./acre from the conventional tillage yield, or 91.7%.

3.2.2.2. Tillage impact for corn following soybeans. For corn following soybeans, results from the same three studies are used in this analysis as for corn following corn. However, the Al-Kaisi and Yin (2004) study reported the results for corn following soybeans from the following sites: Burlington, Nashua, Newell, Sutherland and Crawfordsville, Iowa.

3.2.2.2.1. Conventional tillage yield. In the Burlington (Al-Kaisi and Yin, 2004, p. 99) study, the moldboard plow yield of 9.04 bu./acre is used as the baseline conventional tillage yield for this site. Both the Nashua and the Newel sites (Al-Kaisi and Yin, 2004) included Moldboard and chisel plow data. For Nashua, the moldboard plow yield of 9.15 bu./acre and the chisel plow yield of 9.23 bu./acre (Al-Kaisi and Yin, 2004) are averaged to obtain a yield of 9.19 bu./acre as the site baseline conventional yield. For the Newel site, the average of the moldboard plow yield of 9.16 bu./acre and the chisel plow yield of 9.10 bu./acre (Al-Kaisi and Yin, 2004) are averaged resulting in a 9.13 bu./acre yield which is used as the baseline conservation tillage yield for this site.

In the Al-Kaisi and Yin (2004, p. 99) Sutherland study, the conventional tillage data included only chisel plow. The yield for this was 9.72 and is used as the site baseline conventional tillage. The Al-Kaisi and Yin Crawfordsville study data also included chisel plow as the conventional tillage option. The yield for this was 9.06 bu./acre (Al-Kaisi and Yin, 2004) and is used as the baseline conventional tillage to compare the conservation and no-till yields. The yield for the Vetsch and Randall (2002, p. 536) conventional tillage was 11.4 bu./acre and is used as the baseline conventional data for this site. The Wilhelm and Wortmann (2004, p. 429) study included plow and chisel yields of 7.31bu./acre and 6.99 bu./acre respectively, resulting in a conventional tillage yield of 7.15 bu./acre.

3.2.2.2.2. Conservation tillage yield impact. For each of the seven sites discussed above, the conservation tillage yield is compared as a percentage of the conventional tillage yield. The average of these seven percentages from the individual sites is 98.4% and is used as the conservation tillage yield impact for corn following soybeans in this analysis.

In the Al-Kaisi and Yin (2004, p. 99) study for Burlington, reduced tillage was the only conservation tillage considered. This yield of 9.05 bu./acre is divided by the conventional tillage yield of 9.04 bu./acre, resulting in a site conservation tillage yield impact of 100.1%. In the Al-Kaisi and Yin (2004, p. 99) study for Nashua, Sutherland, and Crawfordsville, ridge tillage was the only conservation tillage considered. Yields of 8.90, 9.35, and 8.68 bu./acre respectively are divided by the site specific conventional tillage yields of 9.19, 9.72, and 9.06 bu./acre, resulting in site conservation tillage yield impacts of 96.8%, 96.2%, and 95.8% respectively. The Al-Kaisi and Yin (2004, p. 99) study for the Newell site included conservation tillage options of field cultivation and tillage plant. The yield results were respectively 9.17 and 8.82 bu./acre with an average of 9.00 bu./acre. The site conservation tillage yield impact is 9.00 bu./acre divided by 9.13 bu./acre from the site conventional tillage yield, or 98.5%.

The Vetsch and Randall (2002, p. 536) conservation tillage yield data included fall strip till yield and rawson zone till yield of 11.5 bu./acre and 11.7 bu./acre respectively. The average conservation tillage yield (11.6 bu./acre) was divided by the conventional tillage yield (11.4 bu./acre) for a site conservation tillage yield impact of 101.8%. The Wilhelm and Wortmann (2004, p. 429) study included disk, ridge till, and subsoil tillage as conservation tillage options. The yield results were respectively 7.07, 7.03, and 7.25 bu./acre, with an average of 7.12 bu./acre. The site conservation tillage yield impact was 7.12 bu./acre divided by 7.15 bu./acre from the site conventional tillage yield, or 99.5%.

3.2.2.2.3. No-till yield impact. For each of the seven sites discussed above, the no-till yield is compared as a percentage of the conventional tillage yield. The average of these seven percentages from the individual sites is 97.0% and is used as the no-till yield impact for corn following soybeans in this analysis.

In the Al-Kaisi and Yin (2004, p.99) study for Burlington, Nashua, Newell, Sutherland, and Crawfordsville the no-till yields were respectively 8.59, 9.03, 8.83, 9.19, and 8.70 bu./acre. These yields are each divided by their site specific conventional tillage yields resulting in the following site no-till yield impacts of 95.0%, 98.3%, 96.7%, 94.5%, and 96.0% respectively. The Vetsch and Randall (2002, p. 536) no-till yield data was 11.50 bu./acre. This was divided by the conventional tillage yield of 11.40 bu./acre for a site no-till yield of 100.9%. Similarly the Wilhelm and Wortmann (2004, p. 429) study no-till yield was 6.97 bu./acre. Therefore the site conservation tillage yield impact was 6.97 bu./acre divided by 7.15 bu./acre from the site conventional tillage yield, or 97.5%.

3.2.2.3. Tillage impact for soybeans following corn. For soy following corn we used the results from five sites. The Yin and Al-Kaisi (2004) study included the results from the third five year study in Burlington, Nashua, and Newell, and the fourth five year study from Nashua; the Wilhelm and Wortmann (2004) study was based in southeastern Nebraska.

3.2.2.3.1. Conventional tillage yield. The Yin & Al-Kaisi (2004, p.731) Burlington study data included only moldboard plow as a conventional option. The yield for this was 3.15 bu./acre and is used as the baseline to compare the conservation and no-till yields for this site. Similarly, the Yin and Al-Kaisi (2004, p.731) Crawfordsville study data included only chisel plow as a conventional option. The yield for this was 2.85 bu./acre and is used as the baseline conservation tillage yield for this site.

In the Yin and Al-Kaisi (2004, p. 731) study for Nashua (third 5 year period) the moldboard plow yield (2.65 bu./acre) and chisel plow yield (2.62 bu./acre) are averaged resulting in a 2.64 bu./acre site and period conventional tillage yield. Similarly in the Yin and Al-Kaisi (2004, p. 731) study for Nashua (fourth 5 year period) the moldboard plow yield (3.10 bu./acre) and the chisel plow yield (3.10 bu./acre) are averaged resulting in a 3.10 bu./acre yield conventional yield for this site and period. The Wilhelm and Wortmann (2004, p. 731) study included both moldboard plow yield (2.59 bu./acre) and chisel plow yield (2.58 bu./acre) resulting in a 2.59 bu./acre average site conventional tillage yield .

3.2.2.3.2. Conservation tillage yield impact. For each of the five sites discussed above, the conservation tillage yield is compared as a percentage of the conventional tillage yield. The average of these five percentages from the individual sites is 96.5% and is used as the conservation tillage yield impact for soybeans following corn in this analysis.

In the Yin and Al-Kaisi (2004, p. 731) study for Burlington, reduced tillage (RDT) was the only conservation tillage considered. This yield of 2.98 bu./acre is divided by the conventional tillage yield for this site of 3.15 bu./acre, resulting in a is a site conservation tillage yield impact of 94.6%. Similarly in the Yin & Al-Kaisi (2004, p. 731) study for Nashua (third 5 year), Crawfordsville, and Nashua (fourth 5 year) reduced tillage/alternative tillage (RT/AL) was the only conservation tillage considered. These yields of 2.56, 2.73, and 2.93 bu./acre respectively were divided by the conventional tillage yields of 2.64, 2.85, and 3.10 by site, resulting in site conservation yield impacts of 97.2%, 95.8%, and 94.5% respectively.

The Wilhelm and Wortmann (2004, p. 431) study included disk, ridge till, and subsoil tillage as conservation tillage options. The yield results were respectively 2.58, 2.60, and 2.59 bu./acre, with a site average conservation yield of 2.59 bu./acre. The site conservation tillage yield impact is 2.59 bu./acre divided by the site conventional tillage yield of 2.59 bu./acre, or 100.2%.

3.2.2.3.3. No-till yield impact. For each of the five sites discussed above, the no-till yield is compared as a percentage of the conventional tillage yield. The average of these five percentages from the individual sites is 95.9% and is used as the no-till yield impact for soybeans following corn in this analysis.

In the Yin and Al-Kaisi (2004, p. 731) study for Burlington the no-till yield was 2.81 bu./acre. This yield is divided by the conventional tillage yield of 3.15 bu./acre resulting in a site no-till yield impact of 89.2%. Similarly in the Yin and Al-Kaisi (2004, p. 731) study for Nashua (third 5 year), Crawfordsville, and Nashua (fourth 5 year) the no-till yields were 2.58, 2.80, and 3.00 bu./acre. These yields were divided by the site conventional tillage yields resulting in site no-till yield impacts of 97.9%, 98.2%, and 96.8% respectively. The Wilhelm and Wortmann (2004, p. 431) no-till yield data was 2.52 bu./acre. This was divided by the site conventional tillage yield of 2.59 bu./acre for a site no-till yield impact of 97.5%.

3.2.3. Combining tillage, rotation, nitrogen, and land quality impacts on corn yield. Three possible crop rotation choices have been included in the present study's model: corn followed by soy (CS), corn followed by corn followed by soy (CCS), and continuous corn (CC). The crop rotational and the nitrogen application level are linked in this analysis because the nitrogen application level for corn depends upon whether the corn is following corn, or is following soy. Hennessy (2006) developed and estimated the following regression model of the yield of corn based on nitrogen input and the crop rotation:

$$q^{corn} = \alpha_0 + \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1 + \delta Y + \varepsilon \qquad (3.7)$$

Here N is the nitrogen application level in pounds per acre, and F_1 is an indicator variable for whether the previous crop was corn (F_1 = 1 for previous crop is corn, F_1 = 0 for previous crop is soy). The δY term is an adjustment based on the number of years since 1979. Since the present model is designed to approximate a medium to long term equilibrium outcome rather than comparisons from one year to another, the δY term is not included in this model. Ignoring the error term, the following form of the Hennessy (2006) model for corn yield has been used in the present study:

$$q^{corn} = \alpha_0 + \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1 \quad (3.8)$$

The following are the estimates for the coefficients calculated by Hennessy (2006) where the number in parentheses is the absolute t-value: α_0 is 102.33 (16.53), α_1 is 0.428 (5.30), and α_2 is -0.00165 (4.33). χ_1 is the yield enhancement effect equal to -16.46 (6.15) bushels per acre for corn following corn, and ρ is the nitrogen input savings effect equal to -50.98 (3.19) in pounds of nitrogen per acre for corn following soybeans.

The Hennessy model estimates the corn yield based on the nitrogen application level, and on crop rotation independent of the choice of tillage. Based on the analysis of the tillage effects detailed in the previous section, we adjust the intercept in (3.1) to account for a tillage impact via a multiplier τ. This accounts for the tillage yield impact first and independent of the nitrogen and rotational yield impacts. The tillage impact already accounts for a difference based on rotation, and nothing in the literature indicated that the nitrogen impact would vary by tillage.

$$q^{corn} = \alpha_0 * \tau + \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1$$

As explained in the previous section, the tillage impact varies by crop rotation. The combined tillage-rotation-nitrogen yield formula is thus given by:

$$q^{corn} = \alpha_0 * (\tau_{CM}^{(F1)MT}) * (\tau_{CN}^{(F1)NT}) * (\tau_{SM}^{(1-F1)MT}) * (\tau_{SN}^{(1-F1)NT})$$
$$+ \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1 \quad (3.9)$$

Here MT is an indicator variable taking on a value of 1 if the tillage is mulch or other conservation tillage, and zero otherwise, NT is an indicator variable taking on a value of 1 if the tillage is no till, and zero otherwise. As explained in the previous section τ_{CM} is the tillage yield impact of corn following corn in mulch or other conservation tillage and equals 97.8%. Likewise, τ_{CN} is the tillage yield impact of corn following corn in no-till and equals 93.2%. Similarly τ_{SM} and τ_{SN} are the tillage yield impacts of corn following soy in mulch or other conservation tillage, and no-till respectively equal to 98.4% and 97.0%, and are included in Table 3.1.

In order to scale the derived Hennessy corn yield equation to regional field data, it is necessary to apply a scalar a_C to the equation and set the Hennessy equation to maximum yield by applying F1 = 0 (corn after soybeans) and MT=NT=0 (conventional tillage), and letting the resulting expression be equal 2.25 * CSR. Thus equating the maximum corn yield achievable under the yield-maximizing combination of the rate of nitrogen application, tillage, and previous crop to the approximation YMAX = 2.25 * CSR derived by Secchi et al (2009). Let N_{Max} denote the yield-maximizing level of nitrogen. This yields the following expression for the soil-quality specific multiplier of the yield equation, details of the derivations can be found in Appendix B.

$$q^{corn} = a_C * [\alpha_0 * 100\% + \alpha_1 (N_{Max} - \rho *0) + \alpha_2 (N_{Max} - \rho *0)^2 + \chi_1 *0]$$
$$q^{corn} = a_C * [\alpha_0 + \alpha_1 (N_{Max}) + \alpha_2 (N_{Max})^2] = 2.25 * CSR$$
$$a_C = 2.25 * CSR / [\alpha_0 + \alpha_1 * N_{Max} + \alpha_2 * N_{Max}^2] \quad (3.10)$$

To determine the yield-maximizing nitrogen application level set the derivative of the corn yield with respect to the nitrogen application level equal to zero. Thus,

$$q^{corn} = a_C * [\alpha_0 * \tau + \alpha_1 (N_{Max} - \rho *(0)) + \alpha_2 (N_{Max} - \rho *(0))^2 + \chi_1 * (0)]$$

$$\frac{\delta q^{corn}}{\delta N} = a_C * [\alpha_1 + 2\alpha_2 * N_{Max}] = 0$$

$$N_{Max} = \frac{-\alpha_1}{2\alpha_2} \quad (3.11)$$

By substituting in Hennessy's parameters the nitrogen application level for maximum corn yield N_{Max} is equal to - 0.428/[2 * (- 0.00165)] = 129.7 pounds per acre. Therefore substituting in to $a_C = 2.25 * CSR / [\alpha_0 + \alpha_1 * N_{Max} + \alpha_2 * N_{Max}^2]$, a_C equals 0.0173 * CSR. The resulting corn yield equation used in the model becomes:

$$q^{corn} = 0.0173 * CSR * [102.33 * 0.978^{(F1)MT} * 0.932^{(F1)NT} * 0.984^{(1-F1)MT} * 0.970^{(1-F1)NT} + 0.428 * (N - 50.98 * F_1) - 0.00165 * (N - 50.98 * F_1)^2 - 16.46 * F_1] \quad (3.12)$$

3.2.4. Combining tillage, rotation, and land quality impacts on soybean yield.

Hennessy (2006) estimated the yield of soybeans in bushels/acre as:

$$q^{soy} = \alpha + \sum_{i=2}^{4} \varphi_i G_i + \delta Y \quad (3.13)$$

Here α = 28.04 (18.53) is the default yield for continuous soy rotation, G_2 is an indicator variable that takes on a value 1 if the previous crop was corn and zero otherwise, and $\varphi_2 = 6.973$ (4.39) is the incremental increase in yield for this rotation. For the corn-corn-soy rotation G_4 is the indicator, and $\varphi_4 = 12.63$ (7.95) is the incremental increase in yield for this rotation. Note, since these rotations are exclusive and comprehensive, then exactly one of G_2 and G_4 is 1, and the other is 0. Also, G_3 is not applied to the two-year memory model. Similar to the corn yield model, the δY (year) impact is ignored for this model. Therefore our adopted Hennessy model for soy yield is:

$$q^{soy} = \alpha + \varphi_2 * G_2 + \varphi_4 * G_4 \qquad (3.14)$$

As with corn, the conventional tillage results in the maximum yield when compared to the other tillage systems, and the effect of mulch tillage and no-till varies with the previous crop. Using the tillage effects discussed in earlier, the Hennessy (2006) model adopted for tillage effect is:

$$q^{soy} = \alpha * \mathcal{T}_{C1M}^{(G2)MT} * \mathcal{T}_{C1N}^{(G2)NT} * \mathcal{T}_{C2M}^{(G4)MT} * \mathcal{T}_{C2N}^{(G4)NT} + \varphi_2 * G_2 + \varphi_4 * G_4 \qquad (3.15)$$

Here MT again is an indicator variable taking on a value of 1 if the tillage is mulch or other conservation tillage, and zero otherwise, NT is an indicator variable taking on a value of 1 if the tillage is no till, and zero otherwise. $\mathcal{T}_{C1M}$ is the tillage yield impact of soy following one year of corn in mulch or other conservation tillage and equals 96.5%. $\mathcal{T}_{C2M}$ is the tillage yield impact of soy following two years of corn in mulch tillage and equals $\mathcal{T}_{C1M}$. Likewise, $\mathcal{T}_{C1N}$ is the tillage yield impact of soy following one year of corn in no-till and equals 95.9%. $\mathcal{T}_{C2N}$ is the tillage yield impact of soy following two years of corn in no-till and equals 95.9%. Since previous research has not investigated the difference between the tillage impact for one previous corn and two previous corn rotations, set $\mathcal{T}_{C1M} = \mathcal{T}_{C2M}$, and $\mathcal{T}_{C1N} = \mathcal{T}_{C2N}$.

As with the case of corn, to derive the expression for the soil quality specific soybean yield functions, we equate the maximum soybean yield achievable under yield-maximizing combination of tillage (conventional) and previous crops (two years of corn) to the approximation $q^{Max} = 0.67 * CSR$ reported by Secchi et al (2009).

The resulting soybean yield equation used in the model becomes:

$$q^{soy} = 0.0169 * CSR * [28.04 * 0.974^{(G2)MT} * 0.951^{(G2)NT} * 0.974^{(G4)MT} * 0.951^{(G4)NT} + 6.973 * G_2 + 11.64 * G_4] \quad (3.16)$$

3.2.5. Profits. The per acre profit from corn (π_C) is equal to the per acre revenue from corn (R_C) minus the per acre production cost of corn (C_C), $\pi_C = R_C - C_C$, The revenue from corn is equal to the price of corn per bushel P_C times the yield of corn in bushels per acre (q^{corn}).

$$R_C = P_C * q^{corn}$$

With the cost functions and the yield functions as described, the equation for the per acre profit for corn production becomes:

$$\pi_C = (P_C * q^{corn}) - (CF_{RT} + CV_B * q^{corn} + D_{RT} * P_D + P_B * P_P * q^{corn} + N * P_N) \quad (3.17)$$

Finally the profit-maximizing nitrogen level is derived by equating the derivative of the profit function with respect to nitrogen to zero. This yields the following expression for the profit-maximizing level of nitrogen:

$$N_\pi = P_N / [(P_C - CV_B - P_B * P_P) * 0.0173 * CSR * 2\alpha_2] - (\alpha_1 / 2\alpha_2) + \rho F_1 \quad (3.18)$$

The profit function for the soybean production is derived similar to that for corn. The profit for soybeans (π_S) is $\pi_S = R_S - C_S$, where the revenue from soybeans (R_S) is

$$R_S = P_S * q^{soy}$$

With the cost functions described in section 3.2.1, and the yield functions described in section 3.2.4, the equation for the per acre profit for soy production becomes

$$\pi_S = R_S - C_S = (P_S * q^{soy}) - (CF_{RT} + CV_B * q^{soy} + D_{RT} * P_D) \quad (3.19)$$

To sum, the model developed in this study assumes that individual farmers face several input parameters including the CSR rating of their land, fuel and fertilizer prices, and anticipated crop prices. Given these parameters, the farmers have to decide what crop rotation, tillage option, and nitrogen application level will maximize their profit. The different rotation and tillage combinations utilize different equipment and input costs. They also generate different crop combinations and yield factors. Applying nitrogen to corn increases crop yield but with diminishing returns. Therefore the model identifies the profit maximizing nitrogen application level. This level varies by CSR, crop rotation, input costs, and anticipated crop prices.

For each given fuel and crop price the model calculates the profit maximizing nitrogen application for each CSR for both corn following corn, and corn following soy based on the nitrogen relationship from the Hennessy derived equation. Then the yield is calculated for all three tillage choices for each of the rotation components: corn following corn, corn following soy, soy following one year of corn, and soy following two years of corn based on the yield relationship from the Hennessy derived yield equations. Profits for each of the yield components are calculated, and the rotation and tillage with the greatest positive profit is selected. Acres without a positive profit are considered fallow.

3.2.6. Model validation. In order to assess the validity of the model going forward, model predictions were tested against historical data. Anticipated crop prices for 2004 and 2005 were input into the model along with the then current fuel and fertilizer prices. The years 2004 and 2005 were chosen for validation because of most complete data availability. While USDA reports the total acreage by crop consistently every year, the data on the acreage by crop and previous crop is not readily available for most years. The latter data comes from the ARMS data that are based on the surveys administered to a sample of farmers. The results from the 2004 corn survey and the 2005 soybean survey are available from the USDA NASS website (http://www.nass.usda.gov/research/Cropland/SARS1a.html, accessed, April 2010) and were used for validation of model predictions, as detailed below. In all, the following model outputs were compared with historic data: total acres planted by crop and previous crop, tillage choice percentages, and nitrogen applied per acre by previous crop.

Historical diesel prices for March of that year were obtained from the website of the Energy Information Administration (EIA) (http://tonto.eia.doe.gov/dnav/pet/hist/ddr001m.htm, accessed April 2010) for *U.S. No 2 Diesel Retail Sales by All Sellers (Cents per Gallon*). Historical propane prices for March of that year were also obtained from the EIA's website (http://tonto.eia.doe.gov/dnav/pet/hist/mprreus4m.htm, accessed April 2010) for *U.S. Propane Residential Price (Cents per Gallon Excluding Taxes).* Historical fertilizer prices for April of the years 2004 and 2005 were obtained from the USDA website (http://www.ers.usda.gov/Data/FertilizerUse, Table 7, accessed April 2010).

The production costs based on Iowa State's Ag Decision Maker formulas were set to reflect the then current production assumptions and costs estimates (such as cost of seeds and gallons of fuel by equipment) for each of the combinations of crop rotation and tillage choice. The historical Chicago Board of Trade data for that year was obtained from Norman's Historical Data (http://www.normanshistoricaldata.com, accessed October 2008) for *CBOT March Corn Futures*. The futures grain prices were used as the expected 2004 price, and the futures grain prices were used as the expected 2005 price.

3.2.6.1. Total acres planted. NASS reported 12.7 and 10.2 million acres planted in Iowa in corn and soybeans, respectively in 2004, and 12.8 and 10.0 million acres, respectively in 2005 (http://www.nass.usda.gov/Statistics_by_State/Iowa/index.asp, accessed October 2008). This analysis estimated that 10.9 million acres would be planted in each for a total of 21.7 million acres planted in both years. The difference of 1.1 million acres included in the NASS data but not included in our data is attributable to the land that had no CSR rating data and that was subsequently omitted from the analysis (Secchi et al., 2009).

3.2.6.2. Crop rotation percentages. NASS data (http://www.nass.usda.gov/ Statistics_by_State/ Iowa/index.asp, accessed October 2008) for 2004 and 2005 indicated that 55% and 56% respectively of the acres planted in the state of Iowa were corn. The percentage for soy beans was 45% and 44% respectively. The crop rotation model for both 2004 and 2005 estimated that the acres planted in corn and soy would be 50% each based on a 100% corn-soy rotation. The five and six percent swings from soy in the model to corn planted in the historical data has several possible explanations. The individual farmers would likely have different price expectations and profit maximization calculations based on individual experiences. Also, the NASS data was extrapolated based on sampling data.

3.2.6.3. Tillage choice percentages. The 2005 ARMS data (http://www.ers.usda.gov/ Data/ ARMS/app/CropResponse.aspx, accessed October 2008) included conventional, reduced, mulch and no-till, while our model combines conventional and reduced tillage. The ARMS data for conventional and reduced tillage of corn totaled 42% but the estimate is listed as unreliable, while our model estimated 0% conventional tillage of corn. The ARMS data for mulch tillage of corn totaled 35% but the estimate was listed as unreliable, while our model estimated 63% mulch tillage of corn. The ARMS data did not report the no-till acres for corn, and there was 23% unidentified. Our model estimated 37% for no-till of corn. Standard errors were not listed but all of the ARMS data was notated as “statistically unreliable due to a combination of a low sample size and high sampling error.” (http://www.ers.usda.gov/Data/ARMS/app/CropResponse.aspx, accessed October 2008)

3.2.6.4. Nitrogen level applied by crop rotation per acre. The model calculates less fertilizer is applied than the market average because of the profit maximization factor. The average calculated applied nitrogen level for corn following soy is 81 pounds per acre compared to the 120 from the Ag Decision Maker. The ARMS survey data actually indicated 140 pounds per (treated) acre average with a 6.0 standard deviation. This difference may be due to the fact that this is survey data. Additionally, farmers may have been trying to maximize yields as much as possible and hoping it would be cost effective. This and other potential arguments have been suggested in the literature to explain why farmers commonly apply fertilizer at the rates that are higher than the profit-maximizing level (Sheriff, 2005).

Overall, the model developed in the study predicted the 2004 and 2005 crop acreage data very well. The quality and reliability of the other reference data, the rotation percentages, tillage percentages, and fertilizer application rates is much worse than those for the total acreage data. It was not expect that the model would generate the same results as the estimated actual results because individuals farmers may be relying on their own anecdotal experience to make their management choices, and in particular are not aware of the extent of the diminishing returns for nitrogen fertilizer, especially for mid to low CSR land.

CHAPTER 4

Results

This chapter begins with the presentation of the agricultural land use implications from changes in the price of diesel. The changes in crop rotation, tillage choice, crop acres planted, crop yields, and crop production are analyzed for the state level. Additionally, the changes in crop rotation, tillage choice, and crop acres planted are analyzed at the field level based on the CSR. The chapter proceeds with the discussion of the agricultural energy use implications from changes in the price of diesel. Both diesel and nitrogen use are evaluated for the state level, and nitrogen use is analyzed at the field level based on the CSR.

A base case scenario was selected with the price of diesel at $2.00/gallon, and the price of corn at $4.21/bushel. Thirteen prices of diesel are included from $2.00 up to $6.28/gallon each 10% higher than the previous price. Five prices for corn are included from $4.21 up to $5.02/bushel each 4.5% higher than the previous price, and each associated with five overlapping diesel prices. The first five scenarios, including the base case, include $4.21/bushel for corn and the first five prices for diesel ($2.00, $2.20, $2.42, $2.66, and $2.93/gallon).

The next five scenarios all include the second price for corn at $4.40/bushel. The diesel prices started with the middle diesel price ($2.42/gallon) for the previous corn price demand level and the next four higher diesel prices ($2.66, $2.93, 3.22, and $3.54/gallon). This pattern is repeated for all the remaining scenarios. The 10% increase in the price of diesel was selected as a reasonable incremental value. The 4.5% increase in the price of corn was selected also as a reasonable incremental value and because by selecting this percentage in each case the middle diesel price for a given corn price demand level included the same total acres in production. This was used in order to incorporate the assumption that corn prices would eventually rise with increases in the price of diesel. The results presented below summarize the findings from the 25 scenarios described.

The base case corn and soybean prices were selected to approximate as much as possible a medium term equilibrium price for each. These commodities are extensively traded on the Chicago Mercantile Exchange (CME). The March 17, 2010 closing price for December 2011 corn (http:// www.cmegroup.com/trading/ commodities/grain-and-oilseed/corn_quotes_ settlements_futures .html, accessed March 17, 2010), and the March 17, 2010 closing price for November 2011 soybeans (http://www.cmegroup.com/trading/commodities/grain-and-oilseed/ soybean_ quotes_ settlements_futures.html, accessed on March 17, 2010) were selected as the farthest future price with a significant exchange volume. In this analysis the price of corn and soybeans were fixed at a constant ratio for all scenarios.

The model is based on a medium term equilibrium for the inputs. The rotations themselves account for two and three year cycles, and the pricing is considered stable enough for farm managers to consider periods of at least this long. However the model does not consider alternative uses of the land in the long term. Given this, the cost of land is not included in the cost function because it is the same for all rotations, and one bad year would not be sufficient to consider selling the property. The only alternative in the model to selecting the profit maximizing rotation, tillage, and nitrogen application is to leave the field fallow, if the costs of tillage exceed the anticipated revenue from tillage. The model results found only a small percentage (about 6%) of acres in the lowest possible land quality selected fallow. This is not inconsistent with tillage expectations in Iowa. This is how the positive profit threshold requirement is defined in this analysis.

4.1. Agricultural Land Use Implications

This analysis detailed below indicates that increases in the price of diesel have a potentially significant impact on agricultural land use in the State of Iowa through field level farm management decisions. Crop rotation patterns in particular demonstrate a high sensitivity to increases in fuel price. The rotation changes, in turn, impact both the average yield per crop and the total production by crop. The tillage choice however was found much less sensitive to increases in the price of diesel.

4.1.1. Crop rotation. The continuous corn (CC) rotation option was never calculated to be the most profitable rotation in any of the scenarios included in this analysis. This finding was not surprising because the of relative energy intensity of corn production when compared to soybeans, the reduction in the expected yield of corn after corn when compared to that after soybeans, and the relative price ratio of corn to soybeans. Both the corn-corn-soy (CCS) and the corn-soy (CS) rotations were significant in the number of acres that were predicted by the model. Generally, as the price of diesel increased, acres shifted from CCS to CS. Also as the price of diesel increased a small percentage of the acres went out of production based on not meeting a minimum positive profit threshold. Table 4.1 identifies the number of acres by rotation for each price of diesel with a constant price of corn at the base case scenario of $4.21/bushel.

Table 4.1

Acres Planted by Rotation

Price of Diesel	**$2.00**	**$2.20**	**$2.42**	**$2.66**	**$2.93**
Fallow Acres	1,337,226	1,360,182	1,360,182	1,615,448	1,635,084
Corn-Soy	8,636,690	10,521,463	12,338,596	13,766,707	15,386,125
Corn-Corn-Soy	11,748,573	9,840,844	8,023,711	6,340,334	4,701,280

Figure 4.1 illustrates the decreased number of acres in CCS rotation and the increased number of acres in CS rotation as the price of diesel increases. There is a relatively small increase in the number of fallow acres as the price of diesel increases. Although this chart illustrates the base case scenario, the same trend transpired for each level of corn price modeled in this analysis.

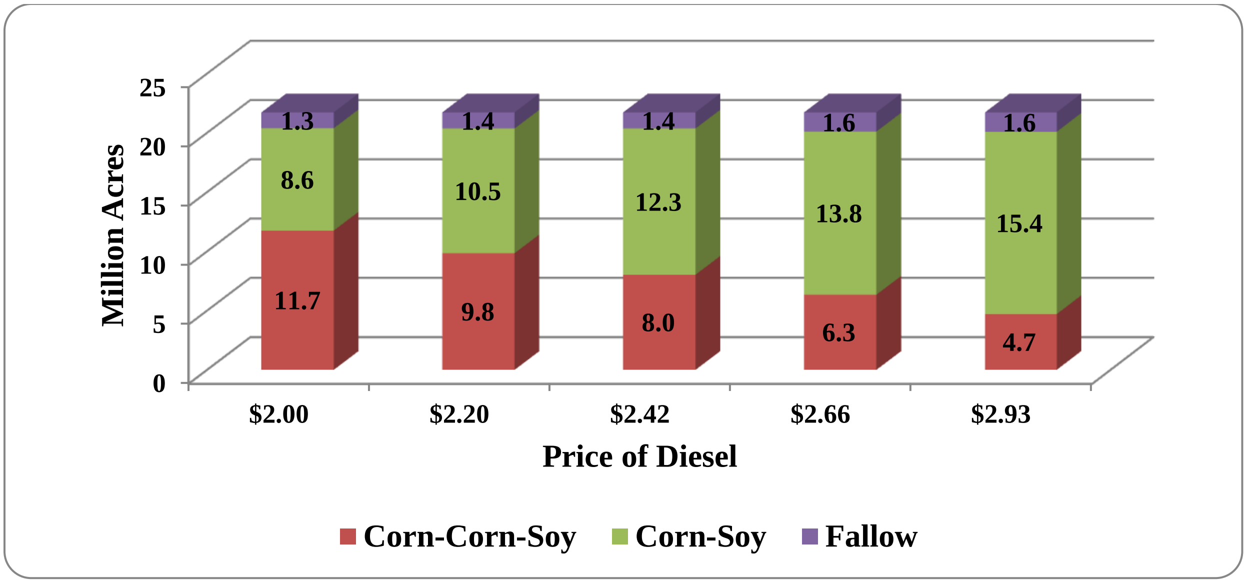

Figure 4.1. Acres Planted by Rotation

4.1.1.1. Acres planted by rotation. The CCS rotation in the base case scenario includes 11.7 million acres or 54% of all available acres. As the price of diesel increases this percentage decreases because the increased diesel and nitrogen pre-harvest costs impact this rotation disproportionately higher compared to the CS rotation. This is because corn, especially corn after corn, is a very tillage intensive crop. Therefore as the price of diesel increases more acres shift from the CCS rotation to the CS rotation. In addition, corn following corn is much more nitrogen intensive. Figure 4.1 illustrates the decrease in the CCS rotation, and the increase in the CS rotation as the price of diesel increases at the base case.

This crop rotation trend is clearly evident in Figures 4.2 and 4.3 which identify the percentages of acres in the CCS and CS rotations respectively for all 25 scenarios in this analysis. Each of the five corn price demand levels is grouped with overlapping diesel prices. Each corn price demand level is represented by a different color. The blue trend represents the base case scenario. The initial CCS rotation percentage is 54% and decreases with each increase in the price of diesel. Similarly the initial CS rotation percentage is 40% and increases with each increase in the price of diesel.

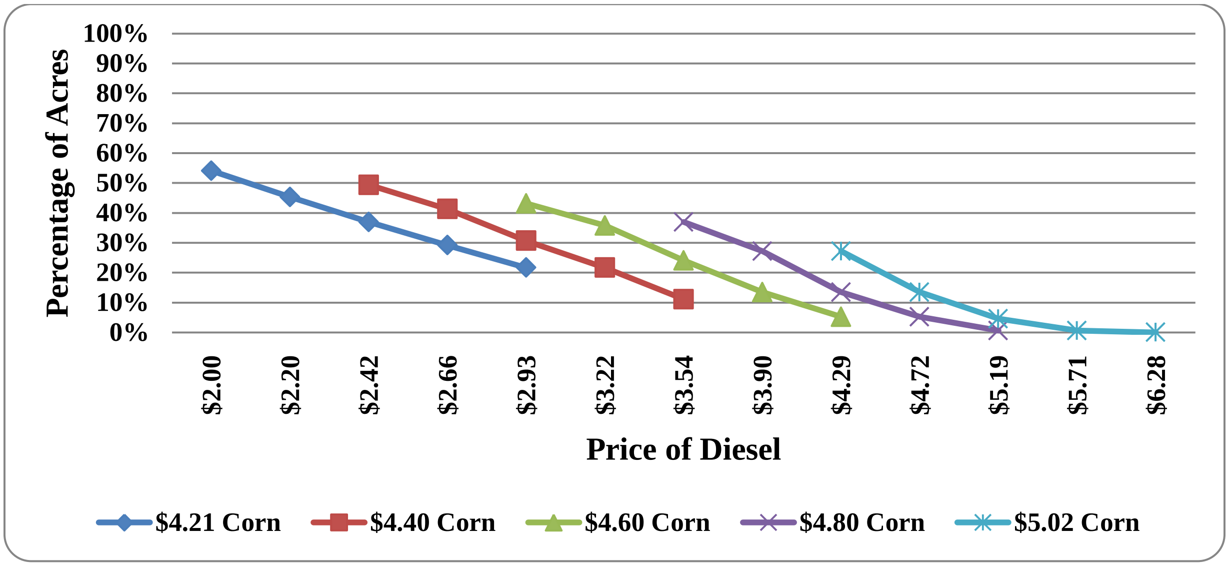

Figure 4.2. Percentage of CCS Rotation

Table 4.2 reports the total acres in the CCS rotation for each of the 25 scenarios, and the corresponding diesel price elasticities. Each of the 20 elasticities of the acres of CCS rotation to the price of diesel is negative because the acres under this rotation always decrease as the price of diesel increases. Table 4.3 includes the total acres in the CS rotation for each of the 25 scenarios, and the corresponding diesel price elasticities. Each of the 20 elasticities of the acres of CS rotation to the price of diesel is positive because the acres under this rotation always increase as the price of diesel increases.

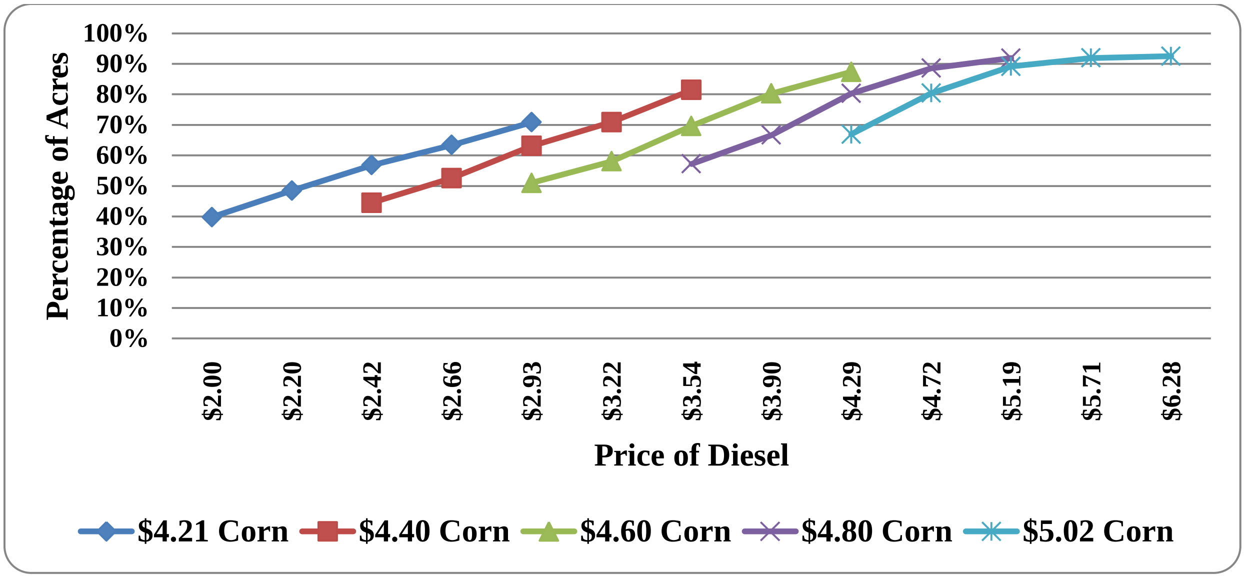

Figure 4.3. Percentage of CS Rotation

Figure 4.2 and Table 4.2 indicate that the total acres in the CCS rotation are significantly dependent upon the price of diesel and upon the price of corn. This result fits the general production theory that increases in the cost of corn production relative to soybean production would decrease corn production and therefore shift rotations at some acres from CCS to CS. Similarly increases in the price of corn at fixed production costs would increase the profit for planting more corn and therefore shift CS rotations at the margins to CCS. A simple regression for the number of acres of the CCS rotation on the price of diesel and the price of corn generates an R Square value of 0.895 from the data in Table 4.2.

$$\text{CCS Acres} = -\,18{,}084{,}447 - 4{,}785{,}728 * P_D + 8{,}894{,}273 * P_C \qquad (4.1)$$

(P-value) (0.015) (0) (6.03E-5)

Similarly, Figure 4.3 and Table 4.3 specify how the total acres in the CS rotation are dependent upon the price of diesel and upon the price of corn. A simple regression for the number of acres of the CS rotation on the price of diesel and the price of corn generates an R Square value of 0.891 from the data in Table 4.3.

Table 4.2

CCS Acres Planted and Elasticity

Price of Diesel	Elasticity of CCS Acres to Price of Diesel	Price of Corn	$4.21	Price of Corn	$4.40	Price of Corn	$4.60	Price of Corn	$4.80	Price of Corn	$5.02
		CCS Acres	Elasticity	CCS Acres	Elasticity	CCS Acres	Elasticity	CCS Acres	Elasticity	CCS Acres	Elasticity
$2.00		11,748,573									
	A		-1.856								
$2.20		9,840,844									
	B		-2.136								
$2.42		8,023,711		10,726,040							
	C		-2.461		-1.871						
$2.66		6,340,334		8,971,370							
	D		-3.117		-3.101						
$2.93		4,701,280		6,662,575		9,377,612					
	E				-3.624		-1.969				
$3.22				4,701,280		7,769,958					
	F				-6.743		-4.094				
$3.54				2,416,042		5,234,680		8,023,711			
	G						-5.937		-3.187		
$3.90						2,927,345		5,909,409			
	H						-9.311		-7.087		
$4.29						1,128,926		2,927,345		5,909,409	
	I								-9.311		-7.087
$4.72								1,128,926		2,927,345	
	J								-16.485		-10.344
$5.19								135,984		995,162	
	K										-15.951
$5.71										135,984	
	L										-21.000
$6.28										0	

Table 4.3

CS Acres Planted and Elasticity

Price of Diesel	Elasticity of CS Acres to Price of Diesel	Price of Corn	$4.21	Price of Corn	$4.40	Price of Corn	$4.60	Price of Corn	$4.80	Price of Corn	$5.02
		CS Acres	Elasticity	CS Acres	Elasticity	CS Acres	Elasticity	CS Acres	Elasticity	CS Acres	Elasticity
$2.00		8,636,690									
	A		2.066								
$2.20		10,521,463									
	B		1.669								
$2.42		12,338,596		9,659,223							
	C		1.149		1.749						
$2.66		13,766,707		11,413,893							
	D		1.167		1.911						
$2.93		15,386,125		13,699,732		11,069,007					
	E				1.231		1.371				
$3.22				15,405,762		12,615,305					
	F				1.450		1.902				
$3.54				17,690,999		15,127,627		12,422,909			
	G						1.488		1.603		
$3.90						17,434,962		14,475,853			
	H						0.890		1.947		
$4.29						18,978,115		17,434,962		14,537,210	
	I								1.030		1.917
$4.72								19,233,381		17,457,918	
	J								0.385		1.089
$5.19								19,951,421		19,367,145	
	K										0.322
$5.71										19,971,057	
	L										0.061
$6.28										20,087,405	

$$\text{CS Acres} = 35{,}433{,}910 + 4{,}559{,}968 * P_D - 8{,}073{,}394 * P_C \quad (4.2)$$
(P-value) (3.28E-5) (0) (1.81E-4)

Note that these and all other estimated regression equations presented in this Results section are based not on sample data from real world observations. Rather, these functions have been estimated from the output of the 25 scenarios which were included in this analysis.

The log-log regressions on the CCS acres and the CS acres to the prices of diesel and corn have R squared values of 0.768 and 0.956 respectively. The estimated elasticities of the CCS acres and the CS acres to the price of diesel from these regressions are -6.24 and 1.33 respectively. Therefore the estimated impact on CCS acres to a 1% increase in the price of diesel is a 6.24% decrease in the number of acres. Likewise the estimated impact on CS acres to a 1% increase in the price of diesel is a 1.33% increase in the number of acres. In addition, from the regression equations the estimated elasticity for the acres of CCS and CS to the price of corn is 14.9 and -3.36 respectively.

$$\ln \text{CCS Acres} = 0.212 - 6.24 * \ln PD + 14.9 * \ln PC \quad (4.3)$$
(P-value) (0.970) (0) (3.40E-3)

$$\ln \text{CS Acres} = 19.9 + 1.33 * \ln PD - 3.36 * \ln PC \quad (4.4)$$
(P-value) (0) (0) (0)

4.1.1.2. Crop rotation by CSR. Figure 4.4 provides further details on how the crop rotation decision is dependent on the CSR. At all the prices considered, the CCS rotation was the most profitable rotation in the acres with the highest CSR, and the CS rotation was the most profitable rotation in the acres with the lower CSR ratings. The bars in Figure 4.4 indicate the number of acres of a particular land quality (CSR rating), and the color of the bar indicates the predicted crop rotation. In the base case, the minimum profitable CSR rating is 39, and the minimum CSR in a CCS rotation is 73.

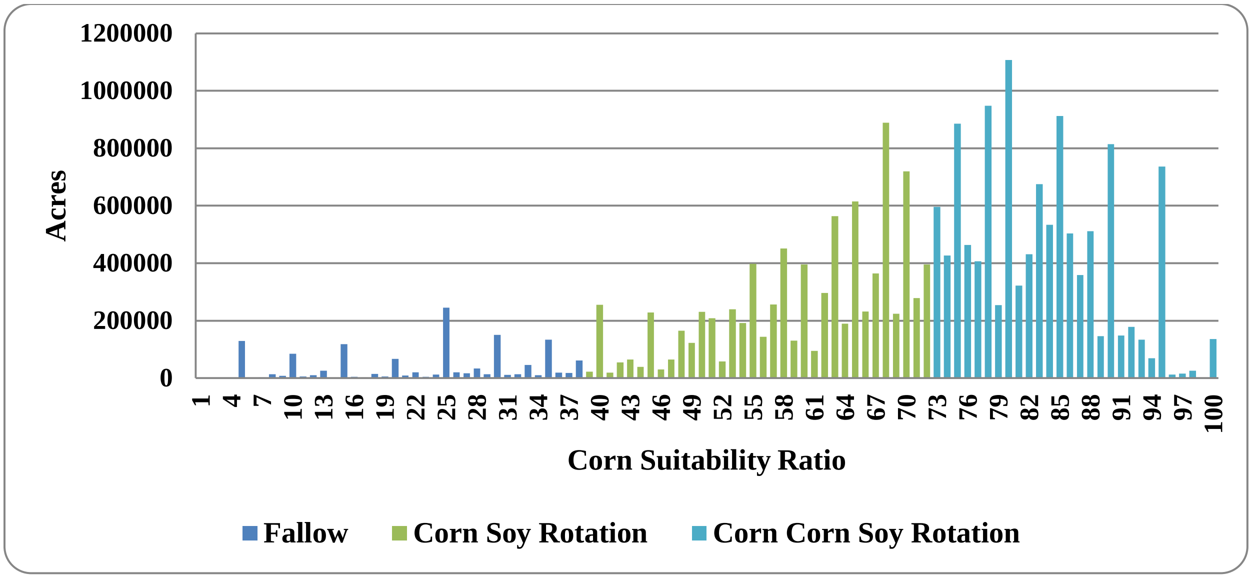

Figure 4.4. Crop Rotation by CSR (base case)

Two important features of the predictions generated in this analysis are the quantity and the soil quality of the acres that change rotation because of the increases in the price of diesel. Figure 4.5 demonstrates this point. The chart indicates the number of acres at each CSR rating by the height of the bars, and the rotation by the color of the bar. Note that the small red section and the large purple section are transitional acres.

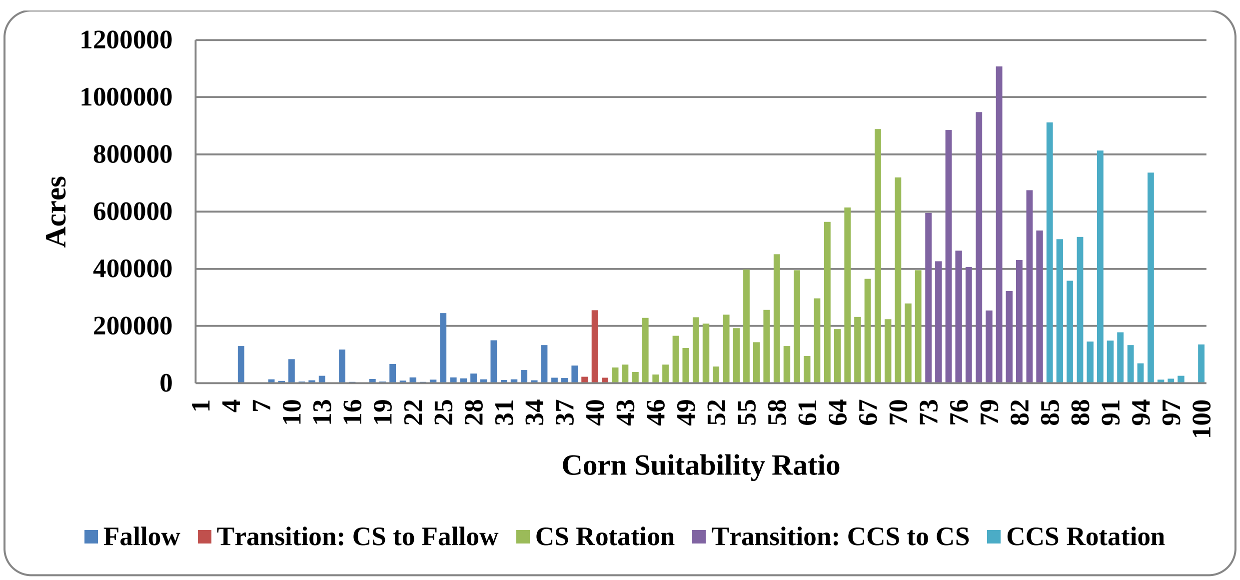

Figure 4.5. Crop Rotation Changes by CSR (Corn Price = $4.21, Diesel Price $2.00 to $2.93)

At $2.00/gallon for diesel the red transitional acres and the green CS acres are in the CS rotation. The acres in red switch to fallow as the price of diesel increases to $2.93. Similarly at $2.00/gallon for diesel the purple transitional acres and the CCS acres are in CCS rotation. The acres in purple switch to the CS rotation as the price of diesel increases to $2.93. There are very few acres that are moved into a fallow rotation even with a nearly 50% increase in the price of diesel and these are the least productive acres. However, almost one third of the high quality acres are predicted to switch from a CCS to a CS rotation. This significantly decreases the number of acres in corn production, but increases the corn yield. This rotational yield impact will be discussed in greater detail to follow.

The same transitional pattern emerges for each of the corn price demand levels considered. The actual CSR rating at which the rotations transition varies but increases with increases in the price of corn. The charts for the four other demand levels are included in Appendix C.

4.1.2. Tillage choice. Conventional tillage dominates the three tillage options modeled in all 25 scenarios (see Table 4.4). Conventional tillage averaged over 99% of the acres tilled, and it was the only tillage in 14 out of the 25 scenarios. By contrast, conservation tillage which included mulch tillage, ridge tillage, etc. did not have any acres in any of the 25 scenarios. No till accounted for the few remaining acres in 11 of the scenarios.

However, these results are highly sensitive to the relative fixed tillage costs between conventional and conservation tillage. A reduction of as little as 2% in the fixed tillage costs for conservation corn tillage and a 5% reduction in the fixed tillage costs for conservation soy tillage dramatically change the tillage selections. In this example 52% of the corn acres and 30% of the soy acres in the base case scenario switch from conventional to conservation tillage. If those fixed tillage cost reductions are increased just 1% more to 3% for corn and 6% for soy even more significant changes to the tillage selection occurs. Corn is switched to 99.5% conservation tillage acres, and soy is switched to 63% conservation tillage acres in the base case scenario.

Table 4.4

Acres Planted by Tillage

	Price of Corn $4.21	**Price of Corn $4.40**	**Price of Corn $4.60**	**Price of Corn $4.80**	**Price of Corn $5.02**
Price of Diesel	**Conventional Tillage Acres**	**Conventional Tillage Acres**	**Conventional Tillage Acres**	**Conventional Tillage Acres**	**Conventional Tillage Acres**
$2.00	20,385,263				
$2.20	20,362,307				
$2.42	20,362,307	20,385,263			
$2.66	20,107,041	20,385,263			
$2.93	20,087,405	20,362,307	20,446,619		
$3.22		20,107,041	20,385,263		
$3.54		20,107,041	20,362,307	20,446,619	
$3.90			20,224,856	20,373,785	
$4.29			20,017,351	20,197,390	20,276,830
$4.72				20,030,677	20,176,261
$5.19				19,640,971	19,845,339
$5.71					19,271,684
$6.28					18,330,578
Price of Diesel	**No Till Acres**	**No Till Acres**	**No Till Acres**	**No Till Acres**	**No Till Acres**
$2.00	0				
$2.20	0				
$2.42	0	0			
$2.66	0	0			
$2.93	0	0	0		
$3.22		0	0		
$3.54		0	0	0	
$3.90			137,451	11,478	
$4.29			89,690	164,917	169,789
$4.72				331,630	209,001
$5.19				446,434	516,968
$5.71					835,358
$6.28					1,756,827

In the cost model for this analysis that was derived from the Ag Decision Maker, there is little or no cost reduction for corn and an increase in the costs for soy by switching to conservation tillage from conventional tillage. Therefore the reduction in yield from conservation tillage relative to conventional tillage without a reduction in the costs makes the conservation tillage option less profitable in all scenarios included in this analysis.

For corn following corn the cost reduction is based primarily on eliminating the pre-harvest chisel plow, and the associated diesel. For corn following soy the increased herbicide costs offset decreases in pre-harvest machinery costs. For soy following corn increases in seed and herbicide costs exceed the decreases in costs from reduced pre-harvest machinery.

Similar trade-offs impact the selection decision between conventional tillage and no-till. However, in the case of no-till there is a significant reduction in diesel use which impacts the tillage selection more as the price of diesel increases. In the most productive and profitable land the increase in the diesel cost for conventional tillage is more easily absorbed by the increased revenue generated by the increased yield. The increase in diesel costs impact the scenarios with the higher diesel costs, and the acres with the lowest yield. These are the CS acres at the lowest CSR ratings, and the corn following corn acres in the CCS rotation with the lowest CSR rating. As seen in Figure 4.6, with the highest corn demand level of $5.02/bushel, the no-till corn and no-till soy make a very low impact even in the scenarios that most favor them.

4.1.3. Acres planted. Corn acres decrease from the base case scenario of 12.2 million acres to a total of 10.0 million acres as the prices of diesel and corn increase throughout the 25 scenarios, see Figure 4.7. For each corn price level the acres of corn is reduced with each increase in the price of diesel. This is due to a shift from the CCS rotation to the CS rotation, there is also a small loss of corn acres from the CS rotation that no longer meet the minimum profit threshold.

The soy acres increased from the base case scenario of 8.2 million acres to a total of 10.0 million acres as the prices of diesel and corn increased throughout the 25 scenarios (see Figure 4.8). For each corn price level the acres of soy are increased with each increase in the price of diesel. This is due to a shift from the CCS rotation to the CS rotation; however, there is a small loss of soy acres from the CS rotation that no longer meet the minimum profit threshold.

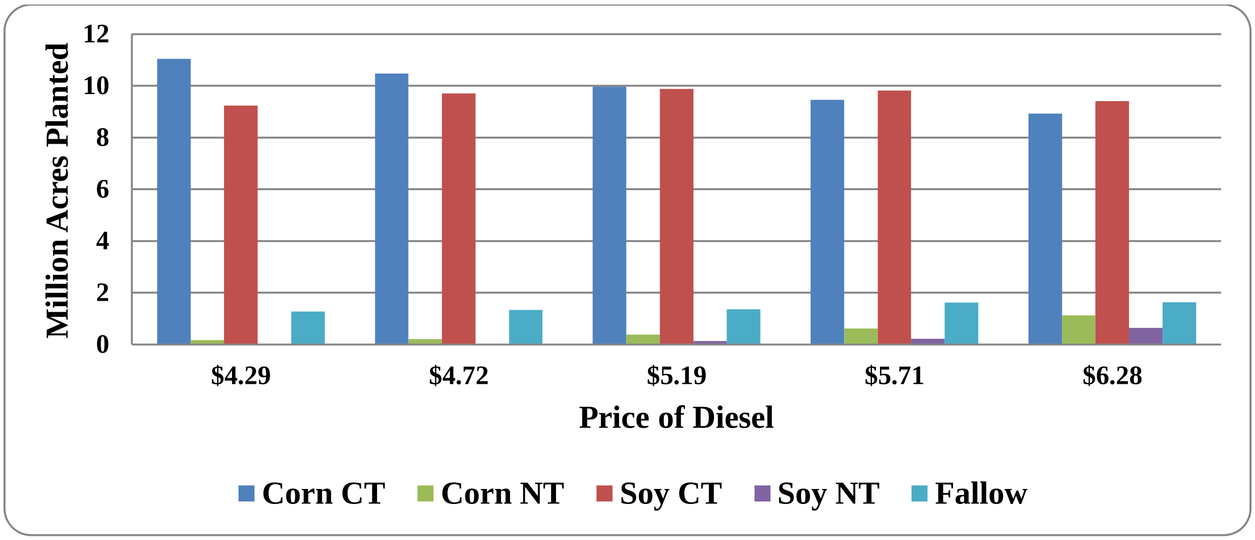

Figure 4.6. Acres Planted by Crop and Tillage

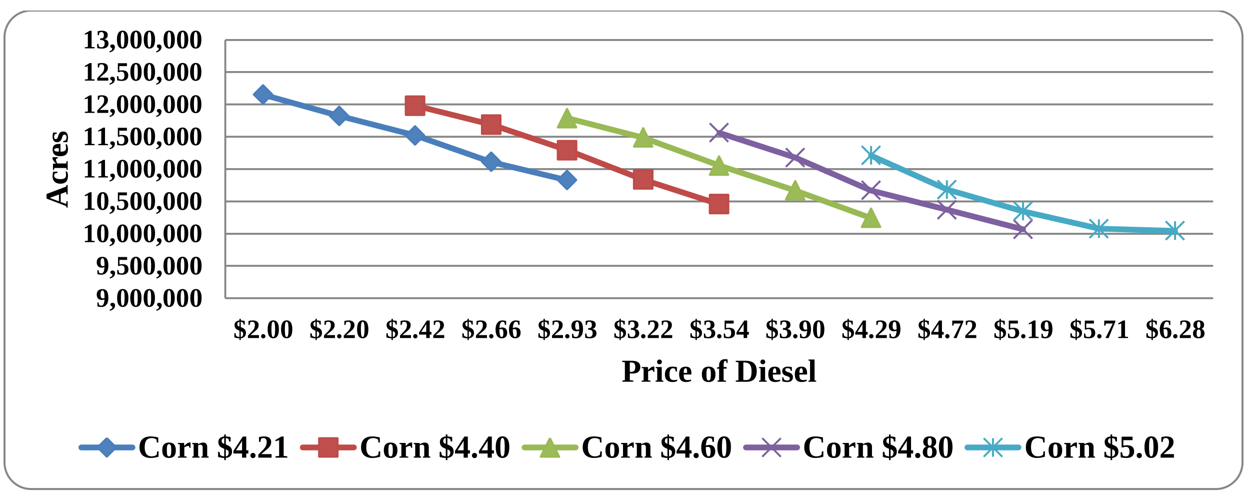

Figure 4.7. Corn Acres Planted

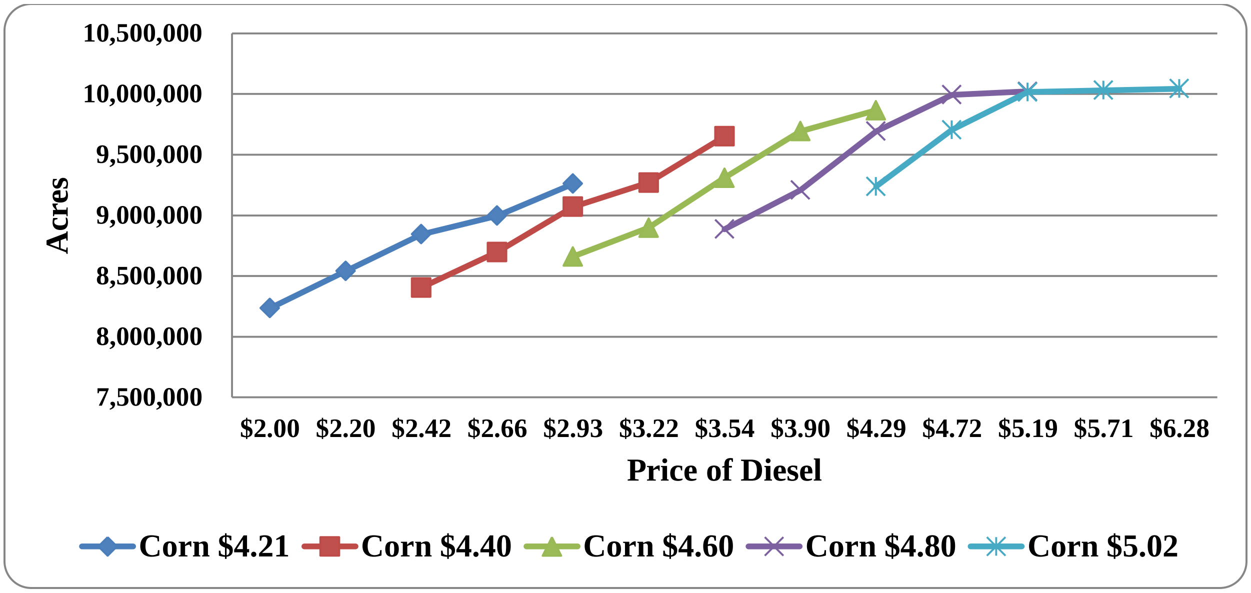

Figure 4.8. Soybean Acres Planted

The equations explaining the quantity of corn acres planted and soy acres planted as the functions of the price of diesel and the price of corn have been estimated using the 25 points of data from the 25 scenarios (see Tables 4.5 and 4.6). A regression of the corn acres has an R Square value of 0.905. A similar regression of the soy acres has an R Square value of 0.879.

$$\text{Corn Acres (millions)} = 5.66 - 0.91 * P_D + 1.89 * P_C \quad (4.5)$$
(P-value) (7.28E-5) (0) (0)

$$\text{Soy Acres (millions)} = 11.7 + 0.68 * P_D - 1.07 * P_C \quad (4.6)$$
(P-value) (0) (0) (1.80E-3)

The log-log regressions on the corn acres and the soybean acres to the prices of diesel and corn have R squared values of 0.979 and 0.957 respectively. The estimated elasticities of the corn acres and the soybean acres to the price of diesel from these regressions are -0.341 and 0.314 respectively. In addition, from the regression equations the estimated elasticity for the acres of corn and soybeans to the price of corn is 0.957 and -0.720 respectively.

$$\ln \text{Corn Acres} = 15.2 - 0.341 * \ln P_D + 0.957 * \ln P_C \quad (4.7)$$
(P-value) (0) (0) (0)

Table 4.5

Corn Acres Planted and Elasticity

Price of Diesel	Elasticity of Corn Acres to Price of Diesel	Price of Corn	$4.21	Price of Corn	$4.40	Price of Corn	$4.60	Price of Corn	$4.80	Price of Corn	$5.02
		Corn Acres	Elasticity	Corn Acres	Elasticity	Corn Acres	Elasticity	Corn Acres	Elasticity	Corn Acres	Elasticity
$2.00		12,150,727									
	A		-0.289								
$2.20		11,821,294									
	B		-0.272								
$2.42		11,518,439		11,980,305							
	C		-0.379		-0.259						
$2.66		11,110,243		11,687,860							
	D		-0.271		-0.362						
$2.93		10,827,249		11,291,583		11,786,245					
	E				-0.431		-0.269				
$3.22				10,837,067		11,487,624					
	F				-0.376		-0.404				
$3.54				10,456,194		11,053,600		11,560,595			
	G						-0.372		-0.354		
$3.90						10,669,044		11,177,533			
	H						-0.429		-0.489		
$4.29						10,241,675		10,669,044		11,208,211	
	I								-0.299		-0.506
$4.72								10,369,308		10,680,522	
	J								-0.311		-0.333
$5.19								10,066,366		10,347,014	
	K										-0.278
$5.71										10,076,185	
	L										-0.034
$6.28										10,043,702	

Table 4.6

Soybean Acres Planted and Elasticity

Price of Diesel	Elasticity of Soy Acres to Price of Diesel	Price of Corn	$4.21	Price of Corn	$4.40	Price of Corn	$4.60	Price of Corn	$4.80	Price of Corn	$5.02
		Soy Acres	Elasticity	Soy Acres	Elasticity	Soy Acres	Elasticity	Soy Acres	Elasticity	Soy Acres	Elasticity
$2.00		8,234,536									
	A		0.384								
$2.20		8,541,013									
	B		0.366								
$2.42		8,843,868		8,404,958							
	C		0.180		0.359						
$2.66		8,996,798		8,697,403							
	D		0.303		0.441						
$2.93		9,260,156		9,070,724		8,660,374					
	E				0.228		0.284				
$3.22				9,269,974		8,897,638					
	F				0.423		0.474				
$3.54				9,650,847		9,308,707		8,886,025			
	G						0.425		0.373		
$3.90						9,693,263		9,207,730			
	H						0.185		0.539		
$4.29						9,865,366		9,693,263		9,238,408	
	I								0.320		0.517
$4.72								9,992,999		9,704,740	
	J								0.029		0.331
$5.19								10,021,038		10,015,293	
	K										0.016
$5.71										10,030,857	
	L										0.013
$6.28										10,043,702	

$$\ln \text{Soybean Acres} = 16.7 + 0.314 * \ln P_D - 0.720 * \ln P_C \quad (4.8)$$
$$(\text{P-value}) \quad (0) \quad (0) \quad (0)$$

4.1.4. Crop yield. There are several interactive impacts on the yield of corn as the price of diesel increases. These impacts occur because of the field level management decisions for crop rotation, tillage choice, and nitrogen application levels. The most significant of these is the crop rotation selection which drives the average corn yield higher as the price of diesel increases. As the price of diesel increases more acres are shifted from the CCS rotation to CS. Since *ceteris paribus* CS has a greater yield for corn than CCS (Hennessy, 2006), the average overall yield increases.

The tillage choice impact on yield has the opposite tendency driving the corn yield down as the price of diesel increases. As the price of diesel increases the no-till option is selected in some of the scenarios with high diesel prices at the lower CSR levels. This decreases the average yield because *ceteris paribus* no-till generates a smaller yield than conventional tillage. However in the model this impact is limited to at most 5% of the acres with the lowest yield.

Finally, as the price of diesel increases the nitrogen application level at any particular CSR level will decrease for a given rotation which would decrease the corn yield. The nitrogen application level selected has a small gradual impact decreasing the corn yield as the price of diesel increases. As the price of diesel and nitrogen increase the profit maximizing nitrogen level decreases at a much smaller percentage, and decreases the corn yield. Like the tillage impact the nitrogen impact is negative in direction and small in magnitude. Unlike the tillage impact the nitrogen impact affects all acres in every scenario. These impacts however do increase as the price of diesel increases as a percentage of the cost of production.

The dominance of the rotational impact on the yield of corn as the price of diesel increases is demonstrated in Figure 4.9. With every increase in the price of diesel except one, the yield of corn increases. Both the tillage choice and nitrogen application level impacts tend to drive the yield down and only the rotational impact drives the yield up. The last scenario has the fewest acres shifting in rotation minimizing the rotational impact. It is also the scenario where both the tillage choice and nitrogen application level choices have the greatest potential impact. This explains why the last scenario is the only scenario where the yield of corn decreases rather than increases with an increase in the price of diesel.

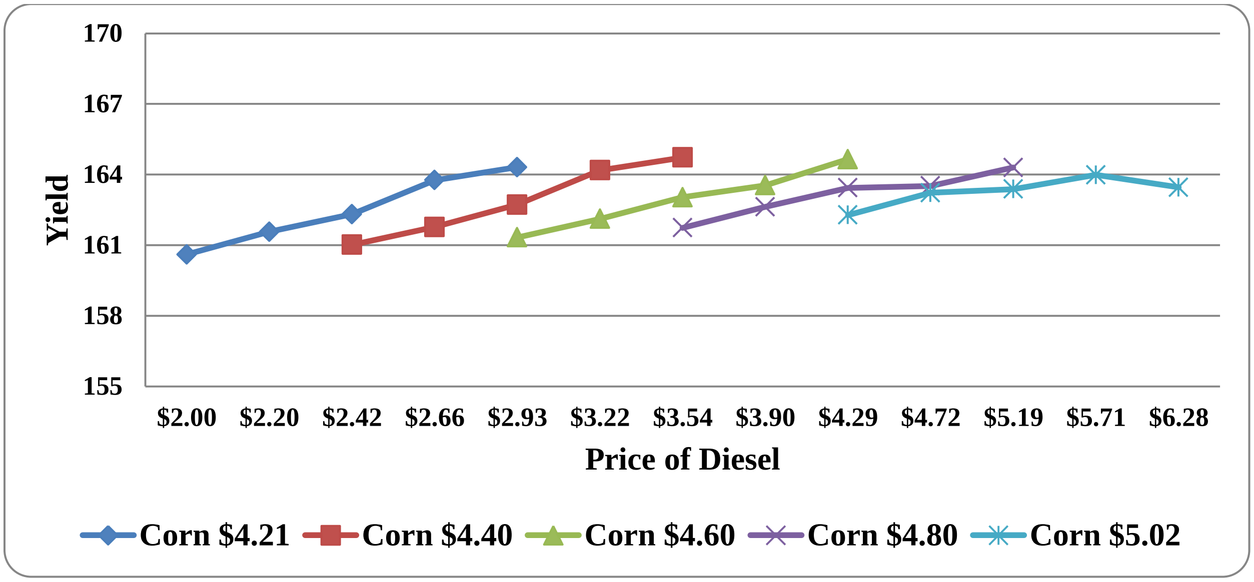

Figure 4.9. Average Corn Yield

The elasticities for the yield of corn to the price of diesel, as identified in Table 4.7, are all positive in direction except for the last. This is because all but the last scenario had increases in the yield of corn as the price of diesel increased. The magnitude for all of these elasticities is less than 0.1 reflecting the relatively small impact the price of diesel has on the average yield.

There are also several interactive impacts on the yield of soybeans as the price of diesel increases. These include field level management decisions for crop rotation, and tillage choice. The most significant of these is the crop rotation selection which drives the soybean yield lower as the price of diesel increases. As the price of diesel increases more acres are shifted from the

Table 4.7

Average Corn Yield and Elasticity

Price of Diesel	Elasticity of Corn Yield to Price of Diesel	Price of Corn	$4.21	Price of Corn	$4.40	Price of Corn	$4.60	Price of Corn	$4.80	Price of Corn	$5.02
		Corn Yield	Elasticity	Corn Yield	Elasticity	Corn Yield	Elasticity	Corn Yield	Elasticity	Corn Yield	Elasticity
$2.00		160.6									
	A		0.063								
$2.20		161.6									
	B		0.049								
$2.42		162.3		161.0							
	C		0.093		0.049						
$2.66		163.8		161.8							
	D		0.035		0.062						
$2.93		164.3		162.7		161.3					
	E				0.094		0.051				
$3.22				164.2		162.1					
	F				0.035		0.059				
$3.54				164.7		163.0		161.7			
	G						0.033		0.058		
$3.90						163.5		162.6			
	H						0.071		0.052		
$4.29						164.7		163.4		162.3	
	I								0.006		0.061
$4.72								163.5		163.2	
	J								0.050		0.010
$5.19								164.3		163.4	
	K										0.039
$5.71										164.0	
	L										-0.034
$6.28										163.5	

CCS rotation to the CS rotation. Since *ceteris paribus* CCS has a greater yield for soy than CS, (Hennessy, 2006) the average overall soy yield decreases. The crop rotation also has a secondary opposite impact. As the rotation shifts from CCS at the highest CSR rated acres to CS there is an increasing number of acres of soy in the higher CSR levels generating higher soy yields for CS.

The tillage choice impact on yield has the same tendency driving the soy yield down as the price of diesel increases. As the price of diesel increases the no-till option is selected in some of the scenarios with high diesel prices at the lower CSR levels. This decreases the average yield *ceteris paribus* because no-till generates a smaller yield than conventional tillage. However this impact is limited to at most 5% of the acres with the lowest yield.

The dominance of the rotational impact reducing the yield of soy as the price of diesel increases is demonstrated in Figure 4.10. With every increase in the price of diesel except three, the yield of soy decreases. The tillage choice impact tends to drive the yield down as well. Only the secondary rotational impact based on the average CSR rating for the soy acres planted in CS tends to drive the yield higher as the price of diesel increases.

The elasticities for the yield of soybeans to the price of diesel, as identified in Table 4.8, are all negative in direction except for three. This is because all but those three scenario had decreases in the yield of soy as the price of diesel. The magnitude for almost all of these elasticities is less than 0.1 reflecting the relatively small impact the price of diesel has on the average yield of soy.

The equations explaining the corn yield and soybean yield as the functions of the price of diesel and the price of corn have been estimated using the 25 points of data from the 25 scenarios. A regression of the corn yield has an R Square value of 0.645. A similar regression of the soybean acres has an R Square value of 0.722.

$$\text{Corn Yield (bushels/acre)} = 180 + 1.69 * P_D - 4.97 * P_C \quad (4.9)$$
(P-value) (0) (0) (1.43E-4)

$$\text{Soybean Yield (bushels/acre)} = 44.4 - 0.405 * P_D + 0.266 * P_C \quad (4.10)$$
(P-value) (0) (4.26E-4) (0.492)

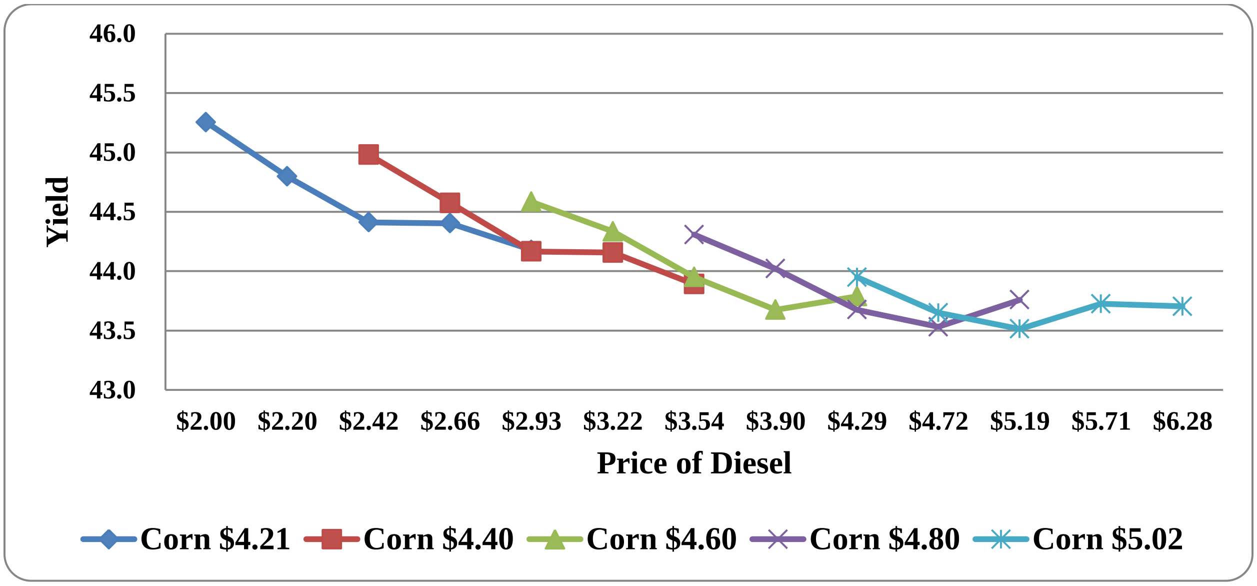

Figure 4.10. Average Soybean Yield

The log-log regressions on the corn yield and the soybean yield to the prices of diesel and corn have R squared values of 0.866 and 0.850 respectively. The estimated elasticities of the corn yield and the soybean yield to the price of diesel from these regressions are 0.0472 and -0.0445 respectively. In addition, from the regression equations the estimated elasticity for the yields of corn and soybeans to the price of corn is -0.180 and 0.0747 respectively.

$$\ln \text{Corn Yield} = 5.31 + 0.0472 * \ln P_D - 0.180 * \ln P_C \quad (4.11)$$
(P-value) (0) (0) (0)

$$\ln \text{Soybean Yield} = 3.73 - 0.0445 * \ln P_D + 0.0747 * \ln P_C \quad (4.12)$$
(P-value) (0) (0) (0.0226)

Table 4.8

Average Soybean Yield and Elasticity

Price of Diesel	Elasticity of Soy Yield to Price of Diesel	Price of Corn	$4.21	Price of Corn	$4.40	Price of Corn	$4.60	Price of Corn	$4.80	Price of Corn	$5.02
		Soy Yield	Elasticity	Soy Yield	Elasticity	Soy Yield	Elasticity	Soy Yield	Elasticity	Soy Yield	Elasticity
$2.00		45.3									
	A		-0.107								
$2.20		44.8									
	B		-0.091								
$2.42		44.4		45.0							
	C		-0.002		-0.096						
$2.66		44.4		44.6							
	D		-0.053		-0.097						
$2.93		44.2		44.2		44.6					
	E				-0.002		-0.059				
$3.22				44.2		44.3					
	F				-0.064		-0.092				
$3.54				43.9		44.0		44.3			
	G						-0.066		-0.068		
$3.90						43.7		44.0			
	H						0.027		-0.083		
$4.29						43.8		43.7		43.9	
	I								-0.035		-0.072
$4.72								43.5		43.7	
	J								0.055		-0.033
$5.19								43.8		43.5	
	K										0.051
$5.71										43.7	
	L										-0.005
$6.28										43.7	

4.1.5. Crop production. The total corn production is the product of the total corn acres and the average corn yield. In the first corn price scenario with the price of corn equal to $4.21 the total production of corn is reduced by 8.8% from 1.95 million bushels down to 1.78 million bushels as the price of diesel increases 46.5% from $2.00/gallon to $2.93/gallon. The primary driver of this reduction is the 10.9% reduction in the total acres of corn planted over the same increase in the price of diesel. The modest 2.3% increase in the yield of corn from 160.6 bushels/acre to 164.3 bushels/acre over the same increase in the price of diesel only helps to offset the reduction in total production of corn caused by the reduction in total acres (see Figure 4.11).

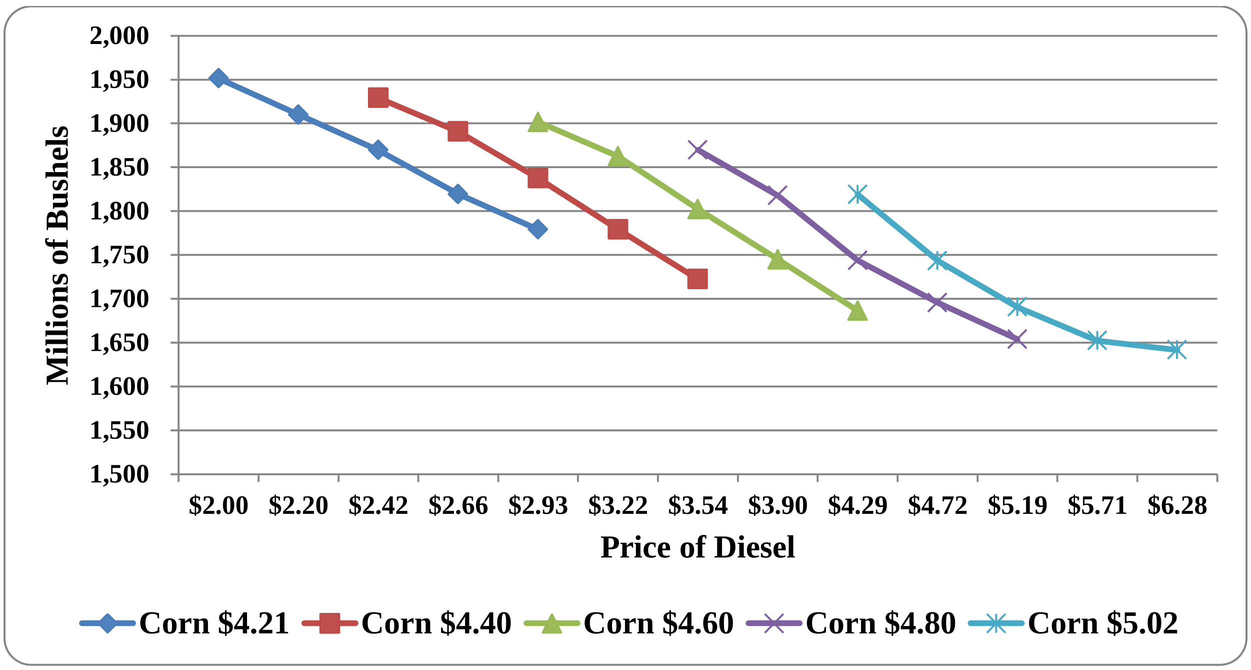

Figure 4.11. Corn Production

The total soybean production is the product of the total soy acres and the average soy yield. In the primary corn price scenario with the price of corn equal to $4.21 the total production of soy is increased by 9.7% from 373 million bushels to 409 million bushels as the price of diesel increases 46.5% from $2.00/gallon to $2.93/gallon. The primary driver of this increase is the

12.5% increase in the total acres of soy planted over the same increase in the price of diesel. The modest 2.4% reduction in the yield of soy from 45.3 bushels/acre down to 44.2 bushels/acre over the same increase in the price of diesel moderates the increase in the total production generated by the increase in total acres of soy planted (see Figure 4.12).

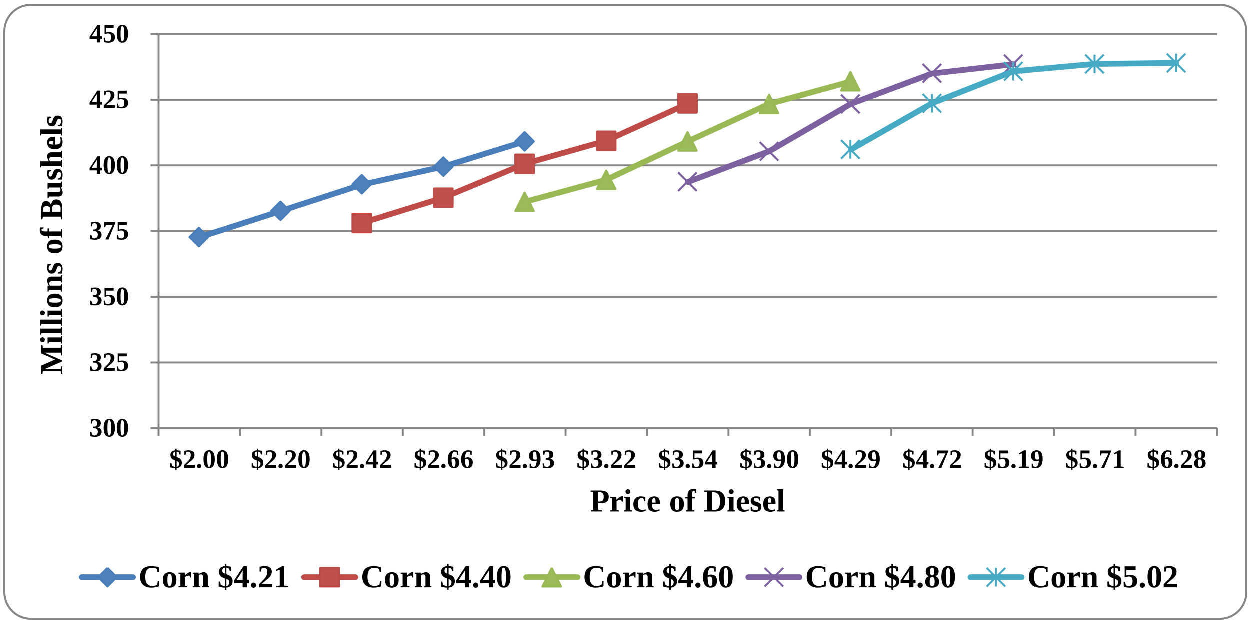

Figure 4.12. Soybean Production

The equations expressing the total corn and soybean productions as the functions of the price of diesel and the price of corn have been estimated using the 25 points of data from the 25 scenarios from Table 4.9 and Table 4.10. A regression of corn production (million bushels) has an R Square value of 0.929. A regression of soybean production (million bushels) has an R Square value of 0.899.

$$\text{Corn Production} = 1{,}102.78 - 129.65 * P_D + 254.06 * P_C \quad (4.13)$$

(P-value) (0) (0) (0)

$$\text{Soybean Production} = 517.85 + 26.49 * P_D - 44.81 * P_C \quad (4.14)$$

(P-value) (0) (0) (2.39E-4)

Table 4.9

Corn Production and Elasticity

Price of Diesel	Elasticity of Corn Production to Price of Diesel	Price of Corn	$4.21	Price of Corn	$4.40	Price of Corn	$4.60	Price of Corn	$4.80	Price of Corn	$5.02
		Production (million bushels)	Elasticity	Production (million bushels)	Elasticity	Production (million bushels)	Elasticity	Production (million bushels)	Elasticity	Production (million bushels)	Elasticity
$2.00		1,951									
	A		-0.225								
$2.20		1,910									
	B		-0.224								
$2.42		1,870		1,929							
	C		-0.286		-0.211						
$2.66		1,819		1,891							
	D		-0.236		-0.300						
$2.93		1,779		1,837		1,901					
	E				-0.338		-0.218				
$3.22				1,779		1,862					
	F				-0.341		-0.345				
$3.54				1,722		1,802		1,870			
	G						-0.339		-0.296		
$3.90						1,745		1,818			
	H						-0.358		-0.437		
$4.29						1,686		1,744		1,819	
	I								-0.294		-0.446
$4.72								1,696		1,743	
	J								-0.262		-0.323
$5.19								1,654		1,691	
	K										-0.240
$5.71										1,652	
	L										-0.068
$6.28										1,642	

Table 4.10

Soybean Production and Elasticity

Price of Diesel	Elasticity of Soy Production to Price of Diesel	Price of Corn	$4.21	Price of Corn	$4.40	Price of Corn	$4.60	Price of Corn	$4.80	Price of Corn	$5.02
		Production (million bushels)	Elasticity	Production (million bushels)	Elasticity	Production (million bushels)	Elasticity	Production (million bushels)	Elasticity	Production (million bushels)	Elasticity
$2.00		373									
	A		0.277								
$2.20		383									
	B		0.275								
$2.42		393		378							
	C		0.178		0.264						
$2.66		399		388							
	D		0.250		0.345						
$2.93		409		401		386					
	E				0.226		0.225				
$3.22				409		394					
	F				0.359		0.383				
$3.54				424		409		394			
	G						0.359		0.305		
$3.90						423		405			
	H						0.212		0.457		
$4.29						432		423		406	
	I								0.285		0.445
$4.72								435		424	
	J								0.084		0.298
$5.19								439		436	
	K										0.067
$5.71										439	
	L										0.008
$6.28										439	

The log-log regressions on the corn production (million bushels) and the soybean production (million Bushels) to the prices of diesel and corn have R squared values of 0.979 and 0.965 respectively. The estimated elasticities of the corn yield and the soybean yield to the priceof diesel from these regressions are -0.294 and 0.269 respectively. In addition, from the regression equations the estimated elasticity for corn and soybean production to the price of corn is 0.777 and - 0.646 respectively.

$$\ln \text{Corn Production} = \underset{(0)}{6.68} - \underset{(0)}{0.294} * \ln P_D + \underset{(0)}{0.777} * \ln P_C \qquad (4.15)$$

(P-value) (0) (0) (0)

$$\ln \text{Soybean Production} = \underset{(0)}{6.66} + \underset{(0)}{0.269} * \ln P_D - \underset{(0)}{0.646} * \ln P_C \qquad (4.16)$$

(P-value) (0) (0) (0)

4.2. Agricultural Energy Use Implications

4.2.1. Diesel use. The total amount of diesel used in the base case scenario was nearly 100 million gallons. This amount always decreased with each increase in the price of diesel. These decreases were based on three changes: switches in crop rotations, acres lost to fallow, and switches in the tillage choice. The most important impact on the gallons of diesel used was the switch in rotation from CCS to CS as the price of diesel increased. This accounted for an average of 53% of the reduction in diesel use, and occurred in all twenty transitions, with an average reduction in diesel use of 667,002 gallons.

The second most important impact on changes in the number of gallons of diesel used was based on acres in the CS rotation being lost to fallow due to the minimum profit requirement. This accounted for an average of 31% of the reduction in diesel use, and occurred in fifteen of the twenty transitions, with an average reduction in diesel use of 383,193 gallons. The third impact on changes in the number of gallons of diesel used was based on acres in the CS rotation being switching from conventional tillage to No Till. This accounted for an average of 16% of the reduction in diesel use, and occurred in ten of the twenty transitions, with an average reduction in diesel use of 199,046 gallons.

The percentage reduction in the use of diesel in the model is significantly less than the percentage increase in the price of diesel. The price of diesel increase by over 46% for each corn price l level scenario, but the reduction in gallons of diesel used ranges from 3.9% to 6.9%, and averages only 5.0%. The twenty elasticities for the gallons of diesel used to the price of diesel are all negative because each increase in the price of diesel results in a decrease in the gallons of diesel used. The elasticities ranged from -0.066 to -0.231, with an average of -0.135.

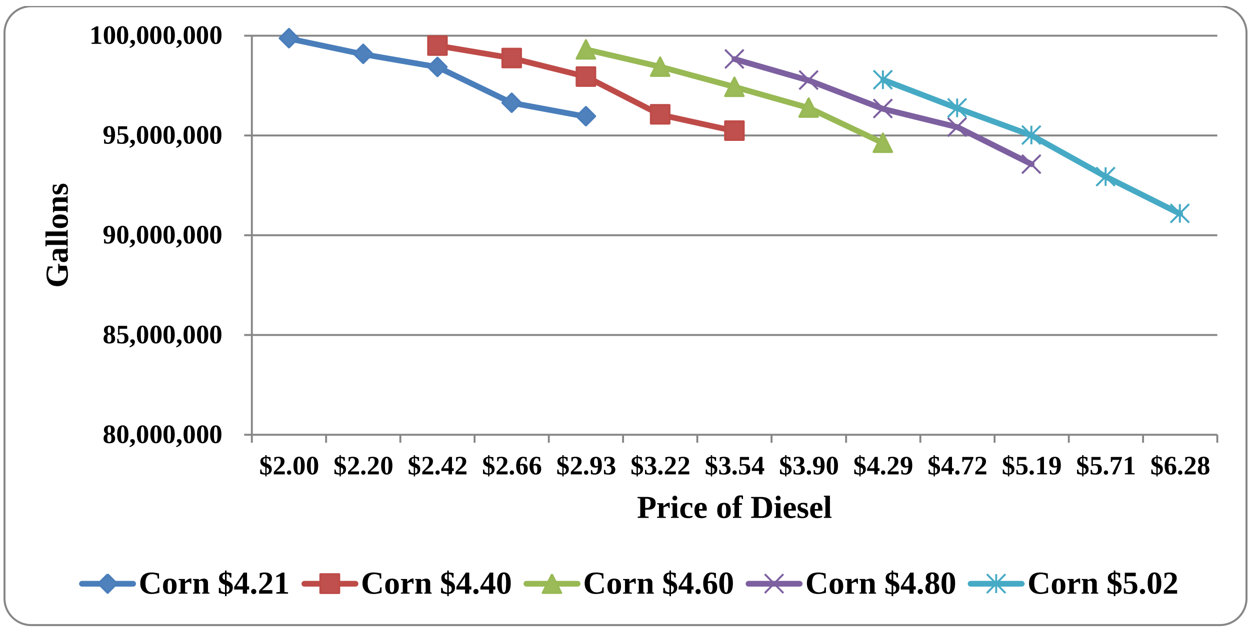

Figure 4.13. Diesel Use

The functions expressing the total gallons of diesel used as the functions of the price of diesel and the price of corn have been estimated using the 25 points of data from the 25 scenarios from Table 4.11. The regression of gallons of diesel use has an R Square value of 0.980.

$$\text{Diesel Use (million gallons)} = 72.1 - 3.51 * P_D + 8.17 * P_C \qquad (4.17)$$

(P-value) (0) (0) (0)

Table 4.11

Diesel Use and Elasticity

Price of Diesel	Elasticity of Diesel Use to Price of Diesel	Price of Corn	$4.21	Price of Corn	$4.40	Price of Corn	$4.60	Price of Corn	$4.80	Price of Corn	$5.02
		Diesel Gallons	Elasticity	Diesel Gallons	Elasticity	Diesel Gallons	Elasticity	Diesel Gallons	Elasticity	Diesel Gallons	Elasticity
$2.00		99,857,776									
	A		-0.083								
$2.20		99,069,991									
	B		-0.069								
$2.42		98,422,234		99,493,271							
	C		-0.194		-0.066						
$2.66		96,624,174		98,867,780							
	D		-0.074		-0.099						
$2.93		95,947,740		97,937,027		99,300,547					
	E				-0.205		-0.091				
$3.22				96,039,896		98,439,510					
	F				-0.089		-0.108				
$3.54				95,225,273		97,428,022		98,817,919			
	G						-0.114		-0.113		
$3.90						96,376,069		97,757,116			
	H						-0.193		-0.154		
$4.29						94,616,729		96,330,219		97,780,794	
	I								-0.101		-0.153
$4.72								95,410,833		96,364,360	
	J								-0.207		-0.150
$5.19								93,550,023		94,996,397	
	K										-0.231
$5.71										92,926,530	
	L										-0.211
$6.28										91,074,014	

The log-log regression on diesel use (million gallons) to the prices of diesel and corn has an R squared value of 0.925. The estimated elasticity of diesel use to the price of diesel from this regression is -0.137. In addition, from the regression equation the estimated elasticity for diesel use to the price of corn is 0.406.

$$\ln \text{Diesel Use} = 4.13 - 0.137 * \ln P_D + 0.406 * \ln P_C \quad (4.18)$$

(P-value) (0) (0) (0)

4.2.2. Nitrogen use. Total nitrogen use in the model decreases as the price of diesel increases for three reasons, the two most important of which are related to changes in the rotation. As the rotation shifts from CCS to CS there are fewer total acres of corn requiring nitrogen. Also, the acres of corn that remain have a greater percentage of corn following soy which requires less average nitrogen per acre than corn following corn does. The third reason is the gradual decrease in the profit-maximizing level of nitrogen use for any given rotation due to the gradual increase in the price of nitrogen. Figure 4.14 indicates this overall decrease in nitrogen use as the price of diesel increases. The nitrogen demand curve flattens out at the highest diesel prices as fewer acres of CCR are converted to the CS rotation.

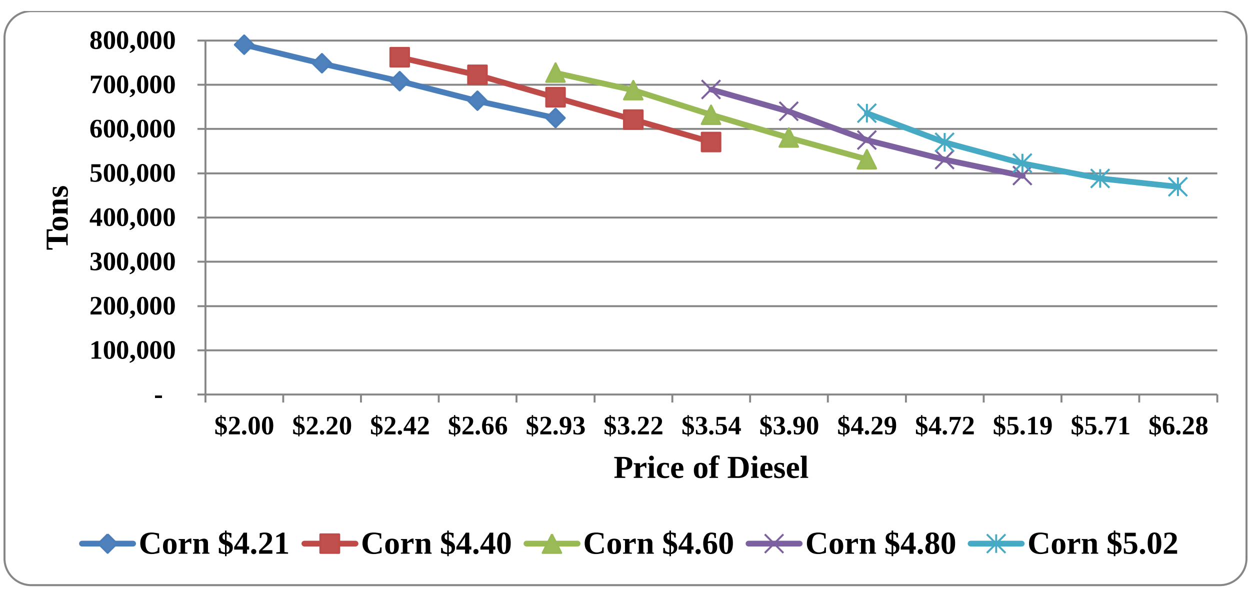

Figure 4.14. Nitrogen Use

The number of tons of nitrogen applied is identified in Table 4.12 for the 25 scenarios by price of corn and diesel, as well as their associated elasticities. As the price of diesel increases, the total use of nitrogen decreases. The demand for nitrogen function has been estimated with a regression on the price of diesel and corn with an R Square value of 0.940.

$$\text{Tons of Nitrogen} = 142{,}368 - 119{,}100 * P_D + 200{,}832 * P_C \quad (4.19)$$
$$\text{(P-value)} \quad (0.293) \quad (0) \quad (0)$$

The log-log regression on nitrogen use (tons) to the prices of diesel and corn has an R squared value of 0.983. The estimated elasticity of diesel use to the price of diesel from this regression is -0.783. In addition, from the regression equation the estimated elasticity for diesel use to the price of corn is 1.82.

$$\ln \text{Nitrogen Use} = 11.5 - 0.783 * \ln P_D + 1.82 * \ln P_C \quad (4.20)$$
$$\text{(P-value)} \quad (0) \quad (0) \quad (0)$$

4.2.2.1. Nitrogen application by CSR. The profit maximizing nitrogen application level for a given price of diesel and corn slowly increases with increases in the CSR. This is because the higher level CSR can cost effectively utilize the additional nitrogen to generate greater yields and higher revenues. This smooth curve is interrupted only by a step increase at the point that the rotation is switched from CS to CCS. There is a greater average nitrogen requirement for the CCS rotation than for the CS rotation.

Figure 4.15 illustrates the average nitrogen application for the acres of corn. The corn after soy component of a CCS rotation would have the same nitrogen application as a CS rotation would, however the second year of corn would have a higher requirement. Also the five scenarios illustrated with a corn price of $4.21 demonstrate that the higher the price of diesel the lower the profit maximizing nitrogen application level, and the higher the CSR rating before the rotation switches to CCS from CS.

Table 4.12

Nitrogen Use and Elasticity

Price of Diesel	Elasticity of Nitrogen to Price of Diesel	Price of Corn Nitrogen Tons	$4.21 Elasticity	Price of Corn Nitrogen Tons	$4.40 Elasticity	Price of Corn Nitrogen Tons	$4.60 Elasticity	Price of Corn Nitrogen Tons	$4.80 Elasticity	Price of Corn Nitrogen Tons	$5.02 Elasticity
$2.00		790,112									
	A		-0.575								
$2.20		748,023									
	B		-0.583								
$2.42		707,633		761,609							
	C		-0.682		-0.562						
$2.66		663,130		721,917							
	D		-0.630		-0.763						
$2.93		624,488		671,274		727,051					
	E				-0.816		-0.587				
$3.22				621,061		687,512					
	F				-0.893		-0.886				
$3.54				570,369		631,846		689,053			
	G						-0.897		-0.784		
$3.90						580,054		639,486			
	H						-0.921		-1.117		
$4.29						531,294		574,881		635,621	
	I								-0.840		-1.148
$4.72								530,645		569,754	
	J								-0.745		-0.916
$5.19								494,284		522,140	
	K										-0.712
$5.71										487,883	
	L										-0.413
$6.28										469,061	

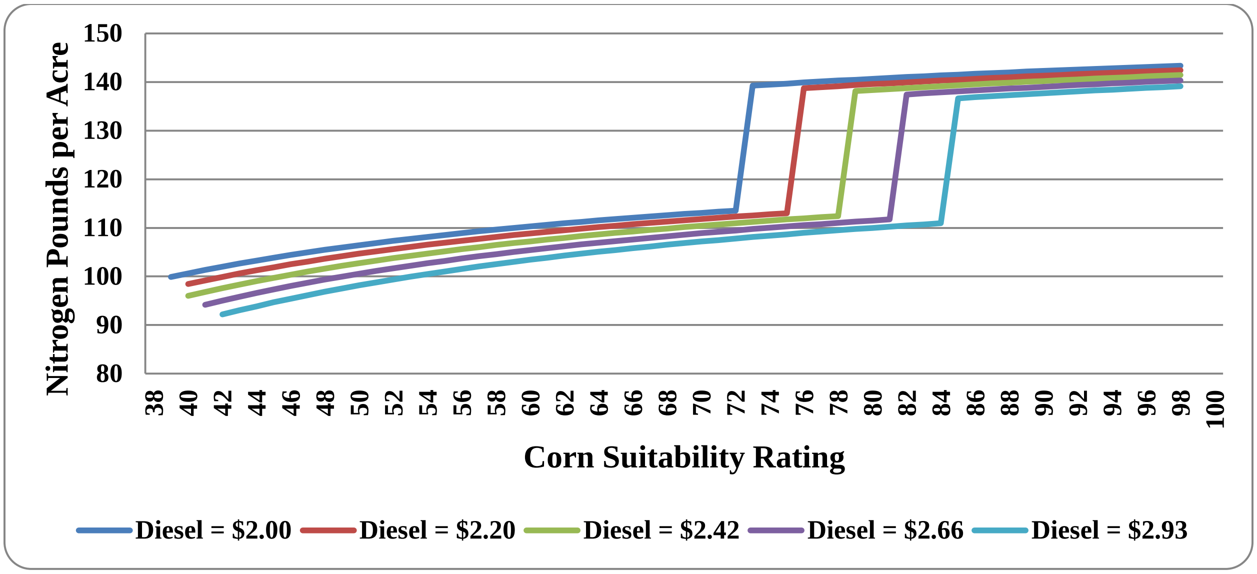

Figure 4.15. Profit Maximizing Nitrogen Use per Acre by CSR

The profit maximizing nitrogen application level (pounds/acre) has been estimated with a regression on the prices of diesel and corn, and the CSR rating with an Adjusted R Square value of 0.989. The CCS variable takes on a value of 1 if the rotation is CCS and 0 otherwise. This indicates that the average increase in nitrogen use in a CCS rotation is 20.6 pounds, and the increase from the first corn rotation to the second corn rotation would be 41.2 pounds.

$$\text{Nitrogen} = 64.5 + 0.486 * \text{CSR} - 6.95 * P_D + 6.87 * P_C + 20.6 * \text{CCS} \quad (4.21)$$

(P-value) (0) (0) (0) (0) (0)

Figure 4.16 illustrates the difference between the traditional yield maximizing average nitrogen application level and this model's profit maximizing application level. Overall there is a 9.5% reduction in the total nitrogen application level from the yield-maximizing application to the profit maximizing application level. This is 83,280 extra tons of nitrogen at a cost of $494/ton and equals over $41 million in extra costs. The extra pounds are greater on a per acre basis at the lower CSR levels. However since the majority of the acres are in the higher CSR levels the majority of the total excess tons of nitrogen are in these acres as demonstrated in Figure 4.17.

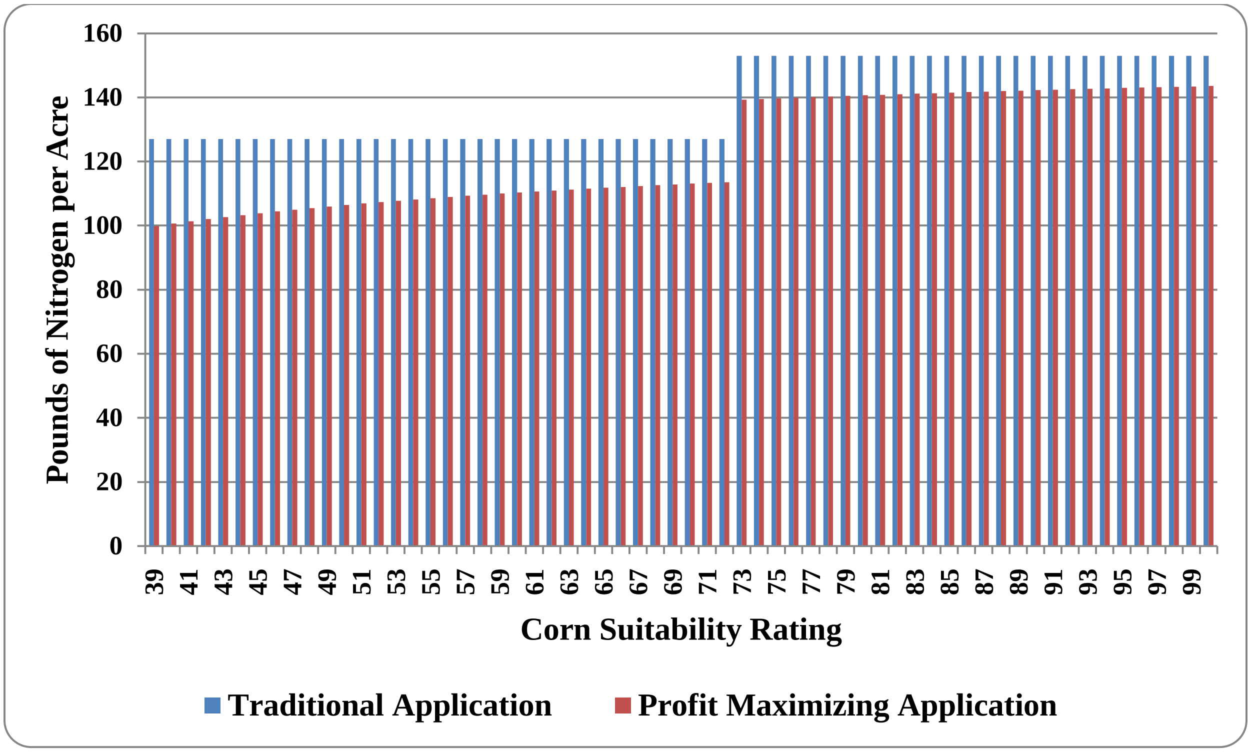

Figure 4.16. Nitrogen Use per Acre by CSR

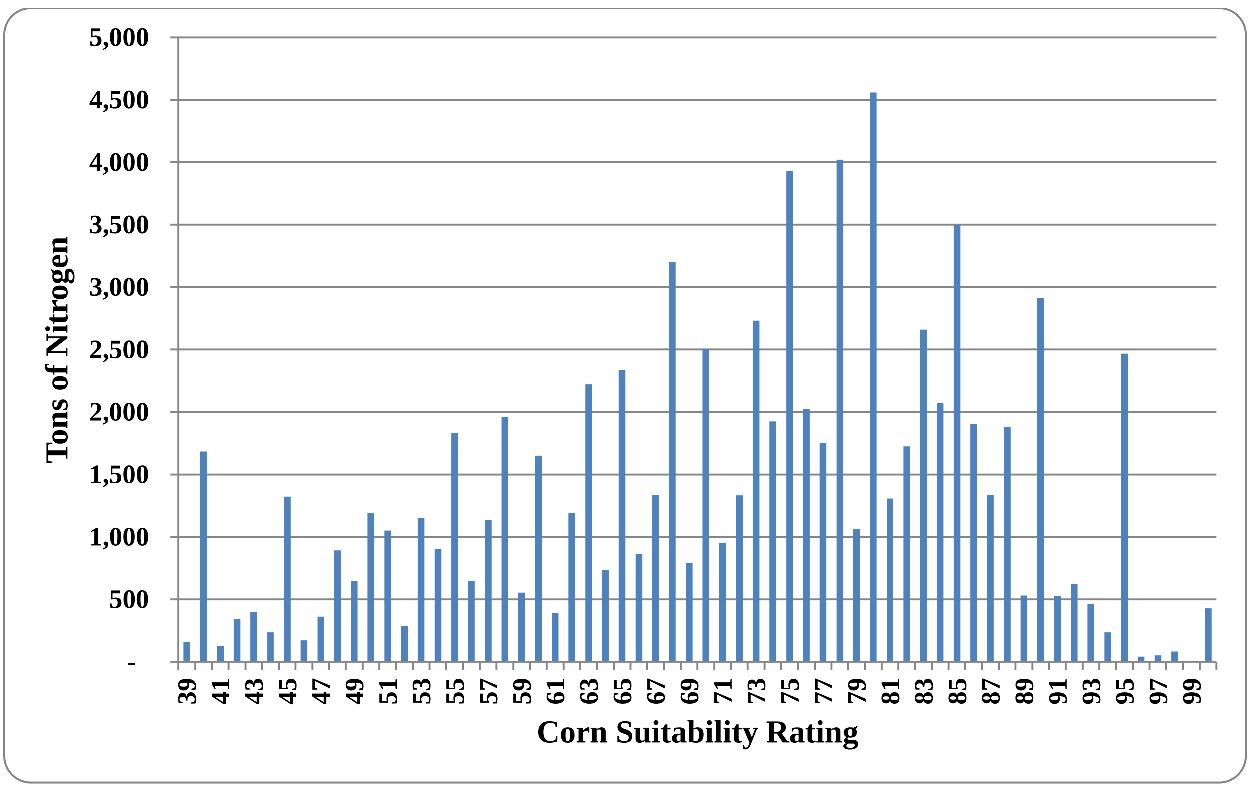

Figure 4.17. Excess Nitrogen Use by CSR

CHAPTER 5

Conclusion

This analysis revealed a general trend towards less intensive crop rotations, tillage options, fuel use, and nitrogen application levels as fuel prices increase. Within the model, changes in energy prices impacted these farm management decisions distinctly unevenly throughout the range of the land quality. Clear trends emerged as changes that impacted lower land quality at lower price levels progressed through to the higher land quality as the price continued to rise. However, these impacts are not spatially uniform due to varying land quality.

One of the results found from the model was that the state level elasticity for corn (or soy) acres, yield, or production varies based on the fuel and grain prices. The direction of the elasticities was as expected, but the magnitude of the elasticities was dependent to a great extent on the number of acres in a particular CSR range. This changed from one farm management decision to another based on changes in the price of diesel at a particular price for corn. Therefore a state level only analysis at a limited diesel price range may not be capturing (or over estimating) significant CSR level impacts which could identify trends and potential turning points, and may not be meaningfully extended beyond the price range in the analysis because of impacts not identified.

Since the state level elasticities over the diesel price range are significantly impacted in magnitude by the mix of the quality of the land, the results in Iowa would not be easily applied to another state with a different mix of land quality, although the methodology and model developed could be applied to the conditions of another state. The elasticities vary by land quality and therefore by region and other land subsets with a different land quality mix such as the acres classified as highly erodible land. This is a potential direction for future work.

The results of the study estimate that the state-level elasticity of corn production to the price of diesel is -0.294, and for soybeans the estimate is 0.269. Corn production decreases in response to higher diesel prices because fewer acres are included in corn production. Soybean production increases because of an increase in the acres of soybeans planted.

The model limitations include: only corn and soybean rotations are considered, only three broadly defined tillage options are considered, and all fuel and fertilizer prices are linked to the price of diesel. In addition, the model is deterministic in that all acres within a particular CSR level select the same farm management decisions for profit maximization, without regard to the magnitude of the incremental profit or the previous selections. There is an undetermined amount of uncertainty that could not be calculated through the model from point estimations in data that was applied from previous research.

References

Al-Kaisi, M., X. Yin, 2004. "Stepwise Time Response of Corn Yield and Economic Return to No Tillage," *Soil and Tillage Research* 78(1): 91-101.

Chen, S., P.M. Porter, C.D. Reese, W.C. Stienstra, 2001. "Crop sequence effects on soybean cyst nematode and soybean and corn yields," *Crop Science* 41, 1843-1849.

Collins, K.J., and J.A. Duffield, 2005. "Energy and agriculture at the crossroads of a new future," In J. Outlaw, K.J. Collins, and J.A. Duffield (Eds.), Agriculture as a Producer and Consumer of Energy, pp. 1-29.

Daberkow, S., D. Lambert, and W. Musser, 2007. "U.S. Corn Producer's Response to Increased Energy Prices: Evidence from Producer Surveys in 2001 and 2005," *Western Economics Forum*, Spring 2007.

De Bruin, J.L., and P. Pedersen, 2009. "Growth, yield, and yield component changes among old and new soybean cultivars," *Agronomy Journal* 101(1), 124-130.

Duffy, M., and D. Smith, 2009. "Estimated Costs of Crop Production in Iowa - 2009," File A1-20, Iowa State University Extention, Ames, Iowa. URL: http://www.extention.iastate.edu/agdm/crops/pdf/a1-20.pdf.

Egli, D.B., 2008. "Comparison of corn and soybean yields in the United States: historical trends and future prospects," *Agronomy Journal* 100, S79-S88.

Hennessy, David A., 2006. "On Monoculture and the Structure of Crop Rotations," *American Journal of Agricultural Economics* 88(4), November 2006.

Huang, W., 2007. "Impact of rising natural gas prices on U.S. ammonia supply," USDA/Economic Research Service World Agricultural Outlook WRS-0702, August 2007.

Huang, W., 2009. "Factors contributing to the recent increase in U.S. fertilizer prices, 2002-08," USDA/Economic Research Service World Agricultural Outlook AR-33, February 2009.

Iowa Cooperative Soil Survey, 2003. Iowa Soil Properties and Interpretation Database, http://icss.agron.iastate.edu/, Accessed March 2010.

Kliebenstein, J.B., and J.P. Chavas, 1977. "Adjustments of Midwest grain farms businesses in response to increases in petroleum energy prices," *Southern Journal of Agricultural Economics* 9(2): 143-148.

Kliebenstein, J.B., and F.P. McCamley, 1983. "Energy-related input demand by crop producers," *Southern Journal of Agricultural Economics* 15(2): 63-69.

Kurkalova, L.A., 2012. "Supply of traditional crops under emerging biomass feedstock markets," Under review.

Kurkalova, L.A., S. Secchi, and P.W. Gassman, 2009. "Greenhouse gas mitigation potential of corn ethanol: accounting for corn acreage expansion," In: *Proceedings of the 2007 National Conference on Environmental Science and Technology,* Springer, New York, NY, pp. 251-257.

Kurkalova, L.A., S. Secchi, and P.W. Gassman, 2010. "Corn stover harvesting: potential supply and water quality implications," In: M. Khanna, D. Zilberman, and J. Scheffran (Eds), *Handbook of Bioenergy Economics and Policy,* Springer, 2010, pp. 307-326.

Malone, R.W., D.W. Meek, J.L. Hatfield, M.E. Mann, R.J. Jaquis, and L. Ma, 2009. "Quasi-biennial corn yield cycles in Iowa," *Agricultural and Forest Meteorology* 149: 1087-1094.

Miller, G., 2005, "Corn Suitability Ratings - An Index to Soil Productivity," Iowa State University Agronomy.

Miranowski, J.A., 2005. "Energy consumption in US agriculture." In: J. Outlaw, K.J. Collins, and J.A. Duffield (Eds.), Agriculture as a Producer and Consumer of Energy, pp. 68-111.

Raulston, J.M., G.M. Knapek, J.L. Outlaw, J.W. Richardson, S.L. Klose, and D.P. Anderson, 2005. "The impact of rising energy prices on Income for representative farms in the Western United States," *Western Economics Forum* 4(2): 7-13.

Sawyer, J., E. Nafziger, G. Randall, L. Bundy, G. Rehm, and B. Joern, 2006. "Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn," Iowa State University extension publication PM 2015, April 2006.

Secchi, S., P.W. Gassman, J.R. Williams, and B.A. Babcock, 2009. "Corn-based Ethanol Production and Environmental Quality: a Case of Iowa and the Conservation Reserve Program," *Environmental Management* 44: 732-744.

Secchi, S., L.A. Kurkalova, P.W. Gassman, and C. Hart, "Land use change in a biofuels hotspot: the case of Iowa, USA," *Biomass and Bioenergy*, 2011, 35(6): 2391-2400.

Sheriff, G., "Efficient waste? Why farmers over-apply nutrients and the implications for policy design," *Review of Agricultural Economics* 27(4): 542-557.

Tewari, and Kulshreshtha, 1988. "Energy Use and Cropping Patterns in Saskatchewan Agriculture Under a rising Energy Price Regime," *Journal of Soil and Water Conservation 43(6): 499-502.*

U.S. Department of Agriculture, National Agricultural Statistical Service (USDA/NASS), Research and Development Division, 2009. Cropland Data Layer, http://www.nass.usda.gov/research/Cropland/SARS1a.html.

Uri, N.D., and K. Day, 1992. "Energy efficiency, technological change, and the dieselization of agriculture in the United States," *Transportation Planning and Technology* 16: 221-231.

Uri, N.D., and J.H. Herbert, 1992. "A note on estimating the demand for diesel fuel by farmers in the United States," *Review of Agricultural Economics* 14(2): 153-167.

Vetsch, J.A., and G.W. Randall, 2002. "Corn Production as Affected by Tillage System and Starter Fertilizer," *Agronomy Journal* 94(3): 532-540.

Vetsch, J.A., G.W., Randall, and J.A. Lamb, 2007. "Corn and Soybean Production as Affected by Tillage Systems," *Agronomy Journal* 99(4): 952-959.

Wilhelm, W.W., and C.S. Wortmann, 2004. "Tillage and Rotation Interactions for Corn and Soybean Grain Yield as Affected by Precipitation and Air Temperature," *Agronomy Journal* 96 (2): 425 - 432.

Werblow, S., 2005. "'New math': will fuel and fertilizer bills drive adoption of conservation tillage?," *Partners* 23(3), November 2005, http://www.ctic.purdue.edu/partners/112005/feature.asp.

Yin, X., M. Al-Kaisi, 2004. "TILLAGE - Periodic Response of Soybean Yields and Economic Returns to Long-Term No-Tillage," *Agronomy Journal* 96(3): 723-733.

Zinser, L., J. Miranowski, J. Shortle, and M. Monson, 1985. "Effects of rising relative energy prices on soil erosion and its control," *American Journal of Agricultural Economics* 67: 558-562.

Appendix A

Tillage Choice Yield Impact

Table 3.1.A

Tillage Yield Impact - Corn Following Corn

	Conventional		Yield	Tillage Impact	Conservation		Yield	Tillage Impact	No Till		Yield	Tillage Impact
Al-Kaisi & Yin	Moldboard Plow	MP	8.61		Ridge Tillage	RT	8.07	95.5%	No Till	NT	7.71	91.2%
Nashua	Chisel Plow	CP	8.29									
	Average		8.45	100.0%								
Al-Kaisi & Yin	Chisel Plow	CP	7.48	100.0%	Ridge Tillage	RT	7.44	99.5%	No Till	NT	7.23	96.7%
Crawfordsville												
Vetsch & Randall	Conventional Tillage	CT	10.50	100.0%	Fall Strip Till	ST	10.2		No Till	NT	9.80	93.3%
					Rawson Zone Till	ZT	10.2					
					Average		10.2	97.1%				
Wilhelm & Wortmann	Moldboard Plow	Plow	6.19		Disk	Disk	5.77		No Till	NT	5.44	91.7%
	Chisel Plow	Chisel	5.68		Ridge-till	Ridge-till	5.94					
	Average		5.94	100.0%	Subsoil	Subsoil	5.96					
					Average		5.89	99.2%				
	Conventional			100.0%	Conservation			97.8%	No Till			93.2%

Table 3.1.B

Tillage Choice Yield Impact - Corn Following Soy

	Conventional		**Yield**	**Tillage Impact**	**Conservation**		**Yield**	**Tillage Impact**	**No Till**		**Yield**	**Tillage Impact**
Al-Kaisi & Yin Burlington	Moldboard	MP	9.04	100.0%	Reduced Tillage	RDT	9.05	100.1%	No Till	NT	8.59	95.0%
Al-Kaisi & Yin Nashua	Moldboard	MP	9.15		Ridge Tillage	RT	8.9	96.8%	No Till	NT	9.03	98.3%
	Chisel Plow	CP	9.23									
	Average		9.19	100.0%								
Al-Kaisi & Yin Newell	Moldboard	MP	9.16		Field Cultivation	FC	9.17		No Till	NT	8.83	96.7%
	Chisel Plow	CP	9.10		Tillage-Plant	TP	8.82					
	Average		9.13	100.0%	Average		9.00	98.5%				
Al-Kaisi & Yin Sutherland	Chisel Plow	CP	9.72	100.0%	Ridge Tillage	RT	9.35	96.2%	No Till	NT	9.19	94.5%
Al-Kaisi & Yin Crawfordsville	Chisel Plow	CP	9.06	100.0%	Ridge Tillage	RT	8.68	95.8%	No Till	NT	8.70	96.0%
Vetsch & Randall	Conventional	CT	11.40	100.0%	Fall Strip Till	ST	11.5		No Till	NT	11.50	100.9%
					Rawson Zone Till	ZT	11.7					
					Average		11.6	101.8%				
Wilhelm & Wortmann	Moldboard	Plow	7.31		Disk	Disk	7.07		No Till	NT	6.97	97.5%
	Chisel Plow	Chisel	6.99		Ridge-till	Ridge-till	7.03					
	Average		7.15	100.0%	Subsoil	Subsoil	7.25					
					Average		7.12	99.5%				
	Conventional			**100.0%**	**Conservation**			**98.4%**	**No Till**			**97.0%**

Table 3.1.C

Tillage Choice Yield Impact - Soy Following Corn

	Conventional		**Yield**	**Tillage Impact**	**Conservation**		**Yield**	**Tillage Impact**	**No Till**		**Yield**	**Tillage Impact**
Yin & Al-Kaisi Burlington	Moldboard	MP	3.15	100.0%	Reduced Tillage	RDT	2.98	94.6%	No Till	NT	2.81	89.2%
Yin & Al-Kaisi Nashua	Moldboard	MP	2.65		Ridge Tillage / Alternative Tillage	RT/AT	2.56	97.2%	No Till	NT	2.58	97.9%
	Chisel Plow	CP	2.62									
	Average		2.64	100.0%								
Yin & Al-Kaisi Crawfordsville	Chisel Plow	CP	2.85	100.0%	Ridge Tillage / Alternative Tillage	RT/AT	2.73	95.8%	No Till	NT	2.80	98.2%
Yin & Al-Kaisi Nashua #	Moldboard	Plow	3.10		Ridge Tillage / Alternative Tillage	RT/AT	2.93	94.5%	No Till	NT	3.00	96.8%
	Chisel Plow	Chisel	3.10									
	Average		3.10	100.0%								
Wilhelm & Wortmann	Moldboard	Plow	2.59		Disk	Disk	2.58		No Till	NT	2.52	97.5%
	Chisel Plow	Chisel	2.58		Ridge-till	Ridge-till	2.60					
	Average		2.59	100.0%	Subsoil	Subsoil	2.59					
					Average		2.59	100.2%				
	Conventional			**100.0%**	**Conservation**			**96.5%**	**No Till**			**95.9%**

Appendix B

Hennessy Equation Derivation Details

3.2.3.1 THE HENNESSY EQUATION FOR CORN YIELD

Hennessy (2006) estimated the yield of corn based on nitrogen input and the crop rotation to be the following:

$$q^{corn} = \alpha_0 + \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1 + \delta Y + \varepsilon$$

The nitrogen application level is N, and F1 is an indicator variable for whether the previous crop was corn (F1 = 1 for previous crop is corn, F1 = 0 for previous crop is soy). The model for corn included only two rotations, continuous corn and corn-soy. This model will ignore the δY term for an adjustment based on the number of years since 1979, therefore the initial Hennessy model for corn yield is the following.

$$q^{corn} = \alpha_0 + \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1$$

3.2.3.1.1 Adopting the Hennessy Corn Equation for Tillage Yield Impact

The Hennessy model estimates the corn yield based on the nitrogen application level, and on crop rotation independent of the choice of tillage. The tillage impact ($\mathcal{T}$) will be applied in this model to the intercept term only.

$$q^{corn} = \alpha_0 * \mathcal{T} + \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1$$

The conventional tillage impact for both rotations will be defined as 100% (output) as the default tillage choice so they will not be included. However, the tillage impact varies by crop rotation for the mulch tillage and no-till. The tillage yield impact by rotation for corn is:

$$\tau = (\tau_{CM}^{(F1)MT}) * (\tau_{CN}^{(F1)NT}) * (\tau_{SM}^{(1-F1)MT}) * (\tau_{SN}^{(1-F1)NT})$$

τ_{CM} The tillage yield impact on the corn following corn rotation for mulch tillage.

τ_{CN} The tillage yield impact on the corn following corn rotation for no-till.

τ_{SM} The tillage yield impact on the corn following soy rotation for mulch tillage.

τ_{SN} The tillage yield impact on the corn following soy rotation for no-till.

F_1 Hennessy's indicator variable that the previous crop was corn.

MT An indicator variable that the tillage choice is mulch tillage.

NT An indicator variable that the tillage choice is no-till.

$$q^{corn} = \alpha_0 * [(\tau_{CM}^{(F1)MT}) * (\tau_{CN}^{(F1)NT}) * (\tau_{SM}^{(1-F1)MT}) * (\tau_{SN}^{(1-F1)NT})] + \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1$$

3.2.3.1.2 Scaling the Hennessy Corn Yield Equation for Regional Field Data

The maximum corn yield from the regional field data by CSR is 2.25 times the CSR. This assumes a corn-soy rotation, conventional tillage, and a nitrogen application level for maximum yield. To get the maximum corn yield from the Hennessy equation, we will apply the same assumptions.

$$q^{corn} = \alpha_0 * [(\tau_{CM}^{(F1)MT}) * (\tau_{CN}^{(F1)NT}) * (\tau_{SM}^{(1-F1)MT}) * (\tau_{SN}^{(1-F1)NT})] + \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1$$

In order to make the yield from the adopted equation equal to the regional field data, we need to apply a scalar a_C.

$$q^{corn} = a_C * [\alpha_0 * (\tau_{CM}^{(F1)MT}) * (\tau_{CN}^{(F1)NT}) * (\tau_{SM}^{(1-F1)MT}) * (\tau_{SN}^{(1-F1)NT}) + \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1]$$

To obtain the maximum corn yield: $F_1 = 0$, $MT = 0$, $NT = 0$ & $N = N_{Max}$

$$q^{corn} = a_C * [\alpha_0 * 1 * 1 * 1 + \alpha_1 (N_{Max} - \rho * 0) + \alpha_2 (N_{Max} - \rho * 0)^2 + \chi_1 * 0]$$

$$q^{corn} = a_C * [\alpha_0 + \alpha_1 (N_{Max}) + \alpha_2 (N_{Max})^2]$$

At maximum yield, these will be equal. $q^{Max} = q^{corn}$

$$2.25 * CSR = a_C * [\alpha_0 + \alpha_1 (N_{Max}) + \alpha_2 (N_{Max})^2]$$

$$a_C = 2.25 * CSR / [\alpha_0 + \alpha_1 (N_{Max}) + \alpha_2 (N_{Max})^2]$$

Inputting Hennessy's parameters yields: $\alpha_0 = 102.33$, $\alpha_1 = 0.428$, $\alpha_2 = -0.00165$

$$a_C = 2.25 * CSR / [102.33 + 0.428 * (N_{Max}) - 0.00165 * (N_{Max})^2]$$

$$q^{corn} = a_C * [\alpha_0 * \tau + \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1]$$

For maximum yield ($N = N_{Max}$, $\tau = 1$, and $F_1 = 0$)

$$q^{corn} = a_C * [\alpha_0 * 1 + \alpha_1 (N_{Max} - \rho *0) + \alpha_2 (N_{Max} - \rho *0)^2 + \chi_1 *0]$$

$$q^{corn} = 2.25 * CSR$$

Combining these equations:

$$a_C * [\alpha_0 + \alpha_1 (N_{Max}) + \alpha_2 (N_{Max})^2] = 2.25 * CSR$$

Solving for a_C

$$a_C = 2.25 * CSR / [\alpha_0 + \alpha_1 * N_{Max} + \alpha_2 * N_{Max}^2]$$

Substituting with Hennessy's values

$$a_C = 2.25 * CSR / [102.33 + 0.428 * (N_{Max}) - 0.00165 * (N_{Max})^2]$$

3.2.3.1.3 Corn Yield Equation

$$q^{corn} = a_C * [\alpha_0 * (\tau_{CM}^{(F1)MT}) * (\tau_{CN}^{(F1)NT}) * (\tau_{SM}^{(1-F1)MT}) * (\tau_{SN}^{(1-F1)NT}) + \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1]$$

Nitrogen level for maximum yield: $\frac{\delta q^{corn}}{\delta N} = 0$

$$\frac{\delta q^{corn}}{\delta N} = a_C * [\alpha_1 + 2\alpha_2 (N_{Max} - \rho F_1)] = 0$$

$$\alpha_1 + 2\alpha_2 (N_{Max} - \rho F_1) = 0$$

$$\frac{-\alpha_1}{2\alpha_2} = N_{Max} - \rho F_1$$

$$N_{Max} = \frac{-\alpha_1}{2\alpha_2} + \rho F_1$$

$$N_{Max} = - 0.428/[2 * (- 0.00165)] + (50.98) * 0$$

Nitrogen level for maximum yield: $\mathbf{N_{Max} = 129.70}$

Solve for the value of a_C

$$a_C = 2.25 * CSR / [102.33 + 0.428 * (N_{Max}) - 0.00165 * (N_{Max})^2]$$

$$a_C = 2.25 * CSR / [102.33 + 0.428 * (129.70) - 0.00165 * (129.7)^2]$$

$$a_C = 2.25 * CSR / [102.33 + 55.51 - 27.76]$$

$$a_C = 0.0173 * CSR$$

Therefore the final adopted Hennessy yield for corn is:

$$q^{corn} = a_C * [\alpha_0 * (\tau_{CM}^{(F1)MT}) * (\tau_{CN}^{(F1)NT}) * (\tau_{SM}^{(1-F1)MT}) * (\tau_{SN}^{(1-F1)NT}) + \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1]$$

$$q^{corn} = 0.0173 * CSR * [\alpha_0 * (\tau_{CM}^{(F1)MT}) * (\tau_{CN}^{(F1)NT}) * (\tau_{SM}^{(1-F1)MT}) * (\tau_{SN}^{(1-F1)NT}) + \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1]$$

Inputting Hennessy's parameter yields: $\alpha_0 = 102.33$, $\alpha_1 = 0.428$, $\alpha_2 = -0.00165$, $\rho = 50.98$, $\chi_1 = -16.46$

$$q^{corn} = 0.0173 * CSR * [102.33 * (\tau_{CM}^{(F1)MT}) * (\tau_{CN}^{(F1)NT}) * (\tau_{SM}^{(1-F1)MT}) * (\tau_{SN}^{(1-F1)NT})$$
$$+ 0.428 * (N - 50.98 * F_1) - 0.00165 * (N - 50.98 * F_1)^2 - 16.46 * F_1]$$

Inputting the estimated tillage yield impact parameters from literature review yields:

$$\tau_{CM} = 0.978, \ \tau_{CN} = 0.932, \ \tau_{SM} = 0.984, \ \tau_{SN} = 0.970$$

$$\mathbf{q^{corn} = 0.0173 * CSR * [102.33 * 0.978^{(F1)MT} * 0.932^{(F1)NT} * 0.984^{(1-F1)MT} * 0.970^{(1-F1)NT}}$$
$$\mathbf{+ 0.428 * (N - 50.98 * F_1) - 0.00165 * (N - 50.98 * F_1)^2 - 16.46 * F_1]}$$

This is the final applied corn yield equation for the model.

3.2.3.2 DETERMINE THE PROFIT FROM CORN

Profit of Corn (π_C): $\pi_C = R_C - C_C$

Revenue from Corn (R_C): $R_C = P_C * q^{corn}$

The revenue from corn is equal to the price of corn $\mathbf{P_C}$ times the quantity of corn $\mathbf{q^{corn}}$.

$$R_C = P_C * 0.0173 * CSR * [\alpha_0 * (\tau_{CM}^{(F1)MT}) * (\tau_{CN}^{(F1)NT}) * (\tau_{SM}^{(1-F1)MT}) * (\tau_{SN}^{(1-F1)NT}) + \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1]$$

Cost of Corn (C_C): $C_C = CF_{RT} + CV_B * q^{corn} + D_{RT} * P_D + P_B * q^{corn} * P_P + N * P_N$

The cost of corn equals the fixed cost of corn $\mathbf{CF_{RT}}$ (by rotation & tillage), plus the variable cost of corn per bushel $\mathbf{CV_B}$ (by rotation & tillage) times the quantity of corn $\mathbf{q^{corn}}$ (by rotation, tillage & CSR), plus the diesel fuel use $\mathbf{D_{RT}}$, (by rotation & tillage) times the price of diesel $\mathbf{P_D}$, plus the propane fuel use gallons per bushel $\mathbf{P_B}$ times the quantity **bushels** of corn $\mathbf{q^{corn}}$ (by rotation, tillage & CSR) times the price of propane $\mathbf{P_P}$, plus the nitrogen application level **N** times the price of nitrogen $\mathbf{P_N}$.

$$CF_{RT} = CF_{CC}^{(F1)CT} * CF_{CM}^{(F1)MT} * CF_{CN}^{(F1)TN} * CF_{SC}^{(1-F1)CT} * CF_{SM}^{(1-F1)MT} * CF_{SN}^{(1-F1)NT}$$

$$CV_B = CV_{CC}^{(F1)CT} * CV_{CM}^{(F1)MT} * CV_{CN}^{(F1)TN} * CV_{SC}^{(1-F1)CT} * CV_{SM}^{(1-F1)MT} * CV_{SN}^{(1-F1)NT}$$

$$D_{RT} = D_{CC}^{(F1)CT} * D_{CM}^{(F1)MT} * D_{CN}^{(F1)TN} * D_{SC}^{(1-F1)CT} * D_{SM}^{(1-F1)MT} * D_{SN}^{(1-F1)NT}$$

$$P_B = P_{CC}^{(F1)CT} * P_{CM}^{(F1)MT} * P_{CN}^{(F1)TN} * P_{SC}^{(1-F1)CT} * P_{SM}^{(1-F1)MT} * P_{SN}^{(1-F1)NT}$$

CF_{CC} is the fixed cost of the corn after corn rotation for conventional tillage.

CF_{CM} is the fixed cost of the corn after corn rotation for mulch tillage.

CF_{CN} is the fixed cost of the corn after corn rotation for no-till.

CF_{SC} is the fixed cost of the corn after soy rotation for conventional tillage.

CF_{SM} is the fixed cost of the corn after soy rotation for mulch tillage.

CF_{SN} is the fixed cost of the corn after soy rotation for no-till.

CV_{CC} is the variable cost (per bushel) of the corn after corn rotation for conventional tillage.

CV_{CM} is the variable cost (per bushel) of the corn after corn rotation for mulch tillage.

CV_{CN} is the variable cost (per bushel) of the corn after corn rotation for no-till.

CV_{SC} is the variable cost (per bushel) of the corn after soy rotation for conventional tillage.

CV_{SM} is the variable cost (per bushel) of the corn after soy rotation for mulch tillage.

CV_{SN} is the variable cost (per bushel) of the corn after soy rotation for no-till.

D_{CC} is the diesel required for the corn after corn rotation for conventional tillage.

D_{CM} is the diesel required for the corn after corn rotation for mulch tillage.

D_{CN} is the diesel required for the corn after corn rotation for no-till.

D_{SC} is the diesel required for the corn after soy rotation for conventional tillage.

D_{SM} is the diesel required for the corn after soy rotation for mulch tillage.

D_{SN} is the diesel required for the corn after soy rotation for no-till.

P_{CC} is the propane (per bushel) required for the corn after corn rotation for conventional tillage.

P_{CM} is the propane (per bushel) required for the corn after corn rotation for mulch tillage.

P_{CN} is the propane (per bushel) required for the corn after corn rotation for no-till.

P_{SC} is the propane (per bushel) required for the corn after soy rotation for conventional tillage.

P_{SM} is the propane (per bushel) required for the corn after soy rotation for mulch tillage.

P_{SN} is the propane (per bushel) required for the corn after soy rotation for no-till.

Profit of Corn (π_C): $\pi_C = R_C - C_C$

$$\boldsymbol{\pi_C = (P_C * q^{corn}) - (CF_{RT} + CV_B * q^{corn} + D_{RT} * P_D + P_B * P_P * q^{corn} + N * P_N)}$$

$$\pi_C = P_C * 0.0173 * CSR * [\alpha_0 * (\tau_{CM}^{(F1)MT}) * (\tau_{CN}^{(F1)NT}) * (\tau_{SM}^{(1-F1)MT}) * (\tau_{SN}^{(1-F1)NT}) + \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1]$$

$$- CF_{CC}^{(F1)CT} * CF_{CM}^{(F1)MT} * CF_{CN}^{(F1)TN} * CF_{SC}^{(1-F1)CT} * CF_{SM}^{(1-F1)MT} * CF_{SN}^{(1-F1)NT}$$

$$- (CV_{CC}^{(F1)CT} * CV_{CM}^{(F1)MT} * CV_{CN}^{(F1)TN} * CV_{SC}^{(1-F1)CT} * CV_{SM}^{(1-F1)MT} * CV_{SN}^{(1-F1)NT})$$

$$* 0.0173 * CSR * [\alpha_0 * (\tau_{CM}^{(F1)MT}) * (\tau_{CN}^{(F1)NT}) * (\tau_{SM}^{(1-F1)MT}) * (\tau_{SN}^{(1-F1)NT})$$

$$+ \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1]$$

$$- (D_{CC}^{(F1)CT} * D_{CM}^{(F1)MT} * D_{CN}^{(F1)TN} * D_{SC}^{(1-F1)CT} * D_{SM}^{(1-F1)MT} * D_{SN}^{(1-F1)NT}) * P_D$$

$$- (P_{CC}^{(F1)CT} * P_{CM}^{(F1)MT} * P_{CN}^{(F1)TN} * P_{SC}^{(1-F1)CT} * P_{SM}^{(1-F1)MT} * P_{SN}^{(1-F1)NT}) * P_P$$

$$* 0.0173 * CSR * [\alpha_0 * (\tau_{CM}^{(F1)MT}) * (\tau_{CN}^{(F1)NT}) * (\tau_{SM}^{(1-F1)MT}) * (\tau_{SN}^{(1-F1)NT})$$

$$+ \alpha_1 (N - \rho F_1) + \alpha_2 (N - \rho F_1)^2 + \chi_1 F_1]$$

$$- N * P_N$$

Nitrogen level for maximum corn profit: $\frac{\delta \pi_c}{\delta_N} = 0$

$$\frac{\delta \pi_c}{\delta_N} = P_C * 0.0173 * CSR * [\alpha_1 + 2\alpha_2 (N_\pi - \rho F_1)]$$

$$- CV_B * 0.0173 * CSR * [\alpha_1 + 2\alpha_2 (N_\pi - \rho F_1)]$$

$$- P_B * P_P * 0.0173 * CSR * [\alpha_1 + 2\alpha_2 (N_\pi - \rho F_1)]$$

$$- P_N = 0$$

$$P_N = (P_C - CV_B - P_B * P_P) * 0.0173 * CSR * [\alpha_1 + 2\alpha_2 (N_\pi - \rho F_1)]$$

$$P_N / [(P_C - CV_B - P_B * P_P) * 0.0173 * CSR] = \alpha_1 + 2\alpha_2 (N_\pi - \rho F_1)$$

$$P_N / [(P_C - CV_B - P_B * P_P) * 0.0173 * CSR] - \alpha_1 = 2\alpha_2 (N_\pi - \rho F_1)$$

$$P_N / [(P_C - CV_B - P_B * P_P) * 0.0173 * CSR * 2\alpha_2] - (\alpha_1 / 2\alpha_2) = N_\pi - \rho F_1$$

$$\mathbf{N_\pi = P_N / [(P_C - CV_B - P_B * P_P) * 0.0173 * CSR * 2\alpha_2] - (\alpha_1 / 2\alpha_2) + \rho F_1}$$

3.2.3.3 THE HENNESSY EQUATION FOR SOY YIELD

Hennessy (2006) estimated the yield of soy based on the crop rotation to be:

$$q^{soy} = \alpha + \sum_{i=2}^{4} \varphi_i G_i + \delta Y$$

In the Two-Year Memory model that Hennessy selects, α is the default yield for continuous soy rotation.

For the corn-soy rotation G_2 is indicator, and φ_2 is the incremental increase in yield for this rotation.

For the corn-corn-soy rotation G_4 is indicator, and φ_4 is the incremental increase in yield for this rotation.

Note, since these rotations are exclusive and comprehensive, then exactly one of G_2 and G_4 is 1, and the other is 0.

We will ignore the δY (year) impact for this model. Therefore our adopted Hennessy model for soy yield is:

$$q^{soy} = \alpha + \varphi_2 * G_2 + \varphi_4 * G_4$$

3.2.3.3.1 Adopting the Hennessy Soy Equation for Tillage Yield Impact

$$q^{soy} = \alpha * T + \varphi_2 * G_2 + \varphi_4 * G_4$$

The conventional tillage impact for both rotations will be defined as 100% (no reduction) so they will not be included.

However, the tillage impact varies by crop rotation for mulch tillage and no-till. Tillage yield impact by rotation for soy:

$$T = \mathcal{T}_{C1M}^{(G2)MT} * \mathcal{T}_{C1N}^{(G2)NT} * \mathcal{T}_{C2M}^{(G4)MT} * \mathcal{T}_{C2N}^{(G4)NT}$$

$\mathcal{T}_{C1M}$ is the tillage yield impact on soy for mulch tillage with one previous crop of corn.

$\mathcal{T}_{C1N}$ is the tillage yield impact on soy for no-till with one previous crop of corn.

$\mathcal{T}_{C2M}$ is the tillage yield impact on soy for mulch tillage with two previous crops of corn.

$\mathcal{T}_{C2N}$ is the tillage yield impact on soy for no-till with two previous crops of corn.

G_2 is Hennessy's indicator variable that there was one previous crop of corn.

G_4 is Hennessy's indicator variable that there were two previous crops of corn.

MT is an indicator variable that the tillage choice is mulch tillage.

NT is an indicator variable that the tillage choice is no-till.

We did not find a study that looked at the difference between the tillage impact for one previous corn and two previous corn rotations. At this point we will set $\mathcal{T}_{C1M} = \mathcal{T}_{C2M}$, and $\mathcal{T}_{C1N} = \mathcal{T}_{C2N}$. It will be left for future research to identify whether and what these differences may be.

$$q^{soy} = \alpha * \mathcal{T}_{C1M}^{(G2)MT} * \mathcal{T}_{C1N}^{(G2)NT} * \mathcal{T}_{C2M}^{(G4)MT} * \mathcal{T}_{C2N}^{(G4)NT} + \varphi_2 * G_2 + \varphi_4 * G_4$$

3.2.3.3.2 Scaling the Hennessy Soy Yield Equation for Regional Field Data

The maximum soy yield from the regional field data by CSR is: $q^{Max} = 0.67 * CSR$

This assumes a corn-corn-soy rotation, and conventional tillage. To get the maximum corn yield from the Hennessy equation, we will apply the same assumptions.

$$q^{soy} = \alpha * \mathcal{T}_{C1M}^{(G2)MT} * \mathcal{T}_{C1N}^{(G2)NT} * \mathcal{T}_{C2M}^{(G4)MT} * \mathcal{T}_{C2N}^{(G4)NT} + \varphi_2 * G_2 + \varphi_4 * G_4$$

In order to make the yield from the adopted equation equal to the regional field data, we need to apply a scale a_S.

$$q^{soy} = a_S * [\alpha * \mathcal{T}_{C1M}^{(G2)MT} * \mathcal{T}_{C1N}^{(G2)NT} * \mathcal{T}_{C2M}^{(G4)MT} * \mathcal{T}_{C2N}^{(G4)NT} + \varphi_2 * G_2 + \varphi_4 * G_4]$$

To obtain the maximum yield: $G_2 = 0$, $G_4 = 1$, MT = 0 & NT = 0,

$$q^{soy} = a_S * [\alpha * 1 * 1 * 1 * 1 + \varphi_2 * 0 + \varphi_4 * 1]$$

$$q^{soy} = a_S * [\alpha + \varphi_4]$$

At maximum yield, these will be equal. $q^{Max} = q^{soy}$

$$0.67 * CSR = a_S * [\alpha + \varphi_4]$$

$$a_S = 0.67 * CSR / [\alpha + \varphi_4]$$

Inputting Hennessy's parameters yields: $\alpha = 28.04$, $\varphi_4 = 11.64$

$$a_S = 0.67 * CSR / [28.04 + 11.64]$$

$$a_S = 0.0169 * CSR$$

Therefore the final adopted Hennessy yield for soy is:

$$q^{soy} = a_S * [\alpha * \mathcal{T}_{C1M}^{(G2)MT} * \mathcal{T}_{C1N}^{(G2)NT} * \mathcal{T}_{C2M}^{(G4)MT} * \mathcal{T}_{C2N}^{(G4)NT} + \varphi_2 * G_2 + \varphi_4 * G_4]$$

$$q^{soy} = 0.0169 * CSR * [\alpha * \mathcal{T}_{C1M}^{(G2)MT} * \mathcal{T}_{C1N}^{(G2)NT} * \mathcal{T}_{C2M}^{(G4)MT} * \mathcal{T}_{C2N}^{(G4)NT} + \varphi_2 * G_2 + \varphi_4 * G_4]$$

Inputting Hennessy's parameters yields: $\alpha = 28.04$, $\varphi_2 = 6.973$, $\varphi_4 = 11.64$

$$q^{soy} = 0.0169 * CSR * [28.04 * \mathcal{T}_{C1M}^{(G2)MT} * \mathcal{T}_{C1N}^{(G2)NT} * \mathcal{T}_{C2M}^{(G4)MT} * \mathcal{T}_{C2N}^{(G4)NT} + 6.973 * G_2 + 11.64 * G_4]$$

Inputting the estimated tillage yield impact parameters from literature review yields:

$$\tau_{C1M} = 0.974,\ \tau_{C1N} = 0.951,\ \tau_{C2M} = 0.974,\ \tau_{C2N} = 0.951$$

$$\mathbf{q^{soy} = 0.0169 * CSR * [28.04 * 0.974^{(G2)MT} * 0.951^{(G2)NT} * 0.974^{(G4)MT} * 0.951^{(G4)NT} + 6.973 * G_2 + 11.64 * G_4]}$$

This is the final applied soy yield equation for the model.

3.2.3.4 DETERMINE THE PROFIT FROM SOY

Profit of Corn (π_S): $\pi_S = R_S - C_S$

Revenue from Corn (R_S): $R_S = P_S * q^{soy}$

The revenue from soy is equal to the price of soy $\mathbf{P_S}$ times the quantity of soy $\mathbf{q^{soy}}$.

$$R_S = P_S * 0.0169 * CSR * [28.04 * \tau_{C1M}^{(G2)MT} * \tau_{C1N}^{(G2)NT} * \tau_{C2M}^{(G4)MT} * \tau_{C2N}^{(G4)NT} + 6.973 * G_2 + 11.64 * G_4]$$

Cost of Soy (C_S): $C_S = CF_{RT} + CV_B * q^{soy} + D_{RT} * P_D$

The cost of soy equals the fixed cost of soy $\mathbf{CF_{RT}}$ (by rotation & tillage), plus the variable cost of soy per bushel $\mathbf{CV_B}$ (by rotation & tillage) times the quantity of soy $\mathbf{q^{soy}}$ (by rotation, tillage & CSR), plus the diesel fuel use $\mathbf{D_{RT}}$, (by rotation & tillage) times the price of diesel $\mathbf{P_D}$.

$$CF_{RT} = CF_{C1C}^{(G2)CT} * CF_{C1M}^{(G2)MT} * CF_{C1N}^{(G2)TN} * CF_{C2C}^{(G4)CT} * CF_{C2M}^{(G4)MT} * CF_{C2N}^{(G4)NT}$$

$$CV_B = CV_{C1C}^{(G2)CT} * CV_{C1M}^{(G2)MT} * CV_{C1N}^{(G2)TN} * CV_{C2C}^{(G4)CT} * CV_{C2M}^{(G4)MT} * CV_{C2N}^{(G4)NT}$$

$$D_{RT} = D_{C1C}^{(G2)CT} * D_{C1M}^{(G2)MT} * D_{C1N}^{(G2)TN} * D_{C2C}^{(G4)CT} * D_{C2M}^{(G4)MT} * D_{C2N}^{(G4)NT}$$

CF_{C1C} is the fixed cost of the soy after corn rotation for conventional tillage.

CF_{C1M} is the fixed cost of the soy after corn rotation for mulch tillage.

CF_{C1N} is the fixed cost of the soy after corn rotation for no-till.

CF_{C2C} is the fixed cost of the soy after two corn rotations for conventional tillage.

CF_{C2M} is the fixed cost of the soy after two corn rotations for mulch tillage.

CF_{C2N} is the fixed cost of the soy after two corn rotations for no-till.

CV_{C1C} is the variable cost (per bushel) of the soy after corn rotation for conventional tillage.

CV_{C1M} is the variable cost (per bushel) of the soy after corn rotation for mulch tillage.

CV_{C1N} is the variable cost (per bushel) of the soy after corn rotation for no-till.

CV_{C2C} is the variable cost (per bushel) of the soy after two corn rotations for conventional tillage.

CV_{C2M} is the variable cost (per bushel) of the soy after two corn rotations for mulch tillage.

CV_{C2N} is the variable cost (per bushel) of the soy after two corn rotations for no-till.

D_{C1C} is the diesel required for the soy after corn rotation for conventional tillage.

D_{C1M} is the diesel required for the soy after corn rotation for mulch tillage.

D_{C1N} is the diesel required for the soy after corn rotation for no-till.

D_{C2C} is the diesel required for the soy after two corn rotations for conventional tillage.

D_{C2M} is the diesel required for the soy after two corn rotations for mulch tillage.

D_{C2N} is the diesel required for the soy after two corn rotations for no-till.

Profit of Soy (π_S): $\pi_S = R_S - C_S$

$$\pi_S = (P_S * q^{soy}) - (CF_{RT} + CV_B * q^{soy} + D_{RT} * P_D)$$

$$\pi_S = P_S * 0.0169 * CSR * [\alpha * \tau_{C1M}{}^{(G2)MT} * \tau_{C1N}{}^{(G2)NT} * \tau_{C2M}{}^{(G4)MT} * \tau_{C2N}{}^{(G4)NT} + \varphi_2 * G_2 + \varphi_4 * G_4]$$

$$- CF_{C1C}{}^{(G2)CT} * CF_{C1M}{}^{(G2)MT} * CF_{C1N}{}^{(G2)TN} * CF_{C2C}{}^{(G4)CT} * CF_{C2M}{}^{(G4)MT} * CF_{C2N}{}^{(G4)NT}$$

$$- (CV_{C1C}{}^{(G2)CT} * CV_{C1M}{}^{(G2)MT} * CV_{C1N}{}^{(G2)TN} * CV_{C2C}{}^{(G4)CT} * CV_{C2M}{}^{(G4)MT} * CV_{C2N}{}^{(G4)NT}) * q^{soy}$$

$$- (D_{C1C}{}^{(G2)CT} * D_{C1M}{}^{(G2)MT} * D_{C1N}{}^{(G2)TN} * D_{C2C}{}^{(G4)CT} * D_{C2M}{}^{(G4)MT} * D_{C2N}{}^{(G4)NT}) * P_D$$

Appendix C

Crop Rotation Changes by CSR

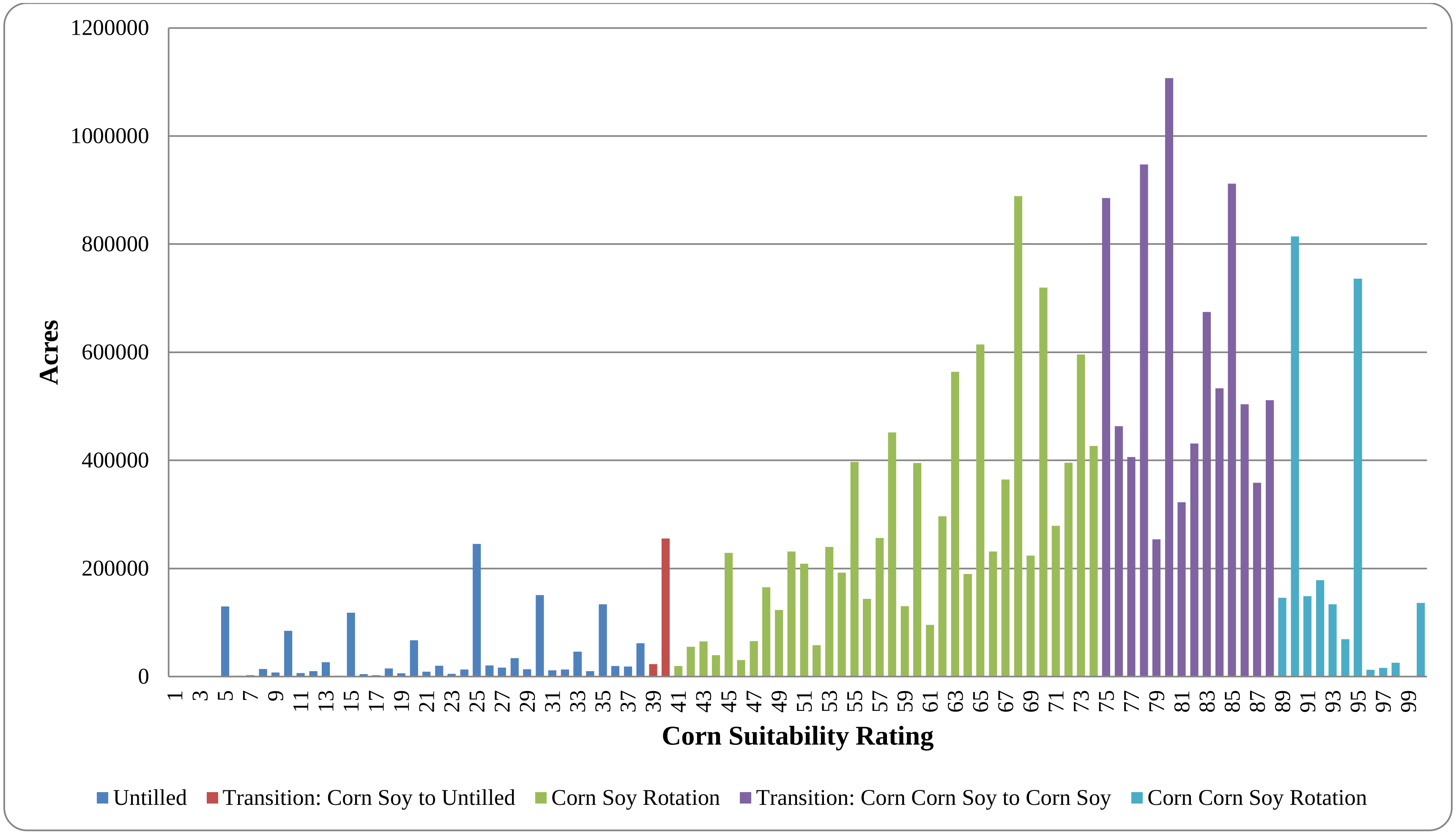

Figure 4.5.B. Crop Rotation Changes by CSR: Diesel Price $2.42 to $3.54/gallon, Corn Price = $4.40/bushel

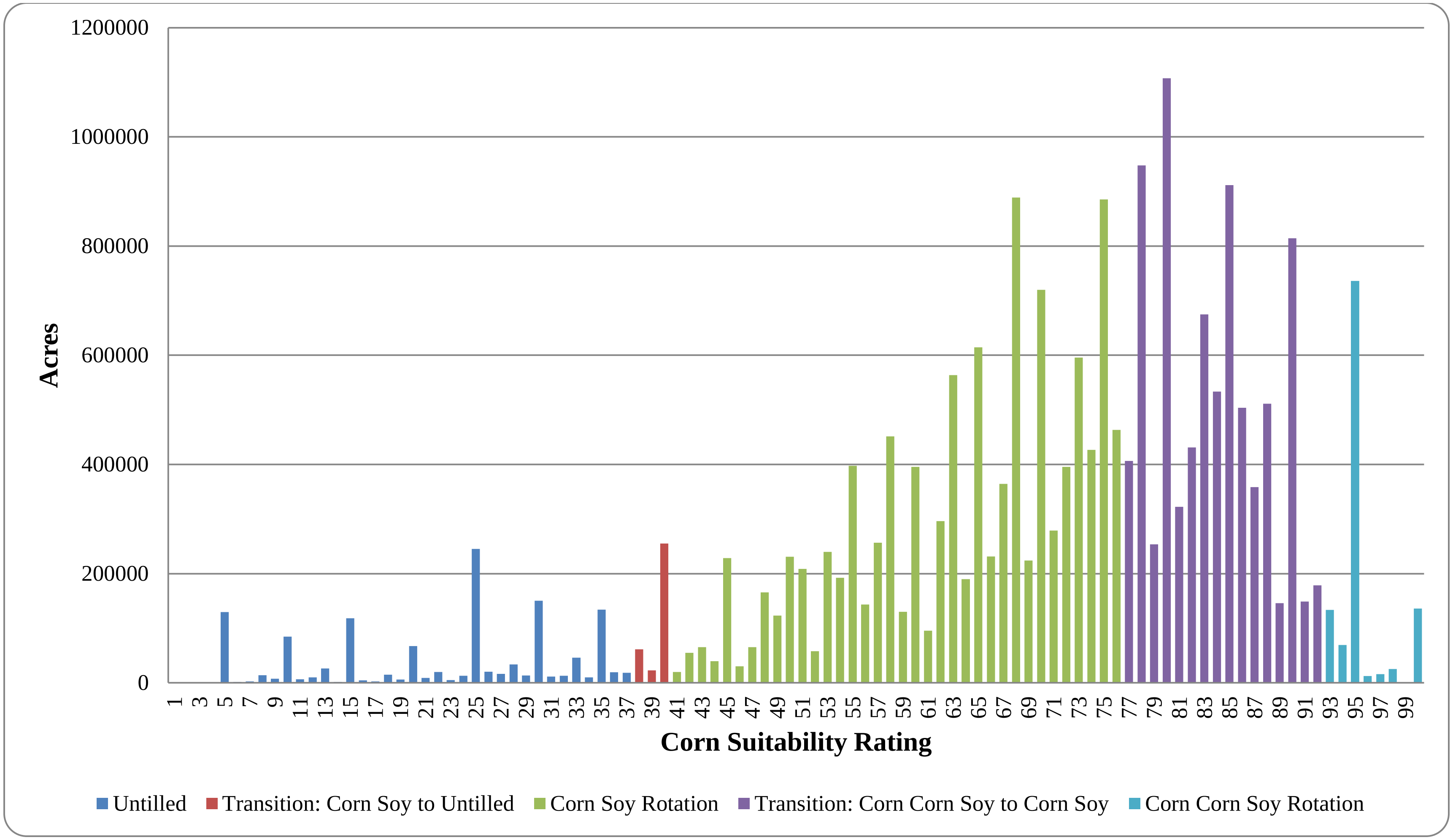

Figure 4.5.C. Crop Rotation Changes by CSR: Diesel Price $2.93 to $4.29/gallon, Corn Price = $4.60/bushel

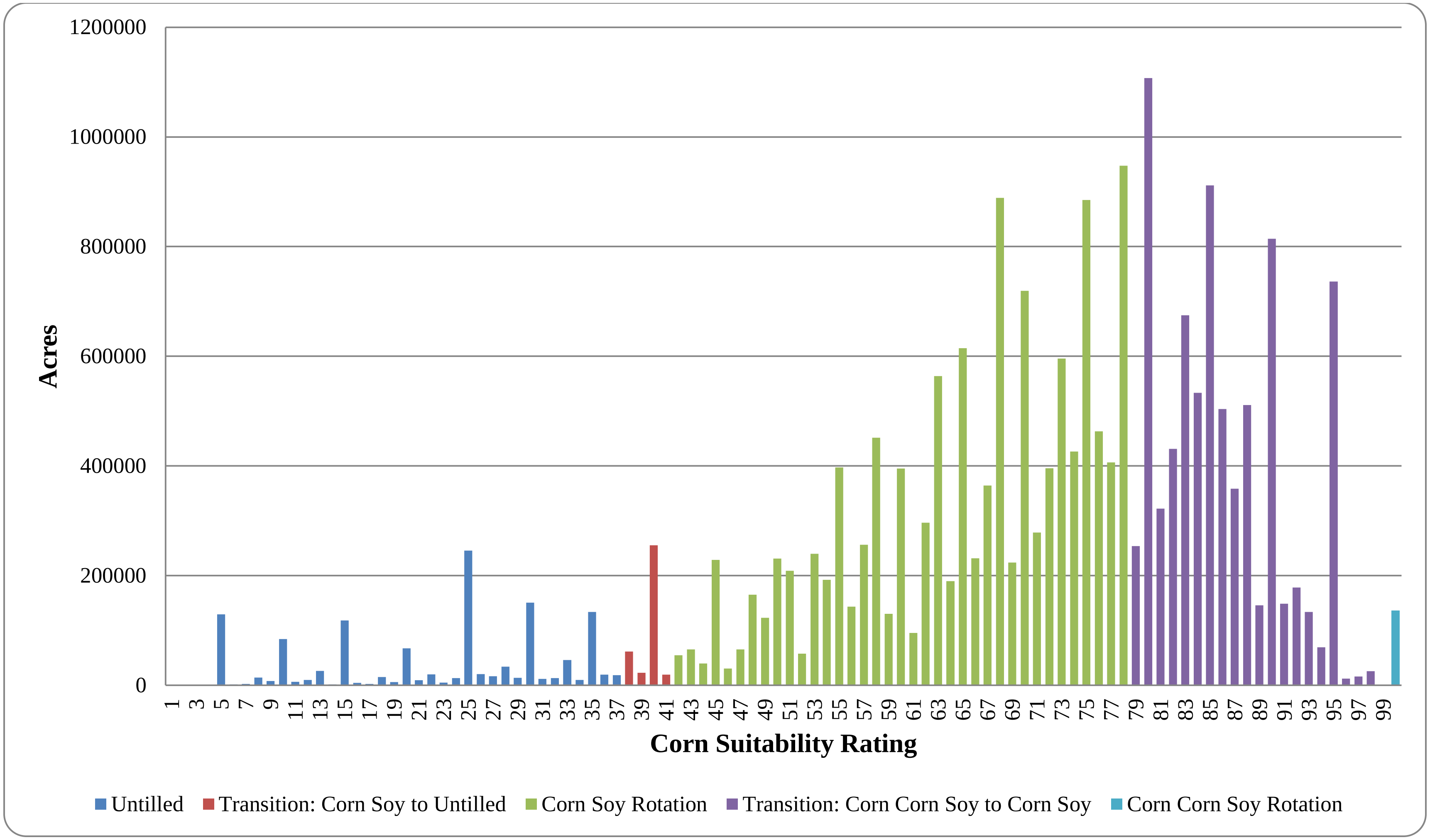

Figure 4.5.D. Crop Rotation Changes by CSR: Diesel Price $3.54 to $5.19/gallon, Corn Price = $4.80/bushel

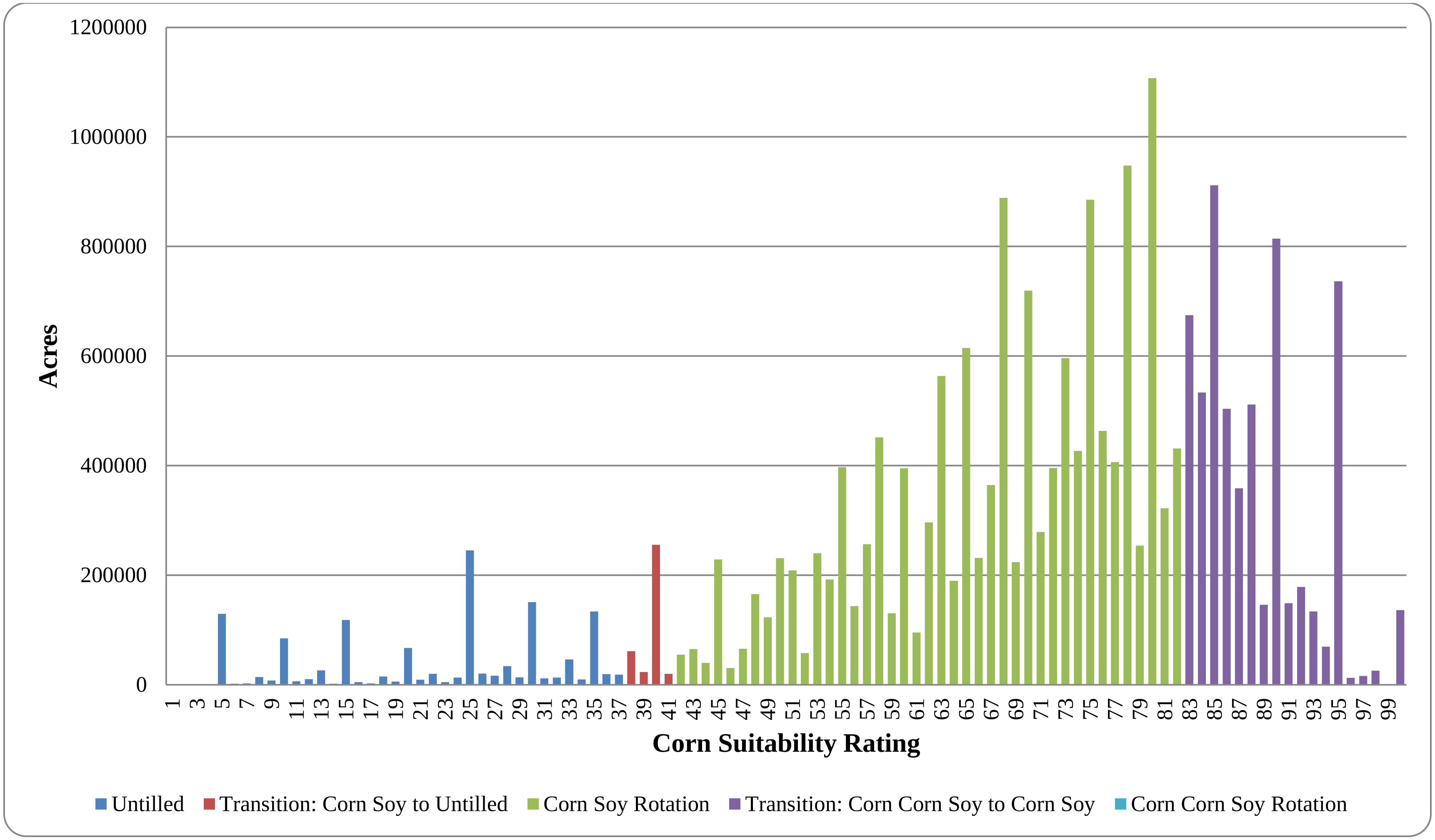

Figure 4.5.E. Crop Rotation Changes by CSR: Diesel Price $4.29 to $6.28/gallon, Corn Price = $5.02/bushel